A New Future for Cassava in Asia:

Its Use as Food, Feed and Fuel to benefit the Poor

Proceedings of the Eighth Regional Workshop
held in Vientiane, Lao PDR. Oct 20-24, 2008

NAFRI CIAT

The Nippon Foundation

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A New Future for Cassava in Asia:
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Editor: R.H. Howeler

Organized by the Centro Internacional de Agricultura Tropical (CIAT) and the National Agriculture and Forestry Research Institute (NAFRI) of Lao PDR

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Cover Photos:

Top: Lee Jun: Boys in Henguo village, Pingwang town in Guangxi province of China enjoying a bowl of boiled cassava

Bottom: R.H. Howeler: Thai Nguyan Ethanol factory in Khon Kaen, the first cassava-based fuel ethanol factory in Thailand

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PREFACE

The Centro Internacional de Agricultura Tropical (CIAT) was established in Cali, Colombia, by the Rockefeller and Ford Foundations in 1969, following the initial success of the previously established international agricultural research centers, IRRI and CIMMYT, which had led to a "Green Revolution" in rice and wheat. CIAT was set up in Latin America, and the International Institute for Tropical Agriculture (IITA) in Nigeria, Africa, mainly to enhance the agricultural development of other food crops important in those two continents. As such, CIAT focused initially on a wide range of crops and animal production systems, but later narrowed these down to cassava (*Manihot esculenta* Crantz), beans (*Phaseolus vulgaris*), tropical forages and rice (for Latin America). In the 1980s this was further expanded to include a resources management program to improve the sustainability of crop and livestock production systems in fragile environments, especially in hillsides.

The CIAT Cassava Program was established in 1972 by assembling a multi-disciplinary team of scientists to work on all aspects of cassava research, including physiology, breeding, agronomy, plant nutrition, diseases, pests, utilization and economics. Being located in the center of origin of cassava and having received the world mandate for basic research on all aspects of the crop, CIAT collected a large number of local cassava varieties, mainly from Colombia, Brazil and other countries in Latin America. Once tissue culture techniques were fully developed, the Latin American cassava germplasm collection was complemented with local varieties from Asia, mainly from Indonesia, Malaysia and the Philippines. The CIAT cassava germplasm collection, held in trust for FAO, now contains over 6000 accessions, including about 400 from Asia.

Collaboration between the CIAT Cassava Program and Asian national programs started in 1975, when the first of several groups of Thai researchers arrived in Colombia for an extended period of training at CIAT in all aspects of cassava research. This was followed by researchers from other Asian countries, such as Malaysia, Indonesia, the Philippines, India and Sri Lanka, who came for individual training in specific disciplines or to participate in one-month intensive cassava production courses, which were held in 1978, 1980, 1985 and 1989. Altogether, 153 cassava researchers from Asia received training in various disciplines at CIAT from 1975 to 2000. This training not only provided Asian researchers with knowledge about the crop, but was also an opportunity to make friends with colleagues in other countries and to strengthen the bond between CIAT cassava researchers and colleagues in the various national programs in Asia. Thus, when the CIAT Regional Office was established in 1983 in Bangkok, Thailand, the CIAT cassava breeder, Kazuo Kawano, could start working immediately with a number of cassava breeders in different countries who had previously received training in Colombia. Similarly, my work in the area of cassava agronomy and soil management, which started in Asia in 1986, has always been conducted in close collaboration with cassava researchers in national programs. Initially this was mainly in Thailand, Indonesia, Malaysia, Philippines, Sri Lanka and India, but was extended in the late 1980s to include Vietnam and China. Only recently, this was further extended to include Laos, Cambodia and East Timor. These countries have all become part of the Asian Cassava Research Network, which has been coordinated by the CIAT Cassava Program in Asia.

In order to document the cassava research that had previously been conducted by scientists in many different countries in Asia and to discuss future collaboration, CIAT organized in 1984 the first Regional Cassava Workshop, which was held in Bangkok, Thailand. This was followed by similar workshops held in Rayong, Thailand in 1987; in Malang, Indonesia in 1990; in Trivandrum, India in 1993; in Danzhou, China in 1996, in Ho Chi Minh city, Vietnam in early 2000 and in Bangkok, Thailand in 2002. The Proceedings of these Workshops have been published and provide an important historical record of the progress made in cassava research and development in Asia during the past 30-40 years. The 8th Regional Cassava Workshop was held in Vientiane, Lao PDR in Oct 2008. This Proceedings of the Workshop provides important information about the latest developments and progress made in cassava research in this part of the world.

Between 2001 and 2007 the Department of Agriculture of Thailand received from CIAT-Colombia several shipments of tissue culture plants comprising about 600 cassava germplasm accessions of the CIAT cassava core collection, i.e. a collection of varieties with a wide range of characteristics that represent the genetic variability of the crop in Latin America. This collection is now being conserved *in-vitro* at the Rayong Field Crops Research Center and is currently being characterized and evaluated for many different attributes. These varieties are now also available to other national programs in the region.

In October 2008 the CIAT Cassava Office in Asia organized a two-week Regional Cassava Training Course in Thailand with participation of about 60 young cassava researchers from Cambodia, China, East Timor, India, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand and Vietnam.. The course was taught mainly by long-time researchers from CIAT's Cassava Program in Colombia and the CIAT office in Asia, as well as by cassava researchers in Thailand. This was an opportunity for the "old guard" to hand-over their knowledge and experience to a new generation of cassava researchers, who will face the challenge of further developing cassava for its many new uses in the future.

During the past five years, cassava has been recognized as a valuable feedstock for production of fuel-ethanol. This is expected to greatly increase demand for cassava roots during the coming years, which in turn will increase the prices of fresh roots and cassava-based products. This should benefit many cassava farmers in Asia and serve as a vehicle for more rapid rural development in the region. But, in order to keep the prices of cassava products competitive, the increasing demand for cassava roots need to be balanced by a comparable increase in supply. Since new land for agriculture in Asia is very limited, this should be achieved mainly by increasing cassava yields. The challenge for cassava researchers in Asia is not only to develop new varieties and technologies that have the potential to increase yields, but also to work with farmers to enhance the adoption of these technologies, in order to achieve real impact and use this opportunity to help poor cassava farmers make significant improvements in their livelihoods.

R.H. Howeler
CIAT, Bangkok
August, 2010

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WELCOME ADDRESS

by Rod Lefroy, CIAT Asia

Dr. Bounthong Bouahom, Permanent Secretary of the Ministry of Agriculture and Forestry, Dr. Monthathip Chanphengxay, Director-General of National Agricultural and Forestry Research Institute, Mr. Shuichi Ohno, Director of the Department of International Affairs of the Nippon Foundation, and fellow participants.

On behalf of CIAT, the International Center for Tropical Agriculture, I would like to extend a warm welcome to all of you to the 8th Asian Cassava Research Workshop. I am sure that this workshop, with the title "A New Future for Cassava in Asia: Its Use as Food, Feed and Fuel to Benefit the Poor" will be an interesting, productive, and enjoyable meeting.

I would like to take this opportunity to thank the Nippon Foundation for their generous support to the Asian Cassava Research Network over the years, and particularly for their support for the current project in Laos and Cambodia and to this workshop. Similarly, I would like to thank NAFRI and MAF for their support and collaboration on these and other areas of research for development.

We are very pleased to see so many people at the workshop – and as you can see from how we fit into this room, this has ended up being a little larger than we anticipated. There are approximately 120 participants from more than a dozen cassava producing countries. Of course, the majority of participants are from countries in the Asian Cassava Research Network, but we are pleased to see participants from other countries and also from our sister CGIAR center in Africa, IITA, the International Institute for Tropical Agriculture. Also, on behalf of CIAT in Asia, I would like to welcome our colleagues from CIAT headquarters in Colombia. They have all had a long-term involvement with CIAT's cassava programme in Asia, so it is great that so many of you have been able to join both this workshop and the recently completed regional training course on cassava.

Nearly a year ago, in November 2007, CIAT celebrated 40 years since the center was established, with its headquarters in Colombia and with a mandate to work on the upland systems in Latin America and the Carribbean. Since this start, CIAT has moved to work increasingly in both Africa and Asia, especially on neo-tropical crops such as cassava and beans, while maintaining major activities in Latin America. This workshop, being the 8th triennial cassava workshop in Asia, marks 24 years since the first Asian Cassava Research Network meeting, and thus over a quarter of a century since CIAT started work in Asia.

In the early 1980s, when CIAT started work on cassava in Asia, Thailand was experiencing a cassava boom as production and export expanded in response to the demand for animal feed in Europe, particularly in the Netherlands. This collaborative work in Thailand resulted in the development of improved cassava varieties, in terms of yield and starch content, and these varieties continue to play an important role in the industry in Southeast Asia today. Currently, we are seeing a further increase in the interest in cassava production, although now as part of the many food and non-food industrial uses for cassava, including for biofuels, with most of the processing occurring in the region. This workshop provides an excellent opportunity for many groups from a wide range of

countries and interests to get together and discuss the current and future needs for research and development in the industry.

At the same time that CIAT was starting to work with partners in Asia on cassava, other scientists from CIAT were becoming more involved in improving livestock production through better feeding regimes based on improved production of tropical and subtropical forages. These activities, carried out in many of the same countries where the cassava work was on-going, have resulted in the identification of improved varieties and species of forages, better forage and livestock management systems, and improved methodologies for working with farmers, extension workers, and researchers. The result of all of this work on cassava and forage systems has been significant positive impacts in the livelihoods of smallholder farmers in the region.

More recently, nearly eight years ago, CIAT decided to move from having individual projects, project offices, and staff that focused on either cassava or forages to having a regional office that could more easily integrate activities in the areas of cassava, forages for livestock, and other areas in which CIAT worked. This move has resulted in greater linkages between cassava-based production systems, livestock-based production systems, and other cropping systems. In addition, there has been an increase in work on linking smallholder farmers to markets. This work has included activities in a wide range of value chains, including cassava, with work on contract farming of cassava, on new ways of getting processors involved in promoting improved production management systems, in starting to match the specific needs of industry with smallholder production systems, and involving smallholders in solving some of the waste management and feedstock supply issues encountered by industry.

I look forward to hearing much more about all of these topics over the next few days and of listening to discussions on how best we can move forward together in ensuring research and extension activities match the requirements of national governments, of industry, and of smallholder farmers in need of improved livelihoods.

Once again, I welcome you to the workshop and look forward to a productive week of presentations and discussion.

Thank you for your attention.

OPENING ADDRESS

by Dr. Monthathip Chanpengxay
DG of the National Agriculture and Forestry Research Institute (NAFRI)
of LAO PDR

Distinguished Participants; Ladies and Gentlemen

It is a great honor and pleasure to speak at the inauguration of the 8th Asian Cassava Research Workshop, held for the first time in the Lao PDR. Let me, first of all, on behalf of MAF, the Ministry of Agriculture and Forestry of Lao PDR, and of NAFRI, the National Agriculture and Forestry Research Institute, express our warm welcome to all of you. We hope that you will have a pleasant stay and enjoy our Lao hospitality.

NAFRI is the national agricultural research institute that, along with our sister organization, NAFES, which focuses on agricultural extension, is charged with improving the capacity of agricultural and forestry production in the country. NAFRI consists of seven thematic centers, which cover areas of cropping, livestock, horticulture, fisheries and aquaculture, forestry, soils, and policy. In addition to these thematic centers, NAFRI has two area-based centers, for the north and the south of the country.

The headquarters of NAFRI are located just outside Vientiane, near the main campus of the National University of Laos. At this campus we are pleased to host the regional office of CIAT in Asia, with whom we collaborate on cassava, as well as on livestock, marketing, and other issues. We also host projects from other CGIAR centers, such as IWMI, IRRI, CIFOR, CIP, and ILRI, and other international groups, such as CIRAD.

I understand that this workshop is the 8th Asian Cassava Research Workshop. These workshops have been organized every three years by CIAT in collaboration with the various host countries. The first one was held in Bangkok, Thailand in 1984, and the subsequent ones were held in Thailand, Indonesia, India, China, Vietnam and Thailand, and now in the Lao PDR. These workshops have been an important activity of the Asian Cassava Research Network, which brings together representatives of all the major cassava producing countries in Asia. Until recently, there were seven main countries involved in the network, namely Thailand, Indonesia, India, China, Vietnam, Philippines, and Malaysia. But this year, for the first time, four other countries have joined, namely Cambodia, Myanmar, East Timor, and the Lao PDR. We are very fortunate to have received funding from the Nippon Foundation to join this cassava network and to work closely with CIAT and cassava researchers from other countries to improve cassava production in our own country. It is obvious that this working together, and the sharing of knowledge and experiences during these triennial workshops, have been very important for the development of the cassava sector in many Asian countries, and hopefully will now bring benefits to the Lao PDR, as well as the other new members of the Asian Cassava Research Network.

In these new countries cassava is still considered a minor crop used mostly for human consumption and animal feeding. But this situation is changing rapidly. During the past two years, many countries in Asia have seen a rapid increase in the demand for cassava for use in either the animal feed industry, the starch industry, or for production of ethanol. This

increase in demand was accompanied by the construction of many new cassava starch and ethanol factories, as well as chipping and drying yards, the latter mostly for export to China, Vietnam and Thailand. Due to the marked increase in demand for cassava roots and the subsequent increase in the price of roots, dry chips and starch, farmers have become more interested in growing cassava in order to earn a good income from the sale of roots. Thus, in many countries, including the Lao PDR, cassava is changing from being a subsistence crop to being a commercial crop. Instead of growing varieties that are good for eating, farmers are now starting to grow high-yielding and high-starch varieties that are not only suitable for animal feeding but also required by various processing industries. As the price of cassava roots increases it is hoped that farmers will become more interested in developing more productive and sustainable cassava-based cropping systems. This may include greater interest and ability to buy inputs such as fertilizers, and to increase cassava yields by adequate weeding, the construction of fences to prevent animals from damaging the crop, and the development of land management systems that minimize erosion.

The initiation five years ago of the Nippon Foundation Cassava Project in the Lao PDR, implemented by CIAT in collaboration with NAFRI and the provincial and district offices in many parts of the country, was very timely. It provided an opportunity to introduce and test new higher yielding varieties, mainly from Thailand, Vietnam and China, and many of them developed through collaboration with CIAT. Experiments conducted on-station and on farmers' fields have shown that these new varieties can produce yields that are 2-3 times higher than those of the local eating varieties. We are grateful to the Nippon Foundation for their generous financial support, and to CIAT and our cassava colleagues in neighboring countries for sharing their best cassava germplasm and their knowledge and experience about the crop. This will definitely help us to more quickly develop the cassava sector and to provide our farmers with a new and profitable market for their cassava roots. We think that cassava can play a major role in rural development and will help our farmers to lift themselves out of poverty.

In declaring this workshop open, I would like to thank the Nippon Foundation for their support to our project and to this workshop. Through this workshop I hope that all of us will gain new knowledge, new ideas, and new friendships to continue our efforts to improve the production and utilization of cassava for the benefit of all.

Thank you.

HIGH-VALUE CASSAVA: FROM A DREAM TO A CONCRETE REALITY

H. Ceballos, T. Sanchez[1], A. Rosero, A.P. Tofiño[2], K. Denyer, A. Smith[3], D. Dufour[4] N. Morante[1], J.C. Pérez[1], M. Fregene[1] and C. Egesi[1]

ABSTRACT

Cassava (*Manihot esculenta* Crantz) is an important food security crop for many tropical and subtropical countries. It is also acquiring an increasing role in rural development as raw material for different industries. The most important industrial uses of cassava are as a source of energy in the feed industry, the bio-ethanol and starch industries, and for processed food. For cassava to be a suitable raw material for different industrial pathways, it has to have a competitive price, which is dependent on high and stable fresh root production, high dry matter content and adequate cultural practices that will maximize yields and reduce production costs. For years many institutions have successfully satisfied these needs. However, to consolidate and expand the industrial uses of cassava, the cassava breeding project at CIAT began increasing the emphasis in the search for value-added traits with the turn of the millennium. Several strategies have been implemented simultaneously. For the feed industry, the main objective is enhanced nutritional quality, particularly with regard to protein and pro-vitamin A carotenoids content. For the starch industry, amylose-free and high-amylose mutations have been identified. Inbreeding has been introduced to cassava genetic improvement because it offers many advantages, including a facilitated identification of useful recessive traits including new plant architecture types. Ongoing research for the production of doubled-haploid lines will reduce the time required to reach full homozygosity. Finally, CIAT has set up a high capacity root-quality laboratory to routinely screen the roots of the thousands of new genotypes generated every year.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial crop native to tropical America, with the probable center of origin in the southern rim of the Amazon basin of Brazil (Olsen and Schaal, 2001). Cassava is one of the most important sources of food energy in many tropical and subtropical countries. There are an estimated 200 million people who obtain more that 500 cal/day from cassava (Cock, 1985; Kawano *et al.*, 1998). The crop produces reasonably well under marginal conditions of climate and soil, and is frequently identified as a famine reserve due to its tolerance to drought and infertile soils and its ability to recover from disease and pest attacks. It can also produce competitively in non-marginal areas. Cassava offers the advantage of a flexible harvesting date, allowing farmers to hold the roots in the ground until needed (Iglesias *et al.*, 1997).

In addition to its important role in subsistence farming and food security, cassava is acquiring an increased role in rural development as raw material for many industrial applications for the production of animal feed, starch, bioethanol and processed food. The main strategy used until now to promote cassava as an industrial raw material has been to increase its productivity and/or reduce production costs, allowing for a competitive price of the roots. Productivity can be increased by genetic improvement to produce varieties with

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high and stable fresh root yields, with tolerance or resistance to the most important pests and diseases as well as with adaptation to abiotic stresses. A key trait for most industries is dry matter content, which has been successfully increased over the years (Kawano, 2003). Productivity can also be increased through adequate cultural practices in which proper fertilization and the control of weeds play a key role. The use of agents for the biological control of pests and diseases is an efficient approach, both from the economic and environmental points of view. Mechanization of planting and harvesting has proved to be effective in reducing production costs.

There has been, however, very little effort made to increase the value of cassava roots. The price of dried cassava roots, when used for the feed industry, is lower than that of maize because of their low levels of proteins. High carotenoids in the root is fundamental for cassava in human nutrition, but also has been proven to be advantageous in the production of animal feed (Posada *et al.*, 2006). In addition, cassava has the disadvantage of low genetic variability for starch quality traits. Compared with the many economically useful mutations found, for example, in the maize kernel (sweet corn, pop corn, waxy maize starch, opaque 2, amylose extender, etc.), very little variability has been reported for cassava. It is valid to assume that such variability exists in the crop, but have not yet been found; to identify them, new and different approaches would be required.

In spite of the problems mentioned above, the globalization of economies and new technological breakthroughs are offering a unique opportunity for cassava never available to the crop before. Tropical production of maize is facing increasing problems in competition with maize from temperate regions. This situation has prompted government and private sectors of many tropical countries to turn to cassava as a competitive alternative to imported maize. In addition, advances in molecular biology, genetic engineering, plant-tissue culture protocols and starch technologies provide important tools that will allow bridging the main gaps between cassava and the cereals.

This paper describes the approaches taken at CIAT to develop and identify cassava clones with higher value in their roots for different industries, and briefly describes some of the new high-value traits that have already been identified.

New Approaches for the Identification or Induction of High Value Traits

Cassava is a highly heterozygous crop. Most loci are, therefore, in a heterozygous status. Many high-value traits affecting, for example, the quality of starch are usually recessive. The fact that cassava seldom undergoes inbreeding drastically reduces the chance of [expectedly] low-frequency recessive alleles from expressing phenotypically. In addition, starch mutations in the roots are more difficult to detect than in grain kernels (where they can be easily identified by visual inspection without the need for any sophisticated tests). To detect a starch mutation in the cassava root, the breeder has to cut the roots and most likely needs to conduct a particular test (e.g. iodine test) or carry out biochemical analyses to be able to pick potentially useful variants. It is possible, therefore, that clones with valuable traits had already been grown in breeding nurseries but could not be detected and, not showing an outstanding agronomic performance, they were unfortunately discarded. To identify high-value traits affecting the quality of the root, it was necessary to implement

different breeding strategies to allow the expression of useful alleles and set up the proper screening protocols. The fact that roots are not reproductive or multiplicative organs may offer cassava (and other root crops) an advantage over the true seed-propagated crops. It is valid to assume that cassava roots could withstand mutations that would otherwise be lethal for reproductive organs such as the kernels of cereals.

Protocols for Systematic Characterization of Root Quality Traits

As stated above, one of the problems to identify high-value traits in cassava roots is that it is not easy to visually identify these traits. Therefore, a high-throughput laboratory was set up to be able to process roots from a large number of cassava genotypes each year. A brief description of the protocols developed and used at CIAT is provided in **Appendix 1**.

A second requirement for the development and identification of high value traits relates to the genetic approaches many of which were already described by Ceballos *et al.* (2006a.) The strategies that have been implemented for the development and identification of high-value traits in cassava are briefly described below.

Root Harvest, Handling and Evaluation

The analysis of reaction to post-harvest physiological deterioration (PPD) was conducted on several different types of genotypes. The harvest was done manually (as it is typically done) and with special care not to cause any injury to the roots. It is well known that rough handling creates localized traumas to the root tissue that accelerates PPD. Commercially sized roots were selected and placed in shelves under a roof but without walls. Air, therefore, circulated freely through the shelves. Evaluations were made at 5, 10, 20 and 40 days after harvest. Up to ten roots per genotype were evaluated at each evaluation date. The standard method for quantifying PPD (Wheatley *et al.*, 1985) removes the proximal and distal ends of the root to accelerate it. In this experiment, however, rather than using the standard approach, the roots were left untouched. This approach reduces the overall levels of PPD compared with previous reports (Sánchez *et al.*, 2005; Van Oirschot *et al.*, 2000), but allows a more realistic appraisal of the value of the tolerance detected. In other words, roots were stored as farmers or processors would keep them until processing.

Scoring the reaction to PPD is a destructive process. Seven transversal slices were cut along the root, starting at the proximal end. A score ranging from 1 to 10 was assigned to each slice, corresponding to the percentage of the cut surface showing discoloration (1=10%, 2=20%, etc). The mean PPD score for each root was calculated by averaging the scores of the seven transversal sections (Wheatley *et al.*, 1985). Roots showing symptoms of microbial rotting (very different from those related to PPD) or affected by insects, were not used for quantification of PPD.

Screening the Cassava Collection to Characterize Starch and Other Root Traits.

Currently CIAT is finalizing the screening of the entire cassava collection (with starch samples from around 6,000 landraces and improved germplasm (Sánchez *et al.*, 2009). Different tests were conducted following standard procedures (Aristizábal and Sánchez, 2007) and have been described above. Accessions from the germplasm collection were recovered from their *in-vitro* status, hardened and transplanted to the field. At the proper age

(10-12 months after planting) the plants grown in the field from each accession were harvested individually and their roots screened for different characteristics, including their starch biochemical and functional properties.

Table 1 summarizes the results of the most relevant root quality traits. Average dry matter content was 33.6%, with a range of variation from 14.28 to 48.12%. There was a slight asymmetry in the frequency distribution with a tendency of longer tails to the left. Cyanogenic potential ranged widely from 14 to 3,274 ppm, with an average of around 327 ppm (dry weight basis). Distribution was highly asymmetrical with a long tale to the right. Total and reducing sugars also showed an asymmetrical distribution with longer right tales, particularly in the case of reducing sugars. Average starch content was 84.5% (dry weight basis), with a tendency of values to concentrate towards the higher values, which accentuated a similar tendency observed for dry matter content (Sánchez *et al.*, 2009).

Amylose content ranged from 15.2 to 26.5% with an average of 20.7% (**Table 2**). The average amylose content of 20.7% is a very robust estimate since it is based on such a large sample of genotypes. Distribution was practically normal with a very slight asymmetry towards a longer right tale. No more than 1.5% of the samples had amylose values below 17.5 or above 24.5%. Water solubility and swelling power showed a more asymmetrical distribution with longer right tales. Average paste clarity was 45.2% with a large variation ranging from 12.5 to 96.6% (**Table 2**).

Table 1. Root quality traits from more than 4000 cassava genotypes.

Parameter	Dry matter content (% fresh root)	Cyanogenic potential (ppm of DM)	Sugar content		Starch content (% of DM)
			Total (% of DM)	Reducing (% of DM)	
Maximum	48.1	3,274	18.8	15.7	91.0
Minimum	14.3	14	0.2	0.0	65.0
Average	33.6	327.4	3.8	1.3	84.5
St.Deviation	6.47	397.7	2.32	1.43	3.34
Skewness	-0.40	2.96	1.76	3.08	-0.65
No. of accessions	4,051	4,050	4,049	4,049	4,049

Source: *Sánchez et al., 2009.*

Table 2. Starch quality traits from more than 4,000 cassava genotypes.

Parameter	Amylose content (%)	Water solubility (% db)	Swelling power (% g/g)	Paste clarity (%)
Maximum	26.5	16.6	15.5	96.6
Minimum	15.2	0.2	0.8	12.5
Average	20.7	2.2	4.6	45.2
St. Dev.	1.61	1.59	2.31	10.54
Skewness	0.22	1.77	1.53	-0.30
No. of accessions	4,042	4,050	4,050	4,044

Source: *Sánchez et al., 2009.*

Table 3. Pasting properties from starches of more than 4000 cassava genotypes.

Parameter	Pasting temperature (°C)	Maximum viscosity (cP)	Break-down (cP)	Consistency (cP)	Setback (cP)	Ease of cooking (min)
Maximum	71.2	1505.0	859.0	626.0	273.0	5.6
Minimum	58.8	146.0	28.1	0.0	-702.0	1.1
Average	65.3	777.5	298.1	155.8	-144.5	2.8
St.Dev.	1.75	165.03	107.1	57.8	96.2	0.72
Skewness	-0.13	0.22	0.81	0.94	-0.38	0.33
No. of accessions	4,051	4,051	4,051	4051	4,051	4,051

Source: *Sánchez et al., 2009.*

Pasting properties of the samples analyzed are described in **Table 3.** Average pasting temperature was 65.3°C and ranged from 58.8 to 71.2. Distribution frequency was relatively symmetrical as for the other parameters described in **Table 4.** Maximum viscosity averaged at 777.5 cP, with a wide range of variation from 146 up to 1505 cP. Breakdown ranged from 28.1 to 859.0 cP with an average around 298.1 cP. Consistency ranged from 626 down to 0 cP with an average of 155.8 cP. Finally, average setback was -144.5 cP with a minimum of -702.0 and a maximum observed value of 273.0 cP.

The results presented in Sánchez *et al.* (2009) article were exploratory. In most cases, samples were un-replicated. However when unusual data were observed, because of the particular interest in identifying unusual starch types, it prompted a second analysis to confirm the data. This approach, although it is limited from the experimental point of view, allowed the analysis of such a large number of genotypes, and provides very reliable information since at least outlaying data points were confirmed. One problem that remains unsolved is the possibility of a plant, for unknown reasons, producing starch samples with characteristics that may not be representative of that genotype. By and large, however, average values presented in this study should be very robust and properly represents starch characteristics of cassava. The range of variation is also useful to provide an idea of what traits may offer alternatives for further genetic improvement.

For some traits (water solubility, swelling power, paste clarity, paste breakdown, consistency, and setback) there was a large range of variation. It is very interesting to examine the relationships of these attributes from data of all evaluated clones (e.g. breakdown versus swelling power). More investigation and comparison on starch structure of clones with a great difference in functionalities are of great interest and this is currently under way.

Introduction of Inbreeding in Cassava

The introduction of inbreeding in the genetic improvement of cassava offers several advantages which have been described (Ceballos *et al.*, 2004; Ceballos *et al.*, 2007a; Contreras Rojas *et al.*, 2009; Pérez *et al.*, 2005a; 2005b). An advantage which has a direct bearing with the theme of this article, is that it would allow for the identification of useful recessive traits (such as the starch quality mutants found in different crops), which may lead to the development of value-added genetic stocks.

CIAT – supported by the Rockefeller Foundation and in collaboration with cassava breeding programs in Africa, Asia and Latin America – began in 2004 a research project to improve tolerance to inbreeding in elite germplasm. Elite germplasm was self-pollinated to generate a large number of botanical seeds with varying degrees of inbreeding. The project also involved the development of a microspore culture protocol for the production of doubled haploids. As soon as partially inbred plants are produced, the search for useful starch and other high-value traits is initiated. The production of doubled haploids provides an appealing option for the introduction of inbreeding in cassava genetic improvement by drastically reducing the time required to produce homozygous parental lines. Two interesting results can be used to illustrate the relevance of this approach.

Amylose-free starch mutation

After several years in search of an amylose-free mutation, this characteristic was finally identified in the self-pollinated genotype AM 206-5 and reported in the literature the following year (Ceballos *et al.*, 2007b). This starch mutation had been requested by the starch industry for many years. In addition to the information already published in relation to this mutation, a comparison of normal and waxy starches from different crops has been conducted. **Tables 4-7** present the most relevant information in relation to this comparison.

Table 4. Physico-chemical properties of normal and waxy starches from different crops.

	Amylose content (%)	Paste Clarity (%)	λ Max
Normal starches			
Maize	19.9 (±0.4)	11 (±2.7)	590
Potato	27.7 (±0.5)	88 (±0.8)	591
CM 523-7 (Cassava)	19.8 (±1.3)	50 (±3.5)	593
MPer 183 (Cassava)	19.5 (±1.8)	51 (±3.8)	590
MTai 8 (Cassava)[1)]	16.5 (±0.6)	47 (±0.8)	592
Waxy starches			
Maize	0	42 (±1.1)	529
Potato	7.7 (±0.83)	92 (±1.4)	550
Cassava (AM 206-5)	0	61 (±0.7)	535

[1)] MTai 8 = Rayong 60

Identification of a new plant architecture mutation

One of the major changes that cassava research at CIAT has had in the past few years is the systematic introduction of partial inbreeding throughout the germplasm collection to allow for the expression (and therefore identification) of recessive traits. Most of these recessive traits result in undesirable characteristics as it happens in other crops, but few offer interesting advantages. During the May-2008 to April-2009 season, a new generation of self-pollinated germplasm was evaluated in the field. It was very apparent in one family composed from 16 genotypes that the parental progenitor (MVen 331) carried an unusual trait. Half of the 16 plants showed a distinctive feature: leaves without petioles. Moreover, several of these plants had a unique and distinctive phenotype (**Figure 1**) with absence of branching at least for the first 6-8 months of age.

Table 5. Pasting characteristics of normal and waxy starches from different crops.

Sample identification	Pasting temp. (°C)	Peak viscosity (cP)	Breakdown (cP)	Setback (cP)	Consistency (cP)
Native starches					
Maize	89.0 (±0.85)	176 (±4)	-30 (±4)	-15 (±3)	-45 (±6)
Potato	65.2 (±0.06)	2550(±15)	1204 (±29)	-1082 (±2)	108 (±5)
CM 523-7	63.3 (±0.12)	1006 (±14)	500 (±22)	-364 (±8)	137 (±14)
MPer 183	64.8 (±0.12)	979 (±12)	482 (±15)	-267 (±10)	215 (±8)
MTai 8	63.7 (±0.00)	876 (±13)	455 (±0)	-338 (±4)	117 (±4)
Waxy starches					
Maize	70.9 (±0.00)	973(±22)	307 (±25)	-289 (±4)	31 (±2)
Potato	65.9 (±0.12)	2491 (±49)	1287 (±30)	-1268	13(±3)
Cassava	67.4 (±0.00)	1119 (±11)	631 (±8)	-595 (±12)	37 (±4)

Table 6. Solubility and swelling values of normal and waxy starches from different crops. Analyses were made at three different final temperatures (60, 75 and 90°C)

Sample identification	Solubility (%db)			Swelling index (g/g)		
	60°C	75°C	90°C	60°C	75°C	90°C
Normal starches						
Maize	0.45 (±0.04)	2.66	10.51	2.76 (±0.16)	6.82 (±0.06)	12.2
Potato	2.5 (±0.66)	5.2	6.0 (±0.21)	13.8 (±0.06)	35.8 (±1.72)	51.1 (±2.92)
CM 523-7	3.1 (±0.27)	5.6	7.1 (±0.41)	22.9 (±1.42)	36.4 (±0.53)	42.4 (±2.62)
MPer 183	2.4 (±0.37)	5.5	7.3 (±0.28)	14.9 (±0.86)	34.5 (±3.3)	40.3 (±2.60)
MTai 8	2.3(±0.12)	5.3	7.6 (±0.07)	18.2 (±1.15)	37.2 (±2.87)	37.0 (±0.54)
Waxy starches						
Maize	0.74 (±0.04)	1.79	3.98	2.24 (±0.06)	36.13	38.34
Potato	0.4 (±0.15)	1.9	n.a.	11.4 (±0.67)	86.6 (±3.67)	n.a.
Cassava	0.6 (±0.07)	5.2	8.8 (±0.35)	4.5 (±0.67)	48.2 (±1.59)	54.7 (±1.63)

n.a. = not available because of difficulties in separations

The phenotype depicted in **Figure 1** offers interesting potential commercial applications. The most immediate one would be for the production of dried cassava foliage. One of the bottlenecks for this new market for cassava is the costs involved in harvesting the foliage. The only practical approach is a mechanical harvest that would also carry a considerable amount of young stems and petiole tissue. Since the kind of plants shown in **Figure 1** do not have petioles, nor any branching, at harvest of the leaves these could be easily stripped off the stem. The result would be a reduced cost of harvest, and, because the reduced proportion of petiole and young stems, a better quality of the foliage with a lower fiber content. This last characteristic would be fundamental for the use of dried foliage in the composition of diets for the poultry industry.

Table 7. Syneresis in normal and waxy starches from different crops after refrigreration or freezing for a period of up to five weeks.

Type of starch	Duration of storage of gels					
	0	1	2	3	4	5
	Syneresis (%) in refrigerated gels					
Normal cassava	0.0	0.0	1.2	3.7	6.7	8.5
Waxy cassava	0.0	0.0	0.0	0.0	0.0	0.0
Normal maize	5.0	8.3	14.0	25.0	35.0	42.0
Waxy maize	0.0	0.0	0.0	0.0	0.0	0.0
Normal potao	0.0	5.0	14.7	21.3	26.0	32.0
Waxy potato	0.0	2.0	2.0	2.0	4.0	6.0
	Syneresis (%) in frozen gels					
Normal cassava	0.0	0.0	8.0	11.0	14.7	21.7
Waxy cassava	0.0	0.0	0.0	0.0	0.0	0.0
Normal maize	11.3	15.3	19.7	26.3	31.7	36.3
Waxy maize	0.0	2.1	1.9	2.3	2.3	3.3
Normal potato	0.0	12.7	22.7	28.0	31.3	41.0
Waxy potato	0.0	4.2	6.0	6.7	7.7	7.7

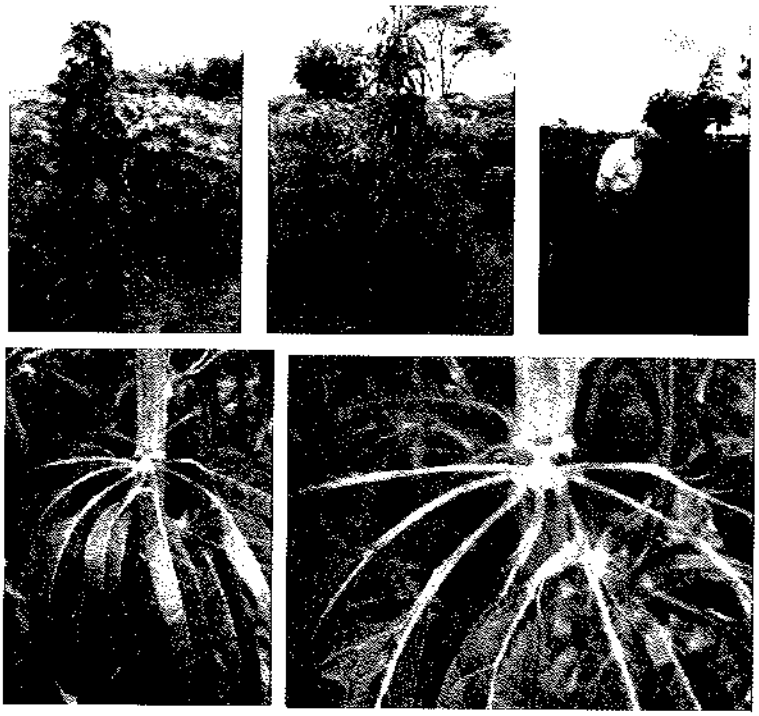

Figure 1. Illustration of a plant type mutation resulting in leaves without petioles and a very erect architecture.

A second important potential application of this mutation would be the possibility of drastically increasing plant densities in commercial planting of cassava. It should also be easy to accept the idea that this new plant type could allow for higher plant densities in cassava fields. Perhaps as many as 30,000 plants per hectare could be used. This concept is important because most of the genetic gains achieved through the last century relates to modifications in plant architecture. The use of semi-dwarf wheat and rice varieties has led to the highly successful green revolution. In the case of maize, if there is a single characteristic that can explain the consistent gains observed after the first introduction of commercial hybrids, it is the reduced plant height with increased tolerance to higher plant densities (Troyer, 2006). Today, modern hybrid maize is planted at much higher densities than 40-50 years ago. So, this mutation observed in cassava may lead to a new plant type and, perhaps, a green revolution for this crop. It should be mentioned that the petioles mutation had been known in cassava for a long time. There are few accessions in the collection with this trait (in addition to the progenitor which does not have the mutation in homozygous condition, MVen 332 shows the petioles phenotype). What this mutation brings in is the certainty of the genetic nature of this mutation, the reasonable hypothesis that it is the result of a single recessive mutation and, more importantly, the combination of the petioles trait with short plant height and non-branching architecture.

Crosses have been or will be made among these mutant plants (in few of them there was a very late flowering) with those accessions in the germplasm collection that show the petioles trait to initiate a breeding with this gene pool characterized by the petioles, non-branching phenotype. These crosses will recover the vigor lost as a result of the inbreeding depression typical of S1 genotypes.

Mutagenesis and the "Tilling" System

Breeders have used chemical products or irradiation such as gamma rays to induce mutations and generate genetic variability with relative success, particularly in the decades of the 1950s and 1960s (Maluszynski *et al.*, 2001; Ahloowalia *et al.*, 2004). Mutation breeding has a few drawbacks. Events are totally random, recessive in nature and usually appear as chimeras. Therefore, thousands of genotypes need to be evaluated before a useful mutation in the desired gene can be found. With the advent of molecular biology tools, an interesting system was developed to overcome some of the limitations of mutation breeding. DNA TILLING (for *Targeted Induced Local Lesions in Genome*) has been successfully used in different plant species (McCallum *et al.*, 2000; Perry *et al.* 2003; Till *et al.* 2003). Sexual seeds are mutagenized and, to avoid ambiguities caused by chimeras in the first generation plants (M_1), they are self-pollinated. The resulting plants (M_2) are then evaluated while DNA is extracted from them. For screening purposes, DNAs are pooled eightfold to maximize the efficiency of mutation detection (description of the TILLING method adapted from Till *et al.*, 2003).

CIAT participated in a project led by Universidad Nacional de Colombia and supported by the IAEA (International Atomic Energy Agency). About 4,000 seeds from six different cassava clones were irradiated with gamma rays (using a Cobalt 60 source with a dosage level of 200 Gy) or with fast neutrons. Seeds were germinated and transplanted to the field early in 2004. Plants were carefully evaluated in search of promising mutant forms

(although it was recognized that the occurrence of chimeras and the lack of expression of recessive mutations would certainly reduce the probabilities of finding such mutants at the M_1 stage). As soon as plants started to produce viable flowers, they were self-pollinated. As many as 5,000 M_2 seeds, from about 140 different M_1 plants, have been obtained. Several genes related to starch biosynthesis were targeted for TILLING analysis. Several mutations were identified in the M_2 generation but only the two most interesting will be described herein.

Small granule – High amylose starch mutation

This mutation has been reported and described already in the literature (Ceballos *et al.*, 2008). The initial discovery was facilitated by the unusual starch granule size which is about 1/3 the normal size for cassava. **Figure 2** illustrates how different the starch granules of this mutation are, not only in relation to size but also regarding its surface. Normal cassava starch granules have a very smooth surface. However, the surface of the granules in the mutated genotype is very irregular and rough (**Figure 2**).

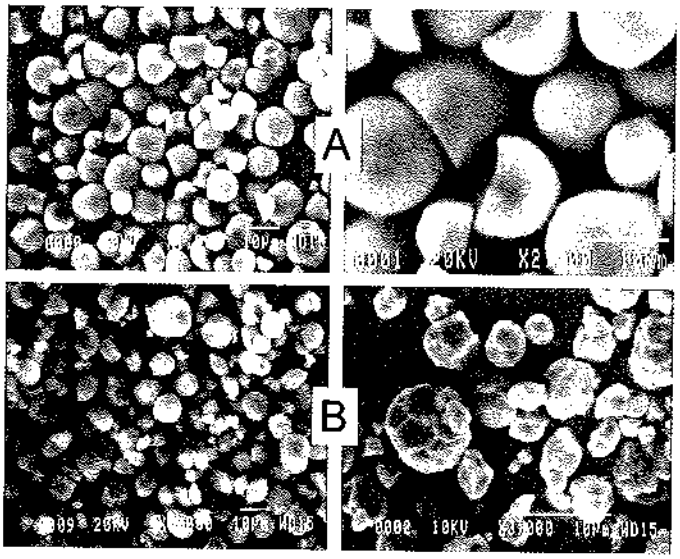

Figure 2. Scanning electron microscope photographs comparing normal (A) and mutant (B) cassava starch granules.
***Source**: Ceballos et al., 2008.*

The small size and irregular surface of the starch granules would make this mutation ideal for ethanol production because it facilitates the activity of starch degrading enzymes (Lehman and Robin, 2007; Thu *et al.*, 2007). The production of bio-ethanol from starch requires its degradation (liquefaction and saccharification), prior to the initiation of fermentation. However, the mutation also has a biochemical abnormality, with almost twice the normal levels of amylose (Ceballos *et al.*, 2008; Sánchez *et al.*, 2009). Amylose is more difficult to degrade (Sharma *et al.*, 2007). It is not possible at this time to know if the morphology of the starch granule will be more prevalent than the biochemical characteristics

(high amylose) of the mutation in the process of starch hydrolysis. When enough roots can be produced this analysis will be made.

The higher-than-normal level of amylose in these mutations has important commercial implications. Increased amylose levels leads to slowly digestible and resistant starches (Jobling, 2004; Lehman and Robin, 2007), which has a distinctive advantage in health, particularly in diabetes management. Slowly digestible starches may influence satiety and help control overweight problems, and they have also been linked to improved mental performances (Lehman and Robin, 2007). In addition, high-amylose starches in different crops offer advantages in the production of sweets, adhesives, corrugated boards and in the paper industry, and reduces the uptake of fat in certain fried products (Jobling, 2004). Very high levels of amylose result in "resistant" starches. Maize starches with more than 50% and up to 90% amylose can be produced commercially. Resistant starches cannot be digested but they are rather fermented in the large intestine, resulting in the production of butyrate that has been found to be beneficial to colon health (Jobling, 2004).

Tolerance to post-harvest physiological deterioration (PPD)

A second high-value trait that was identified in the mutagenized population was tolerance to PPD. Two genotypes were tentatively characterized as PPD-tolerant (2G15-1 and 5G108-8). Quantification of the reaction to PPD requires many commercial-size roots; these genotypes were first multiplied to produce the number of roots required. The result of this evaluation will be described below after other sources of tolerance have been described.

Rapid Cycling Recurrent Selection to Increase Carotenoids Content in Cassava Roots

The HarvestPlus initiative aims at reducing the problems derived from micronutrient deficiencies. The impact of vitamin A deficiency worldwide is an avoidable tragedy. The first step in the identification or production of cassava clones with enhanced nutritional value was the systematic and massive screening of landraces from CIAT's germplasm collection and key improved clones. The screening involved the evaluation for many micronutrients, but currently the work concentrates on pro-vitamin A carotenoids. Germplasm evaluated and the quantification methods were described by Chávez *et al.* (2005). Pro-vitamin A carotenoid levels have been found to be as high as 18 μg/g (fresh root basis) in the roots and considerably higher in the leaves. β-carotene has been found to be the most important component in these measurements. High carotene roots have a tendency for reduced or delayed post-harvest physiological deterioration (Sánchez *et al.*, 2005).

A normal recurrent selection cycle in cassava requires about eight years for completion (Morante *et al.*, 2005). This was considered to be too lengthy for a high-heritability trait as is the case of the carotenoids content in cassava roots. Therefore, a shorter cycle was implemented as illustrated in **Figure 3**. Each selection cycle did not go beyond the F1 stage of selection (when only one plant per genotype is available). Selected plants from the F1 nurseries were then planted in a new crossing block if they were late flowering (in this case each selection cycle required three years for completion). However, if plants flowered earlier, the cycle could be reduced to only two years. This implied making blind crosses among different genotypes without the certainty that they would be selected because of their high carotenoids contents.

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Traditional recurrent selection scheme for cassava							
Planting crossing blocks	Seed from crosses harvested	F1 trial	Clonal evaluation trial	Preliminary yield trial	Advanced yield trial	Regional trial. 1st year.	Regional trial 2nd year
Rapid cycling recurrent selection for increased carotenoids content (late flowering clones)							
Planting crossing blocks	Seed from crosses harvested	F1 trial	Planting crossing blocks	Seed from crosses harvested	F1 trial		
Rapid cycling recurrent selection for increased carotenoids content (early floweringclones)							
Planting crossing blocks. Harvest of seed	F1 trial	Planting crossing blocks. Harvest of seed	F1 trial	Planting crossing blocks. Harvest of seed	F1 trial	Planting crossing blocks. Harvest of seed	F1 trial

Figure 3. Illustration of chronograms used in the rapid cycling recurrent selection approach to increase the carotenoids content in cassava roots.

Results from this approach were outstanding. **Figure 4** presents the gains from selection for high carotenoids content using the rapid cycling recurrent selection approach. The data presented are the results of the seedling (F1 trials) nurseries during the last three years of work. Every year an average of almost 3 µg carotenoids/g of fresh root could be added to the best genotypes. These are unprecedented gains for a crop like cassava. These results also highlight the importance of adapting the breeding schemes to the specific needs and characteristics of the trait to be improved.

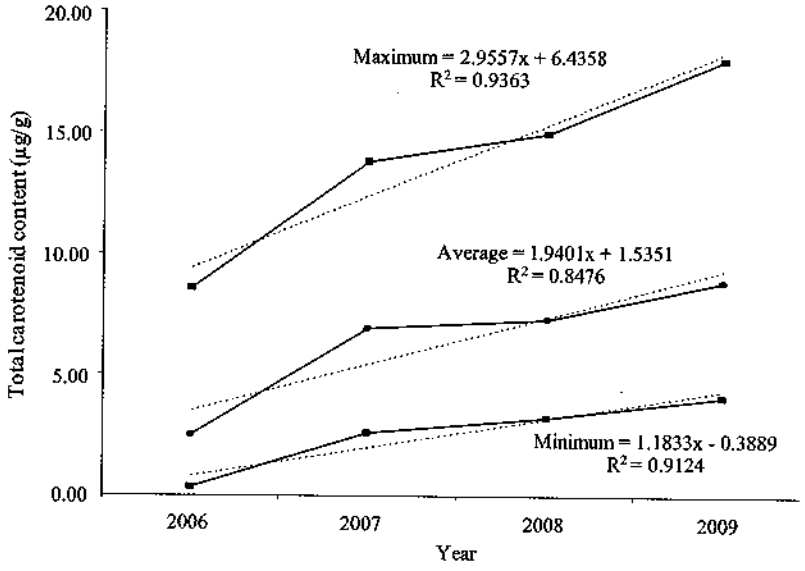

Figure 4. Gains from selection for high carotenoids content using the rapid cycling recurrent selection approach. Data presents the results of the seedling (F1 trials) nurseries during the last three years of work.

Interspecific Crosses

Tolerance to PPD

For several years CIAT has been working to introgress the tolerance to PPD found in the wild relative *Manihot walkerae* (Bertram, 1993; Cuambe, 2007; Fregene *et al.*, 2006). The interspecific cross was originally made with the elite genotype SM909-25 and then a first back-cross to SM909-25 was made to generate family BC289. In addition, the interspecific cross was also crossed to a different elite *M. esculenta* clone: MTai 8 (developed in Thailand and released with the name Rayong 60) to produce family BC284. Many genotypes were generated and evaluated in these two backcrosses (Cuambe, 2007) and three of them were selected for this study (BC284-42, BC284-49 and BC289-30). Results of this strategy are described later in this article.

Increased protein conten:

CIAT has also carried out a long-term project for higher protein content in the roots introgressed from accessions of wild relatives (*M. esculenta* subsp. *fabellifolia* and *M. tristis*) into cassava (CIAT, 2004). A total of 49 interspecific crosses having a range from 6.39 to 10.46% in protein content have been selected and back-crossed into the elite *M. esculenta* clone MTai 8 (Rayong 60 from Thailand). More than 6,000 back-crosses (BC) have been made. Further work is required to recover the root yield potential typical of *M. esculenta,* while maintaining (or even increasing) the current protein contents observed in the BC_1 populations. The issue of quality of proteins is also relevant and the profiling of amino acids is currently underway. In the process of screening for micronutrient content in cassava roots, a serendipitous discovery of interesting variation for crude protein content was made. Certain germplasm, like clone MCol 2436, has the advantage of a high crude protein content (around 7% on dry matter basis) combined with a higher carotene content (7.24 µg total carotenes/g fresh roots). A report on high protein cassava has already been published (Ceballos *et al.*, 2006b).

The standard methodology for estimating protein content has been traditionally through the indirect method of quantifying N by the Kjeldahl method and then multiplying it by the constant 6.25. However, it has been suggested that the N-to-protein conversion factor, in the case of cassava roots, may be considerably lower because of the presence of non-protein sources of N (Hock-Hin and Van-Den, 1996). Crosses have been made among the high-protein clones (based on the indirect Kjeldahl method) that had been identified. The resulting 393 genotypes were grown in Palmira (Colombia), and flour from their roots obtained. A direct method for the quantification of total soluble protein content (TSPC) was tested using the Bradford protein assay (Kruger, 1995; Bradford, 1976), which is a colorimetric method using the BioRad Dye Reagent (BioRad 500-0006). Three aliquots per sample were quantified. A group of 45 genotypes (selected to represent low, intermediate and high levels of TSPC) were also analyzed for their N content using the conventional Kjeldahl method.

Preliminary results confirmed a large variation in soluble proteins with a ten-fold difference between the high and low values (**Table 8**). However, the actual range of variation for TSPC was "compressed" compared with the variation based on indirect protein quantifications based on N contents (Kjeldahl's method).

Table 8. Variation in the total soluble protein contents of (TSPC) samples of 393 genotypes using the colorimetric Bradford protein assay. Three aliquots were taken per sample. Coefficient of variation for each individual sample was obtained and is presented in the right column. Reliability of the method is excellent with the average coefficient of variation below 6%.

Parameter	Soluble protein (%)	Coefficient of variation
Average	0.616144	5.848925
Max	1.02581	32.2906
Min	0.097302	0.102535
St Dev	0.132802	

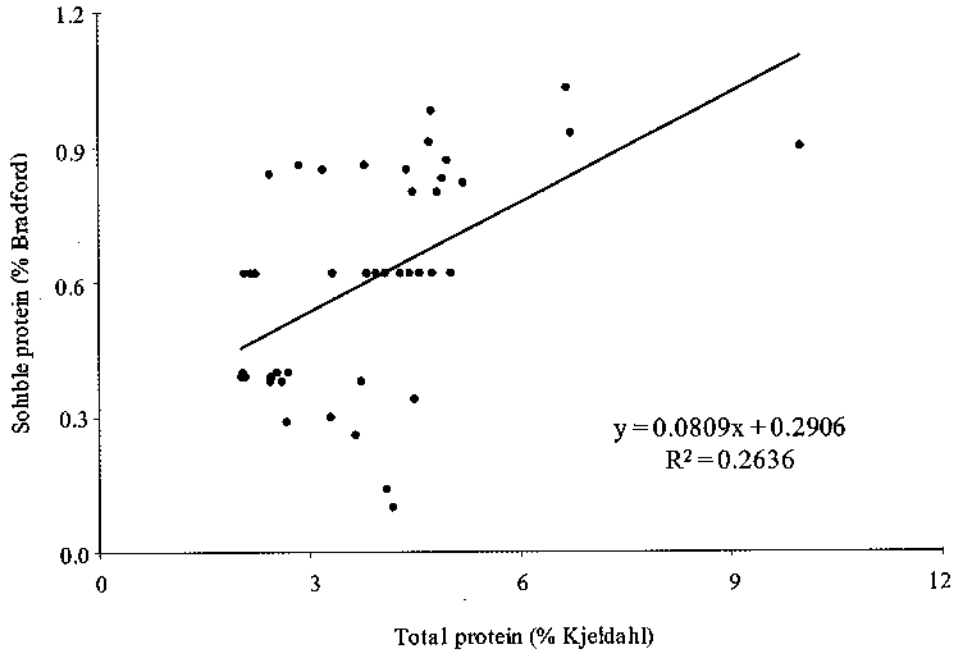

Figure 5. Relationship between TSPC (Bradford method) and crude protein content based on indirect quantification of N content (Kjeldahl's method) based on 45 samples.

Figure 5 illustrates the relationship between TSPC and the crude protein content based on the Kjeldahl's method for the 45 genotypes where N was quantified. This would suggest that the N to protein conversion factor is considerably lower that the conventional factor of 6.25, which is in agreement with reports in the literature (Hock-Hin and Van Den, 1996). The relationship between the two quantification methods was not very strong. The use of protease inhibitors in several samples resulted in similar TSPC, suggesting that proteases activity was not relevant in this type of assay. The Bradford method is a simple, reliable and not an expensive approach to quantify a large number of samples. The amount of individual amino acids in some of the samples analyzed (through HPLC) would allow

quantifying the total protein content (soluble and non-soluble), provide an idea of their nutritional quality and estimate the amount of proteins not accounted for by the Bradford method.

Tolerance to Post-harvest Physiological Deterioration

Cassava roots have a very short shelf life due to a process known as post-harvest physiological deterioration (PPD). PPD rapidly renders the roots unpalatable and unmarketable (Han *et al.*, 2001; Reilly *et al.*, 2003; 2007). Consequently, cassava roots need to be consumed or processed soon after harvesting (Van Oirschot *et al.*, 2000). The short shelf-life of the roots severely limits the marketing options by increasing the likelihood of losses and thus the overall marketing costs. In addition, the access to urban markets and processing facilities is restricted to production sites that are relatively close to them. PPD begins with vascular streaking, which is a blue-black discoloration of the xylem parenchyma, followed by general discoloration of the storage parenchyma. Occlusions and tyloses have also been observed (Rickard *et al.*, 1979). Five to seven days later, microbial activity causes further deterioration. Additionally, respiration increases and starch is hydrolyzed (Hirose *et al.*, 1984; Uritani *et al.*, 1984). The processes involved in PPD resemble typical changes associated with the plant's response to wounding, and triggers a cascade of biochemical reactions in which reactive oxygen species are central. Specific genes involved in PPD have been identified and characterized, and their expressions evaluated (Reilly *et al.*, 2001; Cortés *et al.*, 2002).

Several genotypes considered as potential sources of tolerance to PPD were evaluated (**Table 9**). Results from this evaluation are presented in **Table 10**. Three genotypes did not show any symptoms of PPD even after 40 days of storage (GM 905-66, AM 206-5 and WAXY 4). In addition, mutagenized genotypes, and one of the backcrosses from the interspecific cross with *M. walkerae*, also showed low values of PPD. This is a remarkable finding where many different sources of tolerance to PPD seem to have been discovered; this highlights the importance of aggressive and systematic screening of germplasm for different traits.

Genetic Transformation

The genetic engineering of industrial cassava varieties to produce waxy starch via anti-sense down-regulation of the GBSSI gene has been reported (Salehuzzaman *et al.*, 1993; Munyikwa *et al.*, 1997). GBSSI is the predominant starch synthase gene that catalyses the conversion of ADP-glucose into amylose. The isolation of a full-length GBSSI cDNA clone, construction of sense- and anti-sense transformation cassettes, and their insertion into the genome have been described (CIAT, 2003). Two genetic constructions with the GBSSI gene in anti-sense and sense orientation in the vector pCAMBIA 1305.2 were made to achieve silencing of the gene. The constructs were initially introduced into friable embryogenic callus (FEC) of the model transformation genotype 'MNig 11', from Nigeria, via *Agrobacterium tumefaciens*. Results of GUS transitory assay revealed a successful incorporation of the gene. Transformation of cassava accession MCol 2215 from Colombia was also attempted. Many different transgenic events have been successfully conducted in cassava (Taylor *et al.*, 2004).

High Capacity Root Quality Laboratory

Each year, cassava breeding projects around the world produce thousands of new genotypes. Early stages of selection eliminate a large proportion of these new genotypes without analyzing the quality of their starches or their nutritional properties (Kawano *et al.*, 1998; Jennings and Iglesias, 2002; CIAT, 2003; Kawano, 2003). It is possible, therefore, that along with the eliminated clones, valuable starch or nutritional quality traits have also been discarded. One of the problems, as explained above, is that starch mutants in cassava roots are not as readily identifiable as those in the kernels of cereals.

Table 9. Description of germplasm analyzed for PPD resistance in this study.

Genotype	Observations
CM 523-7 MCol 1505	Susceptible checks
MPer 183	Tolerant check
2G15-1 5G108-4	M_2 genotypes derived from a population mutagenized with gamma rays.
CW 429-1	Inter-specific cross (F_1) with *M. walkerae*
BC 284-42 BC 284-49	First backcrosses to elite clone MTai 8
BC 289-30	First backcross to elite clone SM909-258
CB 7-9 CB 44-15 GM 905-66 MBra 253 MCol 2436	Yellow roots/high carotenes. GM 905-66 is the genotype whose roots were found without PPD symptoms two months after harvest. CB genotypes were from Brazil and MCol 2436 and MBra 253 are landraces from the germplasm collection
AM 206-5	Original source of amylose-free starch
WAXY 2 WAXY 3 WAXY 4 WAXY 5 WAXY 6 WAXY 7	Genotypes with amylose-free starch derived from AM 206-5

Some of the approaches described above (TILLING system for mutation breeding or the iodine test) are specifically targeting the identification of known mutations (e.g. waxy starch). However, it is valid to assume that unknown mutations may also be available in cassava. A common need of many of the strategies described in this paper is for the availability of a high capacity root quality analysis laboratory to screen large numbers of samples (>15,000/year) in search of those genotypes with novel pasting properties of starch or enhanced nutritional value. CIAT is developing, jointly with the Universidad Nacional de Colombia, a laboratory that will be able to generate thousands of amylograms per year using a battery of rapid viscoanalyzers, Brabender, DSC, and other standard equipment and protocols. For crude protein content, the standardization of curves for the use of Near Infrared Analyzers (NIRs) greatly facilitates the breeding work.

Table 10. Post-harvest physiological deterioration (PPD) quantified at 5, 10, 20 and 40 days after harvest. Average total carotenoids content (TCC) and dry matter content (DMC) and number of roots used for each evaluation are also shown.

Clone	PPD (%)					TCC	DMC	Number of roots			
Variable	5	10	20	40	**Mean**	(ug/g)	(%)	5	10	20	40
CM 523-7	27.1	40.7	57.1	64.1	**47.2**	0.4	44.8	10	10	8	5
MCol 1505	25.7	31.6	71.6	66.4	**48.8**	0.7	40.1	10	10	10	9
MPer 183	5.4	4.0	5.3	9.2	**6.0**	0.5	41.3	10	10	10	5
2G15-1	0.5	0.0	0.0	6.9	**1.9**	1.0	44.0	10	10	10	10
5G108-4	2.9	3.7	7.1	7.3	**5.3**	0.7	45.4	10	10	10	9
CW 429-1	12.5	20.7	23.2	18.6	**18.7**	0.6	37.2	7	6	4	3
BC 284-42	16.8	14.1	16.0	n.a.	**15.6**	0.7	40.5	3	5	9	n.a.
BC 284-49	4.7	4.8	23.3	n.a.	**10.9**	2.5	27.4	4	6	6	n.a.
BC 289-30	0.0	1.0	0.0	0.0	**0.3**	0.5	34.5	10	5	10	10
CB 7-9	3.6	10.9	0.0	1.0	**3.8**	10.2	35.8	10	10	10	6
CB 44-15	0.5	0.0	1.0	1.0	**0.6**	11.5	29.5	10	10	7	5
GM 905-66	0.0	0.0	0.0	0.0	**0.0**	11.1	38.3	2	2	2	2
MBra 253	1.5	0.0	2.9	0.0	**1.1**	9.5	42.0	10	10	4	4
MCol 2436	0.0	26.3	38.9	n.a.	**21.7**	9.1	34.6	10	10	5	n.a.
AM 206-5	0.0	0.0	0.0	0.0	**0.0**	0.7	38.5	10	10	10	7
WAXY 2	3.7	8.0	3.6	3.6	**4.7**	0.6	35.6	10	10	8	8
WAXY 3	0.2	0.0	3.7	6.8	**2.7**	0.5	42.2	10	10	7	4
WAXY 4	0.0	0.0	0.0	0.0	**0.0**	0.6	36.2	10	10	10	4
WAXY 5	0.0	0.0	4.1	0.0	**1.0**	0.9	40.2	10	10	9	6
WAXY 6	3.4	1.4	4.7	2.2	**2.9**	0.5	36.1	10	9	10	9
WAXY 7	18.2	31.1	30.4	30.4	**27.5**	1.0	40.0	10	9	8	8
Average	**6.0**	**9.4**	**13.9**	**12.1**	**10.5**	**2.8**	**39.9**	**8.9**	**8.7**	**8.0**	**6.3**

CONCLUSIONS

Cassava is an important crop in the agriculture of many tropical and subtropical countries. It remains one of the most relevant commodities for subsistence farming as food security, and it is acquiring an increasing role in rural development as raw material for many processing pathways. Starch production from cassava roots and the use of dried chips for animal feeding are clearly the most important examples of industrial uses of cassava, particularly in Asia (Chutharatkul, 2005). To maintain this trend and make cassava even more competitive, several approaches have to be taken simultaneously: increased yields and reduced costs of production; wider uses of cassava products; and increased emphasis on the search for value-added traits/products.

Increased productivity has been achieved successfully through the development of high-yielding clones, improved fertilization and soil conservation approaches, and/or better

management of the planting materials (Kawano, 2003; Chutharatkul, 2005; Hoang Kim *et al.*, 2005; Howeler, 2005). Mechanization is gradually being incorporated in the production system with the development of machinery specifically designed for cassava in order to reduce production costs. New strategies are currently under way in the search for tolerance to herbicides, which offers great promises. Tolerance to herbicides allows for minimum tillage practices, which in turn will maximize water and fertilizer use efficiency. The exploitation of foliage for animal feeding opens a new avenue of uses for cassava. All these approaches have had a remarkable impact on the livelihood of millions of cassava farmers in different tropical and subtropical regions of the world.

This paper described a drastic change in the goals of the cassava breeding project at CIAT towards the production and identification of high-value clones. Success in this regard has been achieved through the identification of starch mutations, unusual plant architecture phenotypes, tolerance to post-harvest physiological deterioration, and increased nutritional value. These are traits what were only in the wish list a few years ago (Ceballos *et al.*, 2006a).

The access to these high-value traits will further contribute to poverty alleviation (a chronic and typical problem of many of the marginal agriculture land where cassava is one of the few crops that can be grown) and rural development (cassava roots need to be processed near the fields where they are harvested). Implicit in this new strategy for cassava genetic improvement is the acknowledgement that these high-value cassava clones will target specific needs of the industry and, therefore, an all-purpose variety will no longer be feasible. For instance, high-carotene, high-protein cassava clones are ideal for the feed industry (as well as for human consumption) but they will present additional problems to the starch industry.

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Appendix 1

Protocols for Systematic Characterization of Root Duality Traits used at CIAT

Root and starch moisture content. Up to five roots from the same plant were peeled and immediately cut into small pieces and mixed. Moisture content was determined after drying 50 g of sample (freshly cut pieces or starch) at 60°C for 48 hours (Prieto and Valencia, 1988).

Flour extraction. Freshly cut pieces from the harvested peeled root(s) were lyophilized during 24 hours at -30°C and then ground. A FreeZone Stoppering Tray Drier (Model 79480) and a 6 liter Freeze Dry System, Model 77530 (Labconco Corporation, Kansas City, USA) were used. The flour thus obtained was stored in plastic bags for total and reducing sugar and starch analyses.

Starch isolation. Freshly cut pieces of peeled roots were suspended in tap water and crushed in an Osterizer blender. The slurry was filtered through a 100µm sieve. The starch was allowed to settle. After the supernatant was decanted off, the starch was dried in an oven with fan-forced ventilation at 40°C during 48 hours.

Total and reducing sugars. The contents of total and reducing sugars were determined according to Cronin and Smith (1979). Sugars were extracted from 2 g of root flour using an 80% ethanol solution, a Fehling reagent and a glucose standard curve. A Cecil spectrophotometer model CE 2021, Series 2000 (Cambridge, UK) was used in the determination.

Determination of starch content. Starch was measured after incubation with thermostable α-amylase and then with amyloglucosidase. The released glucose was measured with a spectrophotometer after reaction with ABTS-reagent containing glucose oxidase and peroxidase (Cronin and Smith, 1979). Starch content was calculated as 90% of glucose content.

Paste clarity. The methodology suggested by Craig *et al.* (1989) was used. A 1% db (dry basis) aqueous dispersion of starch was boiled at 97°C (1000 m above sea level) with shaking thoroughly every 5 min for 30 min. Transmittance was measured at 650 nm after cooling to room temperature.

Colorimetric amylose determination. Amylose content in the starch was measured following standard procedures (ISO 6647, 1987). Starch granules were first dispersed with ethanol and then gelatinized with sodium hydroxide. An aliquot was then acidified and treated with an iodine solution, which produces a blue-black stain coloration. The color intensity, which is related to amylose content, was then measured with a spectrophotometer (λ: 620 ηm) and compared with standard curves obtained using purified amylose (ICN) and amylopectin (SIGMA A0512) extracted from potato tubers. Three different quantifications per starch sample were made and mean values were then calculated.

Pasting Properties. Hot starch dispersion viscosity profiles were obtained with a Rapid Visco Analyzer model RVA-4 Series (Newport Scientific, Australia). Starch (1.25 g db) was dispersed in distilled water (near 23 cm^3) to 5% suspension. Viscosity was recorded using the temperature profile: holding at 50°C for 1 min, heating from 50°C to 90°C at 6°C/min,

holding at 90°C for 5 min, and then cooling down to 50°C at 6°C/min with continuous stirring at 160 rpm. Four parameters were measured: pasting temperature (PT), peak viscosity (PV), hot paste viscosity at the end of the plateau at 90°C (HPV), and the cool paste viscosity raising 50°C (CPV). With them, three additional parameters were calculated: breakdown (BD), estimated as PV-HPV; setback (SB), estimated as CPV-PV; and consistency (CS), estimated as CPV-HPV; ease of cooking estimated as time to PV minus time to PT.

Swelling power, solubility and dispersed volume fraction measurements: Swelling power and solubility patterns (Mestres *et al.*, 1997) were determined using 1% db (w/w) starch dispersions (0.28g db dispersed in 27.72 g of distilled water) at 60, 75 and 90°C. The low concentration used in the study was chosen to obtain an optimal separation between the pellet and supernatant phases after centrifugation. Paste was prepared in the Rapid Visco Analyzer (RVA) from 35°C for 1 min, increasing temperatures at 6°C/ min. Three different and independent analyses were made holding final temperatures at 60, 75 or 90°C for 2.5 min. Stirring was at 960 rpm for the first minute and then maintained at 160 rpm during the entire analysis. The paste was immediately transferred to a 50 cm^3 centrifuge tube. The supernatant and sediment after centrifugation for 10 min at 6000 g at 25°C were collected and weighed (Wsu and Wse, respectively) then dried at 100°C for 24 h and 48 h, respectively, and weighed (Dsu and Dse, respectively). Three parameters were calculated: concentration of soluble material in the supernatant (solubility), the swelling power and the volume fraction of the dispersed phase (Φ).

Solubility (% db) = 100 * Dsu /0.28

Swelling Power (g_{Water}/g_{Starch}) = (Wse – Dse)/Dse

(Φ) = (27.91 – (Wsu – Dsu))/27.91

Factor 27.91 is calculated as total volume (cm^3) of the paste. Starch specific density is 1.5 g/cm^3. 27.91 = 27.72 + (0.28 / 1.5) cm^3.

Refrigeration and Freeze/thaw stability: A paste was prepared in the Rapid Visco Analyzer (RVA) (5% db, w/w, containing 0.1% sodium azide) from 35°C, increasing temperatures at 6°C/min rate to 93°C, maintained during 2 min. Protocol followed common procedures.

Refrigeration: Ten centrifuge plastic tubes were filled with approximately 6 g of gel (**WG**) and stored at 4°C. The study lasted for five weeks. Every 7 days, two tubes were taken out of the refrigerator and held at room temperature during 1 hour. Tubes were centrifuged at 5000 rpm for 10 minutes and supernatant was separated and weighed (**WS**). Syneresis was calculated as WS/WG*100

Freeze/thaw: Ten centrifuge plastic tubes were filled with approximately 6 g of gel (**WG**) and stored at -20°C. The study lasted for five weeks. Every seven days, two tubes were taken out of the freezer and held during 1.5 hour in a water bath (30°C). Samples were then centrifuged (5000 rpm for 10 minutes) and the supernatant was separated and weighed (**WS**). Syneresis was calculated as WS/WG*100.

Total cyanide content. Approx. 60 g of freshly cut pieces, 1 cm^3 cubes, were homogenized in 150 cm^3 of 0.1 M H_3PO_4 (25% v/v ethanol), followed by centrifugation. The supernatant was analyzed for cyanogens after appropriate dilution, by hydrolysis with exogenous linamarase prepared in the lab from cassava peel extraction. HCN was evaluated by colorimetric measurement after coloration with 1,3-dimethyl barbiturate/isonicotinate reagent according to Essers *et al.* (1993) at λ: 605 ηm.

Carotenoids content. Carotenoids were extracted following the method suggested in the literature (Rodriguez-Amaya, 2001; Rodriguez-Amaya and Kimura, 2004), except that separation of the solid and liquid phases was carried out by centrifugation and not by filtration. Approximately 5 g of tissue were homogenized for 1 min with 10 ml acetone:petroleum ether (1:1) using a Polytron homogenizer, followed by centrifugation at 3000 rpm for 10 min, at 10°C. The liquid phase was collected and extraction of the residue, followed by centrifugation, was repeated until it turned colorless (usually three times). The extracts were then combined, water was added, and the petroleum ether phase containing the carotenoids was separated from the lower aqueous-acetone phase.

The total carotenoid content was determined by visible absorption spectrophotometry with a Cecil spectrophotometer model CE 2021 (Cambridge, UK), using an absorbance at 450 nm and the absorption coefficient of -carotene in petroleum ether (2592) (Rodriguez-Amaya, 2001; Rodriguez-Amaya, 2004). β-carotene quantification was done by HPLC. From the petroleum ether solution used for spectrophotometric quantification of total carotenoid, aliquots (15 ml) were taken, partially dried by rota-evaporation and completely dried with nitrogen. Immediately before injection, the dry extract was dissolved in 1 ml of HPLC grade acetone and filtered through 0.22 m PTFE syringe filter. Separation and quantification of carotenoids was achieved using an YMC Carotenoids S-5 C_{30} reversed-phase column (4.6 mm X 250 mm: particle side, 5 μm) in a HPLC systems (HPLC Agilent Technologies 1200 series) using DAD detector with wavelength set at 450 nm. Identification and quantification were performed by comparing retention times and visible spectra with a standard for -carotene (Aldrich 85,555-3).

CASSAVA IN ASIA: A POTENTIAL NEW GREEN REVOLUTION IN THE MAKING

Reinhardt H. Howeler[1]

ABSTRACT

Over the past decade the cassava planting area in Asia has slightly increased while yields have markedly increased, resulting in a steady increase in production, from 45.10 million tonnes in 1998 to 78.75 million tonnes in 2008. Due to a serious drought in Thailand in 2004, cassava production there temporarily dropped to 17 million tonnes in 2005 but increased again to 26.9 million tonnes in 2007, and 27.6 million tonnes in 2008. In most countries cassava is utilized domestically, but in Thailand it is mainly for the export market. China is presently a major importer, importing about 80% of its domestic requirement. In several countries in Asia, cassava is still principally used as food, but in Thailand, China and Vietnam it is mainly used for animal feed or industrial purposes.

Potential markets for cassava are mainly in the area of starch and starch-derived products, for domestic animal feed, and for processed food. Cassava starch can generally compete with other sources of starch on the basis of price in the mass market, and on the basis of its functional properties in certain specialized markets. However, recently there has been major interest in the use of cassava as a raw material for the production of ethanol, mainly as a "bio-fuel" to mix with gasoline to produces "gasohol". In this market cassava has to compete with sugarcane in tropical countries and with maize in the temperate zone.

Due to the increasing use of maize for ethanol production in the US, the price of maize and maize-derived products have markedly increased over the past 2-3 years. Thus, animal feed factories and farmers alike are looking at cassava roots as a cheaper source of energy and at cassava leaves as a protein source in animal feed rations. Similarly, the high price of maize starch has made cassava starch more competitive, increasing its price to unprecedented levels of over $500 per tonne in 2010. Finally, the construction of many cassava-based bio-ethanol factories, particularly in China but also in Thailand, Indonesia and Vietnam, have markedly increased the demand for cassava fresh roots and dry chips. Unfortunately, the recent accidental introduction of a new mealybug species, *Phenaccocus manihoti,* from either Africa or southern Latin America into Asia has seriously affected cassava yields in Thailand in 2009/10. In spite of significant increases in yields throughout much of Asia during the past few years, this problem will inevitably affect the supply of cassava in the region this year. This reduced supply will not be able to satisfy the increasing demand, resulting in marked increases in the prices of all cassava products. But since these lower yields have resulted in high root prices many farmers in Asia will still be able to obtain a good income from selling cassava. This in turn may stimulate the use of greater inputs in fertilization, weeding and even investments in drip irrigation to further boost yields. It also provides an incentive to increase the cassava planted area, in some cases on steep slopes or in previously forested areas. To make the current Cassava Revolution indeed a "Green" Revolution, urgent measures need to be taken to reduce negative environmental impacts by enhancing the adoption of soil conservation measures to prevent erosion and soil degradation. The recent introduction into Thailand of a parasitic wasp, *Anagyrus lopezi*, to control the new mealybug species gives hope that this problem will soon be resolved. In addition, there is an urgent need to breed and select higher yielding varieties that will increase farmers' yields and income, lower root prices and satisfy the needs of producers, consumers

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and processors alike, without the need to further encroach on steep slopes and forested areas. This truly "Green" Revolution will benefit all involved.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) has its origin in Latin America where it has been grown by the indigenous Indian population for at least 4000 years. After the discovery of the Americas, European traders took the crop to Africa as a potentially useful food crop; later it was also taken to Asia to be grown as a food security crop and for the extraction of starch. Thus, in the 19th century cassava became an important food crop in southern India, as well as on Java island of Indonesia and in the southern Philippines, while in Malaysia and parts of Indonesia it was also used for extraction of starch. After the Second World War it became an important industrial crop in Thailand, mainly to produce starch for local consumption, and dried chips and later pellets for the rapidly growing European animal feed market. In Indonesia the crop remains first and foremost a food crop, used in a great variety of dishes, but in southern Sumatra it is now mainly grown for starch extraction.

PRESENT SITUATION

1. Cassava Production Trends

Table 1 indicates that in 2008 about 51% of cassava in the world was produced in Africa, 34% in Asia, and only 15% in the Americas. Cassava production in Asia increased at a fairly high rate of 1.7% annually during the late 1970s and early 80s, slowed down considerably during the 90s, and has been growing very rapidly again at 5.7% per year during the past ten years (**Table 2**) (**Figure 1**); this was due to a modest increase in harvested area, as well as a remarkable increase in yields, averaging 3.8% per year; the latter compares with annual yield increases of 1.7% in Africa and 1.5% in Latin America during the same period.

Figure 2 shows the production and yield in the main cassava producing countries in Asia from 1961 to 2008. In some countries, cassava production kept pace with increases in population, while in others it decreased as a result of rapid urbanization and a more secure supply of the preferred food, rice. A marked exception is Thailand, where cassava production increased rapidly in the 1970s and 80s in response to a rapidly growing demand for animal feed in Europe, as well as a favorable tariff structure. But when the Common Agricultural Policy (CAP) in the EU changed in the late 80s, cassava became less competitive with locally produced barley, and exports of cassava pellets declined rapidly, from a peak of 9.1 million tonnes in 1989 to about 260,000 tonnes in 2005. In 2007 and 2008 it increased again to 1.6 million tonnes (**Figure 3**).

Table 1. Cassava production, area, and yield in the world, the continents and in various countries in Asia in 2008.

	Production ('000 tonnes)	Area ('000 ha)	Yield (t/ha)
World	**232,950**	**18,695**	**12.46**
-Africa	118,049 (51%)	11,989	9.85
-LAC	35,904 (15%)	2,718	13.21
-Asia	**78,754 (34%)**	**3,968**	**19.85**
-Cambodia	3,676	180	20.43
-China	4,362 [1)]	269	16.24
-India	9,054	270	33.55
-Indonesia	21,593	1,193	18.09
-Laos	233	11	21.19
-Malaysia	430	41	10.49
-Myanmar	211	16	12.79
-Philippines	1,942	212	9.17
-Sri Lanka	241	24	9.92
-Thailand	27,566	1,184	23.29
-Timor-Leste	49	12	4.14
-Vietnam	9,396	556	16.91

1) Chinese data indicate a production of 7.94 million tonnes, an area of 387,000 ha, and a yield of 20.52 t/ha.
Source: *FAOSTAT, Feb 2010.*

Table 2. Annual growth rates (%) in cassava production, area and yield, by continent, 1978-2008.

	Production			Area			Yield		
	'78-88	'88-98	'98-08	'78-88	'88-98	'98-08	'78-88	'88-98	'98-08
Africa	2.8	3.6	2.7	1.4	2.9	1.0	1.4	0.7	1.7
Asia	**1.7**	**-1.6**	**5.7**	**0.7**	**-2.0**	**1.9**	**1.0**	**0.4**	**3.8**
Americas	-0.8	-0.5	2.7	-1.2	-0.2	1.2	0.4	-0.3	1.5

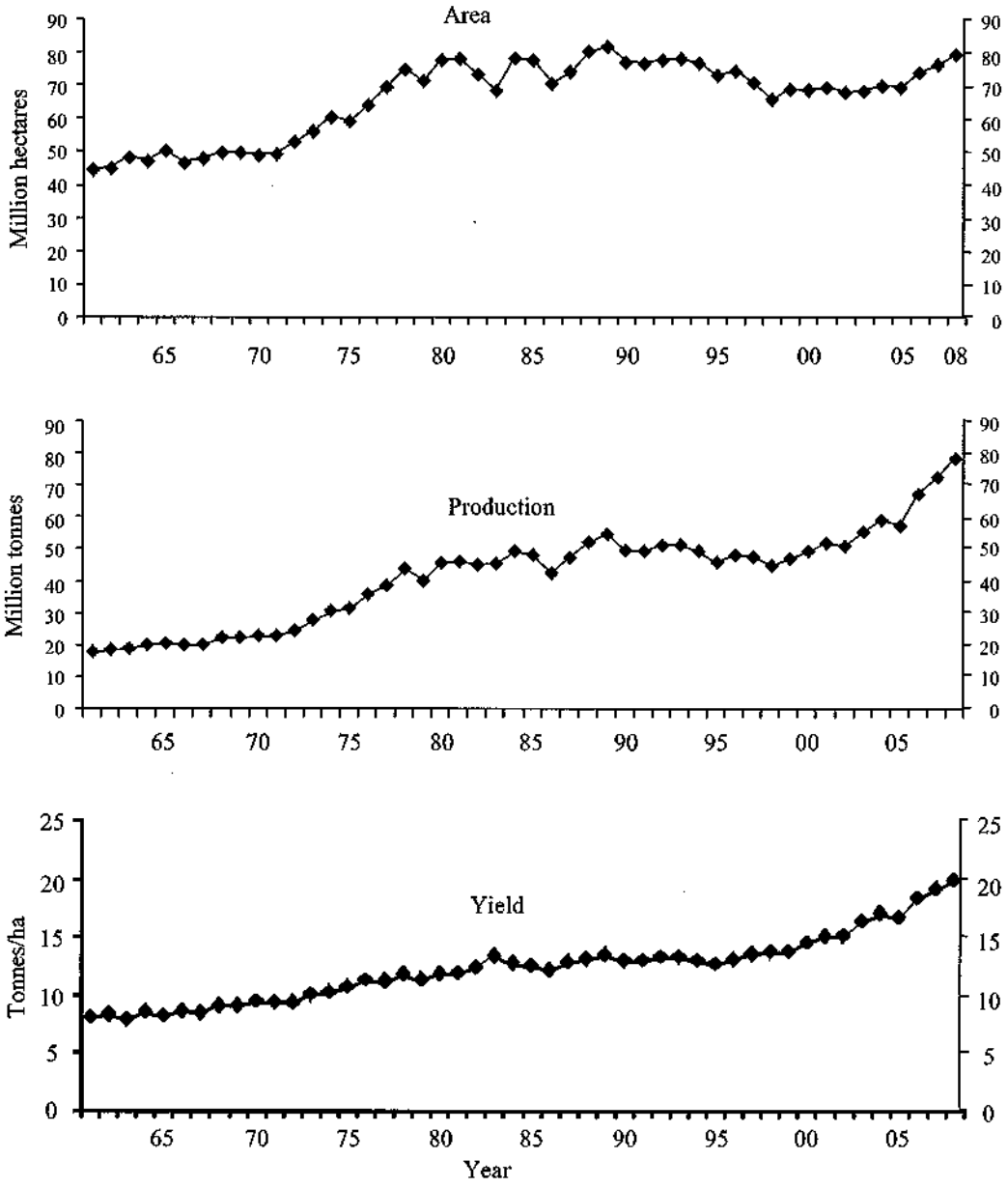

Figure 1. Total harvested area, production and yield of cassava in 12 countries growing cassava in Asia, 1961-2008.
***Source:** calculated from FAOSTAT, Feb 2010.*

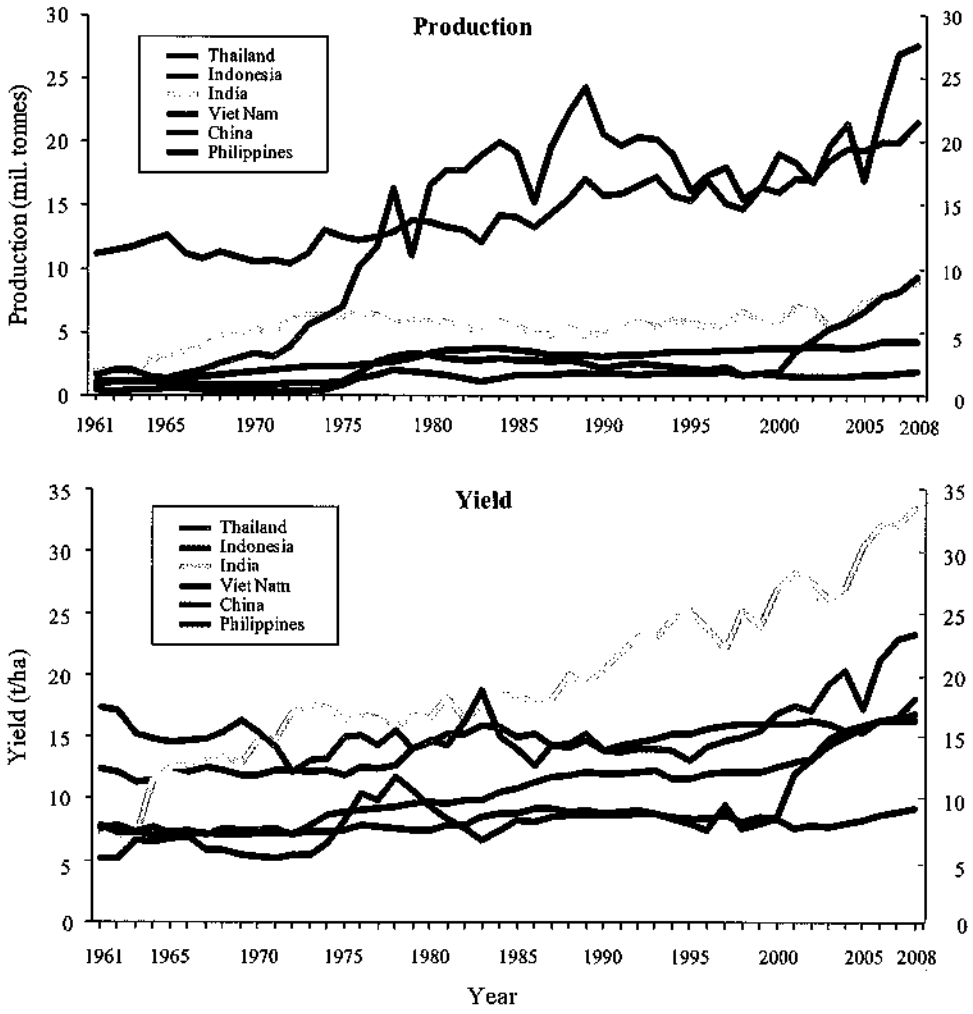

Figure 2. Cassava production and yield trends in Asia's principal cassava producing countries, 1961-2008.
Source: *FAOSTAT, Feb 2010.*

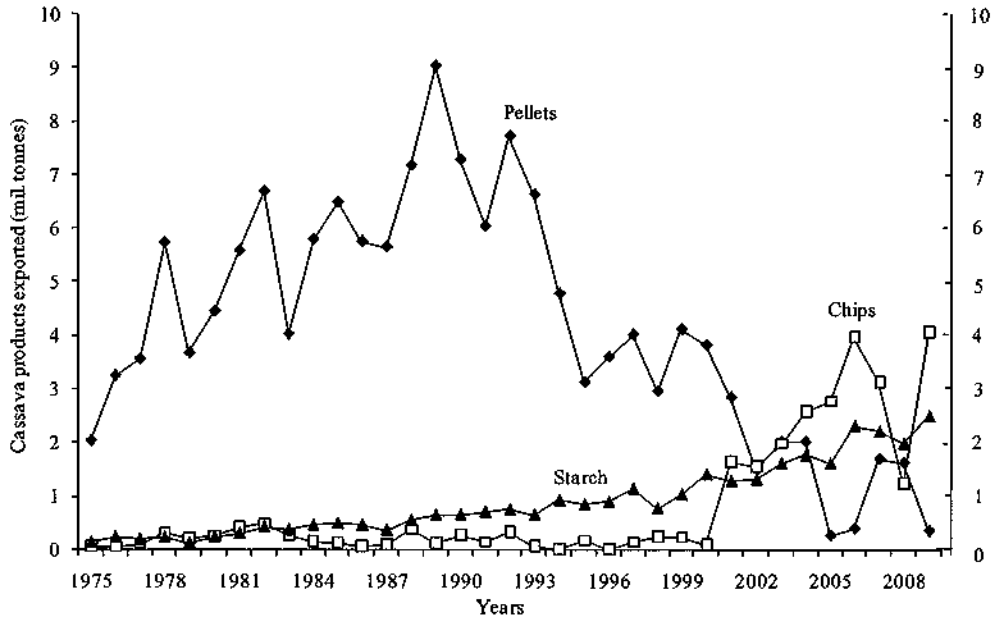

Figure 3. Quantities of cassava products exported from Thailand from 1975 to 2009.
***Source:** Adapted from TTTA, 2008 and 2009.*

This near-collapse of the export market in Europe was partially offset by accelerated growth in the production of starch and starch derivatives, as well as by increasing demand for cassava chips in China. Meanwhile in Vietnam, cassava production was in decline during the 1980s and 1990s as the economy improved and production of rice increased. But during the past eight years, cassava production suddenly increased from about 2 million tonnes in 2000 to over 9.4 million tonnes in 2008, in order to meet buoyant internal demand for starch, and for export of chips and starch. This ability to increase production was a result of a substantial increase in planted area, from 237,600 ha in 2000 to 555,700 ha in 2008, as well as a remarkable increase in yield, from 8.36 t/ha in 2000 to 16.91 t/ha in 2008. In both Thailand and Vietnam, the yield increases achieved during the past 10 years, are mainly due to a concerted effort to distribute widely the new high-yielding and high-starch varieties, as well as to the adoption of improved cultural practices, such as more balanced fertilizer use and soil conservation measures. In Thailand, new varieties are now planted in nearly 100% of the area, while 80-90% of farmers apply chemical fertilizers; in Vietnam the new varieties are now planted in about 60% of the cassava area while about 80% of farmers apply chemical fertilizers and/or organic manures. These two factors combined more than doubled yields in Vietnam over the past eight years.

2. Production Systems

Cassava is known to be a very drought-tolerant and water-efficient crop, while the crop is also exceptionally tolerant of high soil acidity and low levels of available phosphorus (P). Thus, cassava can compete with other, more valuable, crops such as maize, soybean and vegetables mainly in areas of acid and low-fertility soils, and those with low or unpredictable rainfall, such as the northeast of Thailand, the central coast of Vietnam and in east Java.

Until very recently there were no economically important pests or diseases in Asia – with the exception of India – so there was no need for the use of pesticides. Fertilizers or organic manures are commonly used on cassava, but not necessarily in adequate amounts or in the right proportions of N, P and K. Usually, responses to organic manures can be greatly enhanced by additional application of chemical fertilizers high in N and K.

During the past five years, and particularly during the past year, cassava production costs in Thailand have increased rapidly, about 75% from 2003/04 to 2007/08 in US dollar terms (**Table 3**). But root prices have increased about 140% during the same period, resulting in a five-fold increase in the net income for farmers, from $ 112/ha in 2003/04 to $ 629/ha in 2007/08.

Production costs vary significantly across the region. Production costs for advanced farmers in Indonesia, India and China seem to be higher than in Cambodia, the Philippines and Thailand, while they are lowest in Vietnam. When calculated per tonne of fresh roots, production costs in Vietnam and Thailand are lower than in India, Cambodia or the Philippines, and much lower than in Indonesia and China (**Table 4**). It is clear that cassava products from Thailand remain competitive because farmers increased their yields through the use of improved varieties and better production practices (Howeler, 2001; 2005).

After years of stagnating or declining profit margins, farmers in Thailand, as well as in other parts of Asia, are finally making a good income from growing cassava. This is due to an ever increasing demand for cassava roots, which currently far outstrips supply, resulting in record-high prices for all cassava products, and a "boom" in cassava production all over Asia. Cassava is becoming a "high-value crop", which encourages and enables farmers to intensify production practices to increase yields.

3. Products and Markets

Both cassava roots and leaves (or young plant tops) have multiple end-uses, including direct human consumption of fresh roots and leaves (after boiling), on-farm animal feeding, commercial production of animal feed, and production of starch or starch derivatives. **Figure 4** shows in more detail the various products made from cassava starch

and dried chips, as well as from the peels and pulp, which are by-products from the starch industry.

a. Fresh roots for human consumption

In Kerala state of India, as well as in East Timor, Lao PDR, Cambodia, the Philippines and in some areas of China and Vietnam, fresh cassava roots are consumed directly after boiling or roasting. In most other parts of Asia cassava is not consumed as fresh roots, but only after some form of processing.

Table 3. Average cassava production costs in Thailand from 2003/04 to 2007/08 (US $/ha).

	2003/04	2004/05	2005/06	2006/07	2007/08
1. Variable Costs ($/ha)	**313.49**	**350.80**	**393.12**	**478.09**	**575.01**
1.1 Labor costs	***187.84***	***206.70***	***239.43***	***292.86***	***354.59***
-land preparation	45.61	50.72	59.09	75.18	95.00
-planting	21.26	25.31	28.47	34.36	40.21
-crop maintenance	53.94	62.99	70.98	84.99	104.85
-harvest	67.03	67.68	80.89	98.33	114.53
1.2 Agricultural input costs	***97.15***	***112.21***	***126.26***	***151.88***	***180.30***
-planting material	31.86	35.08	37.66	44.10	51.02
-fertilizers	42.36	50.19	58.17	70.85	85.35
-insecticides/herbicides	20.90	24.90	28.25	34.02	40.51
-fuel and lubricants	1.04	1.05	1.15	1.60	1.83
-machinery and others	0.73	0.73	0.76	0.96	1.18
-machinery repair/maintenance	0.26	0.26	0.27	0.35	0.41
1.3 Interest on production costs	***28.50***	***31.89***	***27.43***	***33.35***	***40.12***
2. Non-variable costs ($/ha)	**52.16**	**52.28**	**52.47**	**59.60**	**67.28**
-land rental	50.48	50.60	50.78	57.69	65.12
-machinery depreciation	1.50	1.50	1.51	1.71	1.93
-interest on machinery	0.18	0.18	0.18	0.20	0.23
3. Total Production costs ($/ha)	**365.65**	**403.08**	**445.59**	**537.69**	**642.29**
Production cost per tonne	18.03	23.46	21.13	23.45	28.67
Cassava yield (t/ha)	20.28	17.18	21.09	22.93	22.40
Cassava root price (B/kg) [1)]	0.95	1.32	1.42	1.21	1.77
Cassava root price (US$/t) [1)]	23.56	32.92	35.62	34.51	56.74
Gross income (US$/ha)	477.80	565.57	751.22	791.31	1,270.98
Net income (US$/ha)	112.15	162.49	305.63	253.62	628.69
Exchange rate (baht/US$)	40.16	40.06	39.92	35.14	31.13

[1)] Estimated at 90% of the root price at 30% starch (TTTA, 2007)

Source: *Office of Agricultural Economics (OAE) of Thailand, 2008.*

Table 4. Estimated cost of cassava production for advanced farmers in several countries in Asia in 2008.

	Cambodia	China	India	Indonesia	Philippine	Thailand	Vietnam
1. Variable Costs ($/ha)							
Labor cost ($/manday)	2.93	5.80	4.35	3.87	3.33	4.41	2.50
-land preparation. (md/ha)	-	*5*	*31*	-	*8*	*6*	*34*
-stake preparation	-	-	*5-*	*5*	*6*	-	-
-planting	*15*	*5*	*12*	*18*	*10*	*10*	*6*
-fertilizer application	*10*	*5*	*6*	*5*	*4*	*6*	*1*
-manure application	*2*	*0*	*75*	*5*	*0*	*6*	*2*
-irrigation	-	-	*17*	-	-	-	-
-weeding	*29*	*30*	*86*	*17*	*8*	*11*	*40*
-plant protection	-	-	*0.5*	-	-	-	-
-harvesting	*34*	*20*	*37*	*33*	*30*	*14*	*42*
-loading	*10*	*10*	*9*	*1*	-	*12*	-
Total mandays/ha	*100*	*75*	*210.5*	*84*	*66*	*65*	*125*
Total Labor Costs ($/ha)	**293.00**	**435.00**	**915.68**	**325.08**	**219.78**	**286.65**	**312.50**
Other Costs							
-fertilizers	156.10	137.00	88.50	402.76	355.56	110.29	131.25
-manures	73.17	0	96.50	66.30	0	99.91	43.75
-planting materials	88.62	107.00	15.78	0	111.13	99.91	0
-plant protection chemicals	-	-	3.33	-	-	-	-
-other materials	8.94	64.00	10.00	37.57	0	0	30.00
-fuel	71.95	0	16.00	0	0	0	0
-transportation of roots	73.17	60.00	-	173.35	16.67	22.06	0
-land prep. by tractor	102.44	107.00	96.35	119.34	177.77	82.72	0
-land prep. with bullocks	-	-	24.35	-	-	-	-
Total Other Costs ($/ha)	**574.39**	**475.00**	**350.81**	**799.32**	**661.13**	**414.89**	**205.00**
Total Variable Costs ($/ha)	**867.39**	**910.00**	**1,266.49**	**1,124.40**	**880.91**	**701.54**	**517.50**
Land rent or taxes ($/ha)	97.56	220	31.80	331.00	0	99.91	0
Total Product. Costs ($/ha)	**964.95**	**1,130.00**	**1,298.29**	**1,455.40**	**880.91**	**801.45**	**517.50**
Production Costs ($/tonne)	**35.74**	**41.85**	**38.75**	**55.98**	**35.24**	**28.62**	**19.90**
Yield of cassava (t/ha)	**27**	**27**	**33.5**	**26**	**25**	**28**	**26**
Root price ($/tonne)	**77.24**	**66.20**	**87.00**	**80.11**	**44.44**	**56.74**	**56.25**
Gross income ($/ha)	**2,085.48**	**1,787.40**	**2,914.50**	**2,082.86**	**1,111.00**	**1,588.72**	**1,462.50**
Net income ($/ha)	**1,120.53**	**657.40**	**1,616.22**	**627.46**	**230.09**	**787.27**	**945.00**
Exchange rate (currency/ $)	R 4,100	RMB 7.00	Rp 46.00	Rp 9,050	P 45.00	B 33.00	D 16,000

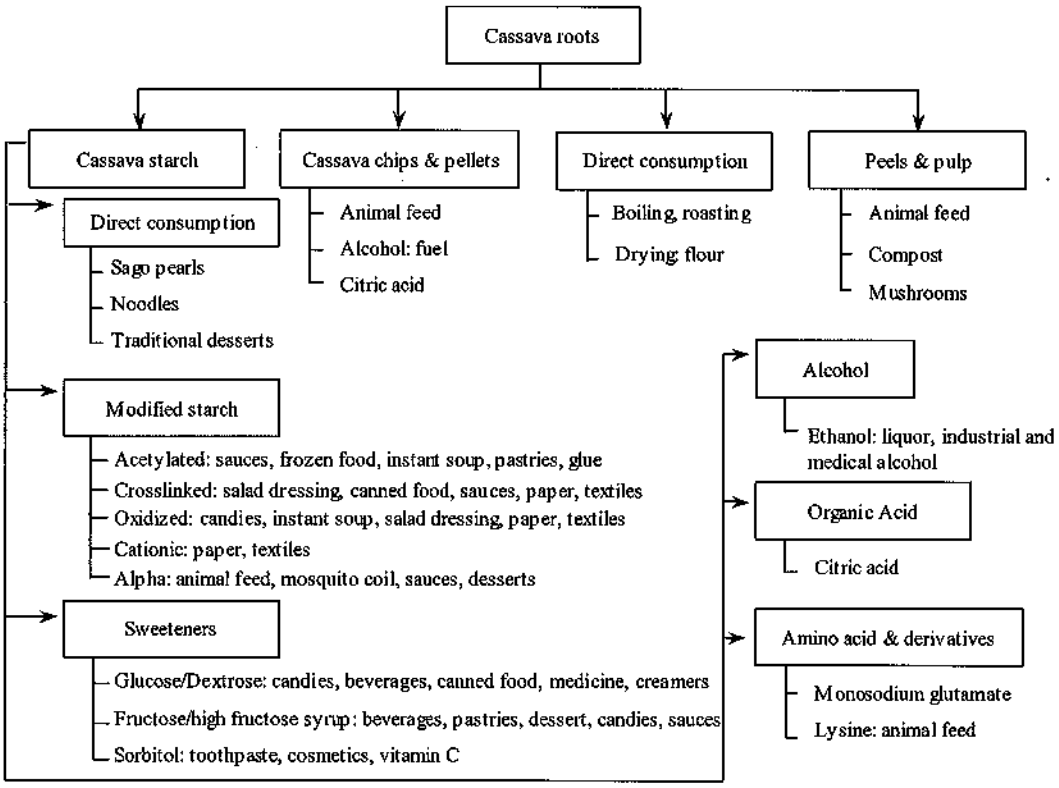

Figure 4. Cassava root processing into value-added products.
***Source:** Adapted from TTFITA, 2000.*

b. Flour for human consumption

The simplest and most common form of processing, used widely in Indonesia, is to peel the roots, wash and slice and then sun-dry for 2-3 days to produce dry cassava chips or chunks, in Indonesia known as *gaplek*. *Gaplek* can be stored and is traded in village markets. When needed, the dry root pieces are pounded into a flour, which is shaken on a bamboo screen with some warm water to produce granules, called *tiwul*. The size and shape of these granules is similar to rice grains and the *tiwul* is often cooked together with rice to extend the family's limited supply of rice. Presently, small processing plants in Indonesia buy fresh roots to be processed directly into various flour mixes (supplemented with vitamins and flavors) as well as semi-cooked *instant tiwul*. These are mainly destined for urban consumers.

c. Chips and pellets for animal feed.

Up until very recently, cassava chips and pellets were the mainstay of the Thai "tapioca" trade, mainly for export to Europe (**Figure 3**). However, in 2009, Thailand exported only about 17,000 tonnes of cassava pellets to Europe, down from 6.0 million tonnes in 1989; but unlike in 1989 it exported considerable quantities of dry chips, about 4 million tonnes, to China, where these are used mainly for production of commercial animal

feed and alcohol. **Table 5** shows that the export of dry cassava products is still dominated by Thailand, while China is the main importing country, both for cassava chips and starch. Chip imports were 4.672 million tonnes in 2007, but increased to over 6 million tonnes in 2009, mostly from Thailand and Vietnam, with smaller quantities from Indonesia and other countries (**Table 6**).

Table 5. Total world trade in cassava products in 2007.

	Exports ('000 t)					
	Fresh root equivalent	Dry products ('000 t)				
		Starch	Tapioca pearls	Chips+ pellets	Flour	**Total**
World	**27,212**	**1,572**	**32**	**6,497**	**6**	**8,107**
-Americas	573	46	1	127	2	**176**
-Europe	970	16	0	256	1	**273**
- Africa	99	1	1	24	2	**28**
-Asia	**25,560**	**1,510**	**30**	**6,088**	**0**	**7,628**
-Cambodia	7	3	-	0	-	**3**
-China	38	4	13	0	-	**17**
-India	10	1	2	1	0	**4**
-Indonesia	839	23	11	210	0	**244**
-Japan	0	0	0	0	0	**0**
-Korea (ROK)	0	0	0	0	0	**0**
-Malaysia	4	0	0	1	0	**1**
-Philippines	4	0	0	1	0	**1**
-Thailand	19,738	1,422	0	4,559	0	**5,981**
-Vietnam	4,789	-	-	1,317	-	**1,317**

	Imports ('000 t)					
	Fresh root equivalent	Dry products ('000 t)				
		Starch	Tapioca pearls	Chips+ pellets	Flour	**Total**
World	**29,181**	**1,956**	**50**	**6,783**	**16**	**8,805**
-Americas	589	85	13	98	4	**200**
-Europe	6,266	113	2	1,650	3	**1,768**
- Africa	143	29	1	19	2	**51**
-Asia	**22,127**	**1,706**	**35**	**5,013**	**8**	**6,762**
-Bangladesh	129	51	7	-	0	**58**
-China	19,002	892	14	4,672	-	**5,578**
-India	2	0	1	0	0	**1**
-Indonesia	680	306	0	0	0	**306**
-Japan	420	143	2	27	0	**172**
-Korea (ROK)	1,176	35	0	302	0	**337**
-Malaysia	281	118	2	4	0	**124**
-Philippines	89	40	0	0	0	**40**
-Thailand	11	0	0	3	0	**3**
-Vietnam	-	-	-	-	-	**-**

Source: FAOSTAT, Feb 2010.

Table 6. Importation of cassava chips from various countries by China in 2009.

Country	Dry cassava chips ('000t)
Thailand	3,863
Vietnam	2,011
Indonesia	143
Laos	2
Others	0.3
Total	**6,019**

Source: Boonmee Watanaruangrong, 2010. (from www.chinajci.com,)

Tables 7 and **8** show that in 2007 China was the main domestic consumer of cassava products and that over 80% of its requirement of 22.3 million tonnes of fresh root equivalent was imported from other countries in Asia. Most of the cassava was imported in the form of dry chips (**Table 5**) and used for production of animal feed and other (mostly industrial) uses (**Table 7**). Only about 10% was used for food. In contrast, Indonesia had a similar domestic requirement of about 20 million tonnes, but about 50% of that was used for food.

Table 7. Production, supply and domestic utilization of cassava in 13 cassava producing countries in Asia in 2007. Data are in fresh root equivalents.

	Domestic supply ('000 t)				Domestic utilization ('000 t)			
Country	Produc-tion	Import	Export	Domestic uses	Food	Feed	Other uses	Waste
Asia	**72,914**	**22,629**	**23,515**	**66,093**	**24,379**	**19,214**	**17,411**	**5,087**
-Thailand	26,916	10	18,404	2,676	883	135	312	1,346
-Indonesia	19,988	1532	991	20,529	9,974	400	7,555	2,600
-India	8,232	6	16	8,222	7,811	-	0	412
-Vietnam	8,193	-	3,762	4,431	623	3,399	-	410
-China	4,362	18,188	318	22,262	2,015	15,098	5,018	131
-Cambodia	2,215	-	12	2,203	364	<1	1,728	111
-Philippines	1,871	161	5	2,027	1,791	75	161	-
-Malaysia	430	610	3	1,036	398	21	595	21
-Lao PDR	233	13	-	126	79	23	-	23
-Sri Lanka	220	22	<1	242	154	55	22	11
-Myanmar	211	2	-	213	192	-	-	21
-East Timor	41	-	-	41	40	-	-	1
-Bangladesh	-	235	-	235	29	-	206	-

[1)] Much of the "waste" (peels, solid residue from starch extraction etc.) is used for industrial purposes or animal feed.

***Source:** FAOSTAT, Commodity Balances, July 2010.*

Table 8. Total domestic food supply (in fresh root equivalents, '000 t) and utilization (%) of cassava, as well as the per capita supply as food and its contribution to the diet in 13 cassava producing countries in Asia in 2007.

		Domestic utilization (%)				Total	Per capita supply			
Country	Popula-tion (mil.)	Food	Feed	Other uses	Waste	food supply ('000 t)	Fresh equiv. (kg/yr)	Energy (kcal/d)	Protein (g/day)	Fat (g/day)
Asia (13)	**3,108**	**36.9**	**29.1**	**26.3**	**7.7**	**24,379**	**6.15**	**16.15**	**0.09**	**0.04**
-Thailand	63	33.0	5.0	11.7	50.3	888	13.18	39.89	0.31	0.07
-Indonesia	223	48.6	1.9	36.8	12.7	9,974	44.39	121.67	0.70	0.29
-India	1,081	95.0	-	-	5.0	7,811	6.71	15.19	0.07	0.02
-Vietnam	82	14.0	76.7	-	9.3	622	7.23	20.01	0.14	0.06
-China	1,313	9.1	67.8	22.5	0.6	2,014	1.51	4.44	0.04	0.01
-Cambodia	14	16.5	0.1	78.4	5.0	364	25.43	70.37	0.49	0.21
-Philippines	81	88.4	3.7	7.9	-	1,791	20.19	55.85	0.39	0.17
-Malaysia	25	38.5	2.0	57.5	2.0	398	14.99	40.86	0.29	0.11
-Lao PDR	6	63.2	18.4	-	18.4	79	13.04	35.63	0.23	0.10
-Sri Lanka	19	63.6	22.7	9.1	4.6	154	7.74	32.45	0.15	0.04
-Myanmar	50	90.1	-	-	9.9	192	3.91	10.81	0.08	0.03
-East Timor	<1	97.6	-	-	2.4	40	37.57	91.36	0.38	0.15
-Bangladesh	150	12.3	-	87.7	-	29	0.19	0.46	0.00	0.00

[1)] much of the "waste" (peels, solid residue from starch extraction etc.) is used for industrial purposes or animal feed.

Source: *FAOSTAT, Food Supply, July 2010.*

In India, East Timor, Myanmar and the Philippines practically all cassava was domestically produced and used for human consumption, mostly after boiling of fresh roots, or in the form of processed products such as sago, starch and a variety of snack foods. In Vietnam cassava is mainly used for animal feeding, either on-farm or in commercial animal feed rations, but much cassava is also used for starch production, which is not shown in **Table 7**.

Table 8 shows that per capita consumption of cassava-based foods was highest in Indonesia, followed by East Timor, Cambodia and the Philippines. It is an important source of calories, especially for the poorer and rural segments of the population, while it is an important ingredient in many snack foods consumed by the general population of Indonesia. While Thailand is the largest producer of cassava in Asia, only about 10% is used domestically, mainly for production of food, commercial animal feed and various industrial (non-food) products such as modified starch for the paper and textile industries, and recently for production of fuel-ethanol (**Table 9**). Thai data show up to 30% domestic use of cassava in the country, much higher than the FAO data in **Table 7**.

Table 9. Estimated use of cassava starch in various industries in Thailand in 2007.

Industries or products	Starch usage ('000 t)	Starch usage (%)
Glucose, high fructose, sorbitol	460	35.4
Monosodium glutamate	250	19.2
Food factories and cooking	200	15.4
Modified starch	150	11.6
Paper	120	9.2
Tapioca pearls (sago)	60	4.6
Textiles	10	0.8
Others (glue, medicine, plywood)	50	3.8
Total	**1,300**	**100**

Source: *Office of Agricultural Economics, Ministryof Agriculture and Cooperatives..*

In China the total annual consumption of starch and derived products in 1998 was about 4.03 million tonnes, of which 3.32 million tonnes (82.3%) was maize starch, 470,000 tonnes (11.7%) cassava starch, 96,000 tonnes (2.4%) each of sweet potato and wheat starch, and 48,000 tonnes (1.2%) potato starch (Tian Yinong *et al.*, 2001). In 2007, China imported about 4.67 million tonnes of cassava chips and 892,000 tonnes of starch. Most of the chips are used for production of alcohol and animal feed, respectively, while the starch is used mainly for production of modified starch, sweeteners and MSG.

d. Starch for food and industry

Cassava starch can be divided into *native starch* and *modified starch*. The production of native starch is a relatively simple process, that can be done at many scales, either at the household level, such as in some villages in north Vietnam, Cambodia and on Java island of Indonesia, up to very large and fully-mechanized starch factories, such as those in Thailand, south Vietnam, and in Lampung province of Indonesia. One tonne of fresh roots usually results in 250-300 kg of starch. During the past decade, the cassava starch industry in Thailand has expanded very rapidly (**Figure 3**), and total production in 2009 was approximately 3.8 million tonnes consuming about 50% of the total production of 27.7 million tonnes of cassava roots. Of the 3.8 million tonnes of starch produced, about 2.5 million tonnes were exported, of which 1.8 million tonnes was native starch and 0.7 million tonnes modified starch, with a value of 488 and 376 million US dollars, respectively. Most of the starch was exported to China, Japan, Taiwan and Indonesia.

In Indonesia the cassava starch industry suffered significant losses after the 1997 economic crisis, but has now mostly recuperated. In 2002, total production was 1.34 million tonnes of starch (P.T. Corinthian, 2004). Practically all cassava starch produced in Indonesia is for the domestic market. In India, most cassava starch is produced in Tamil Nadu (about 90%) and Andhra Pradesh (10%) with a total annual production of cassava

starch and tapioca pearls (or sago) of 330,000 tonnes (Edison, 2001). In China, cassava starch production was about 900,000 tonnes in 2007, while an additional 500,000 tonnes of cassava starch were imported (Tian Yinong, 2010). In Vietnam cassava starch production is increasing rapidly and for 2003 it was estimated at about 500,000 tonnes, of which 70% was exported (mainly to China, Taiwan and Korea) and 30% used domestically (Hoang Kim, personal communication).

e. Modified starch

Native starch can be modified by either physical, chemical or enzymatic processes, producing different forms of "modified" starch with distinctly different properties and different uses. Modified starches are used in many different types of foods as well as in industry, mainly for production of high quality paper, for textile sizing and some animal feeds (**Figure 4**). One of the main users of modified starch is the paper industry. Cationic starches made from cassava starch are particularly suitable for the sizing and coating of paper in high-speed paper making machines (Jin Shuren, 2001). Other main users of modified starch are in the food industry, textiles, in agriculture and in animal feed, while smaller amounts are used in construction materials, in casting, oil drilling and medicines.

f. Starch-based sweeteners

Cassava starch can be used for the production of many types of sweeteners after hydrolyzation by either acids or enzymes, or both. These sweeteners include maltose, glucose syrup, glucose and fructose, which can be further processed into various oligo-saccharides (Jin Shuren, 2001) or into ethanol.

g. Hydrogenated sweeteners.

These include sorbitol, mannitol and maltol. They are produced by treating starch with hydrogen gas in high-pressure tanks, using a special catalyst and ion-exchange resins. Sorbitol is used mainly for the production of vitamin C and as a moisture conditioner in toothpastes (Jin Shuren, 2000).

h. Organic acids

Organic acids made from cassava starch include citric acid, acetic acid, lactic acid and itaconic acid, which are used in the food industry as well as for the production of plastics, synthetic resins, rubber products etc. Lactic acid is produced by the fermentation of starch with *Lactobacillus amylovorus* (Wang Xiaodong *et al.*, 1997; 2000).

i. Monosodium glutamate (MSG) and Lysine

MSG is a well-known flavor-enhancing agent used in many Asian kitchens. It is made through the microbial fermentation of starch or sugar (molasses) in the presence of ammonium salts. In Thailand, MSG production is one of the main consumers of native cassava starch (**Table 9**). Lysine is an important amino-acid used as a supplement in animal feed, especially for pigs.

j. Ethanol

In some countries cassava is used for the production of ethanol. In the late 1970s several alcohol distilling factories were set up in Brazil using fresh cassava roots as raw material. The alcohol was used as automotive fuel, either mixed with gasoline (up to 20% ethanol) for which no motor modification is required, or as pure anhydrous ethanol, in which case the carburator and some other parts need to be modified (de Souza Lima, 1980). Both result in less atmospheric pollution than the use of 100% gasoline.

In China, several factories in Guangxi have been using the solid waste (pulp) of the cassava starch industry for the production of ethanol (Gu Bi and Ye Gozhen, 2000). Other alcohol factories in China are switching from the use of molasses to that of cassava chips for alcohol production, because of strict pollution control requirements that makes the use of molasses uneconomic. In Guangxi there are now about 200 alcohol factories, most of which still use molasses as the raw material. But about 20 factories use mainly cassava fresh roots, supplemented with cassava dry chips and molasses when no fresh roots are available. In 2008 these produced about 150,000 tonnes/year of hydrous ethanol (95% ethanol), mainly for drinking or industrial use (Tian Yinong, 2010).

Since about 2002 the Chinese government has promoted the use of "gasohol" instead of gasoline, in order to reduce the importation of oil and reduce air pollution from greenhouse gasses. There are presently four large companies producing anhydrous or fuel-ethanol in four provinces, mostly located in the north and northeast. Three of these use maize and one uses wheat as the raw material. Together they produce about 1 million tonnes of fuel-ethanol per year, or 3.35 million liters per day. Since maize and wheat can be better utilized as food or animal feed, the government is now phasing out the use of these crops for production of fuel-ethanol. Instead, they are promoting the use of sweet sorghum in the northern provinces and cassava in the south. Thus, in the southern provinces of Guangxi, Guangdong, Hainan and Yunnan, major investments are now being made in the construction of large factories to produce anhydrous (99.5%) ethanol for the production of "gasohol E10", i.e. 10% ethanol mixed with 90% gasoline. One factory, located in Beihai is producing about 840,000 liters per day from cassava, while at least two others are under construction or in the planning phase (**Table 10**).

Table 10. Actual or planned factories for the production of anhydrous ethanol from cassava in Asia (July 2010).

Country/Company	Location	Capacity ('000 l/day)	Date completed	Fresh root requirement ('000 t/year)[1)]
Cambodia				
MH Bio-Energy Co.	Kandal	144	2008	270
China				
China Food Comp (COFCO)	Beihai, Guangxi	840	2007	1,575
China Food Comp (COFCO)	Wuzhou, Guangxi	1,260	planned	2,362
Other Company	Longan, Guangxi	420	planned	787
		2,520		4,724
Indonesia				
Medco	Lampung	200	2009	375
Indonesia Ethanol		167		312
EN 3 Green Energy	South Sulawesi	600	2013	1,125
		967		1,812
Thailand				
Thai Nguan Ethanol Co.	Khon Kaen	130	Aug 2005	244
Ratchaburi Ethanol	Ratchaburi	150	Jan 2009	281
Supthip	Lopburi	200	May 2009	375
Taiping Ethanol	Sra Kaew	150	July 2009	281
PSB Starch Production	Chonburi	150	Aug, 2009	281
Khon Kaen Alcohol	Kanchanaburi	150	Jan 2010	281
Sima Inter Products	Chachoengsao	150	Mar 2010	281
Double A Ethanol	Prachinburi	250	Oct 2010	469
PTK Ethanol	Nakhon Ratchasima	1,020	Dec 2010	1,912
Impress Technology	Chachoengsao	200	Oct 2011	375
		2,550		4,780
Vietnam				
Petrosetco+Itochu Co.	Phu Tho	333	Dec 2011	624
Petrosetco+Itochu Co.	Binh Phuoc	333	Mar 2012	624
Petrosetco+Itochu Co.	Quang Ngai	333	Mar 2012	624
		999		1,872

[1)] based on 300 working days per year and a conversion of 160 l ethanol/ t fresh roots

In Thailand "gasohol", containing 10% ethanol, is presently available in most gas stations and this has become a popular fuel because of its lower price ($0.12-0.13/liter lower than gasoline). Initially almost all ethanol was made from molasses, but recently many factories have been completed or are under construction that will use fresh or dried cassava, or can use either cassava or molasses, depending on the price of raw materials (**Table 10**). In mid 2010 six factories have been completed that will use cassava or cassava/molasses as the raw material, but most of these are currently not operating because of the exceptionally high price and low availability of cassava. When all fuel ethanol plants that are currently under construction are completed by the end of 2011, Thailand will

have an installed capacity to produce 4.55 million liters of ethanol per day, of which 2.25 mil. liters from cassava, 1.67 mil. liters from molasses/sugarcane and the remaining 625,000 liters from either molasses or cassava (**Table 11**).

Table 11. Current and future ethanol production capacity in Thailand.

1. Factories having received licenses to produce anhydrous ethanol.

	No. of factories	Production capacity (mil. liters/day)	Actual production (mil. liters/day)
Total	45	12	
-from molasses or cane juice	20	3.49	
-from cassava	25	8.51	

2. Factories completed (March 2009).

	No. of factories	Production capacity (mil. liters/day)	Actual production (mil. liters/day)
Total	19	2.93	
-from cassava	4	0.63	
-from cassava or molasses	6	1.00	
-from molasses/sugarcane	9	1.30	

3. Factories completed or under construction (to be finished in 2011).

	No. of factories	Production capacity (mil. liters/day)	Actual production (mil. liters/day)
Total	24	4.545	
-from cassava	9	2.250	
-from cassava or molasses	5	0.625	
-from molasses/sugarcane	10	1.670	

***Source**: Dept. of Alternative Energy Development and Efficiency (DEDE); www.dede.go.th.*

k. Degradable plastics

Various types of starches are being used for the production of bio- or photo-degradable plastics, either by mixing starch or modified starch with polyvinyl hydrocarbons, or by polymerization of starch, which is then blended with various other polymers (Sriroth *et al.*, 2001). The use of cassava starch for these processes still requires much research.

FUTURE POTENTIAL

Cassava-based products can only be competitive in the world market if the cost of processing and the cost of the raw materials is lower than those of competing crops. The competitiveness also depends on government policies, on import duties, tariffs and other trade barriers. Thus, during the 1970s and 80s the Thai tapioca export industry benefited from relatively low import duties into the European markets as well as artificially high prices of domestic coarse grains; but those policies changed in the late 80s. With ever increasing trade liberalization, products will more and more have to compete on the basis of price and quality characteristics. **Table 12** shows the relative potential for growth of various cassava-based products in the seven major cassava producing countries in Asia.

Table 12. Summary of market potential[1] for cassava by country in 2008.

	Food		Animal feed		Starch and starch-based products	Ethanol
	Fresh	Processed	Domestic	Export		
China	*		**		***	***
India -Kerala	*	**				
- Tamil Nadu					***	
Indonesia	*	**	**	*	**	***
Malaysia		***	**		**	
Philippines	*	**	**		***	**
Thailand			***	**	***	***
Vietnam-North	*	**	**	*	***	**
-South		**	**	*	***	***

[1] * = maintenance of existing consumption levels
** = growth in existing markets
*** = unexploited growth potential

1. Food

Fresh cassava for human consumption does not have major growth potential as rice remains the preferred food in the region. Total food demand may increase due to increases in population, but as Asian societies become more affluent, they are likely to reduce their consumption of high-energy staples like rice and cassava in preference for meat products or convenience foods. Moreover, in Asia, as in other parts of the developing world, there is an unrelenting trend for rural populations to move to the cities. It is expected that after 2020 more than 50% of the population in Asia will be urban rather than rural. This will have profound effects on food consumption patterns as urban populations have to buy all their food, and they prefer clean, attractively packaged and convenient foods. For that reason, there is likely to be a greater future potential for processed foods and snack foods, where cassava-based products may find a niche market.

2. Feed

Table 12 shows that in all countries in Asia except India there is likely to be a substantial growth in the domestic animal feed market. This market is still largely untapped in Thailand, which has traditionally concentrated on the export of cassava-based animal feed. However, during the 1990s, due to changes in the CAP policies the export of cassava pellets to Europe became increasingly more difficult. But, the recent sharp increases in the price of maize, barley and soybean and the comparatively smaller increases in the price of cassava chips and pellets (at least up to 2010) (**Figure 5**), has made the latter more attractive again in the European animal feed market, thus reversing the previous downward trend in exports to Europe (**Figure 3**) In addition, there is a large potential to develop the use of both cassava roots and leaves for the domestic animal feed market, adding value to an otherwise cheap export product. Previously, this was unattractive due to large domestic supplies of other sources of feed ingredients, such as maize, rice bran and soybean. But, starting in the 1990s Thailand became an importer of maize and especially soybeans. While world soybean prices have been in decline since 1997, they have increased again since 2004 and especially in 2007 (**Figure 5**) due to high demand in China. Cassava leaves may be a good alternative source of protein, which could be incorporated, together with root meal, into animal feed rations. When cassava is grown specifically for leaf production and is well-managed, cassava tops can be cut five times in a one-year crop cycle, producing 13-15 t/ha of dry leaves and 2.5-2.8 t/ha of crude protein; this is 3-4 times higher than a good crop of soybean!!! Roots can still be harvested at 11-12 months with yields of 15-20 t/ha.

During the past four decades both chicken and pig production in Asia increased markedly as increasing affluence in many countries increased demand for meat products, and thus for animal feed. Even though production of the major food and feed crops, i.e. rice, maize and cassava, increased dramatically in Asia, this still could not satisfy the high demand for feed ingredients, resulting in major increases in grain imports, especially of maize and soybeans. Whether or not locally produced cassava chips and pellets can compete with maize as a major feed ingredient depends largely on the prices of maize, cassava chips and soybean, as the latter will need to be mixed with cassava at a ratio of about 85:15 to obtain the same protein content of a maize-based feed (**Table 13**). Since the mid 1990s the prices of nearly all feed ingredients (not adjusted for inflation) have shown a downward trend, but during the past four years these prices have increased substantially, especially the price of soybean. While the cassava–soybean mix tended to be cheaper than locally produced barley in Europe during the 1990s, this was not the case in the early 2000s; this may have reversed again in 2007.

In spite of recent price increases of all three crops, the cassava-soybean or cassava chips-leaf meal-soybean mixes are now considerably cheaper than maize-soybean mixes with the same crude protein contents (**Table 13**). Further research is urgently needed concerning the large-scale production and utilization of cassava leaves as a protein source in commercial feeds.

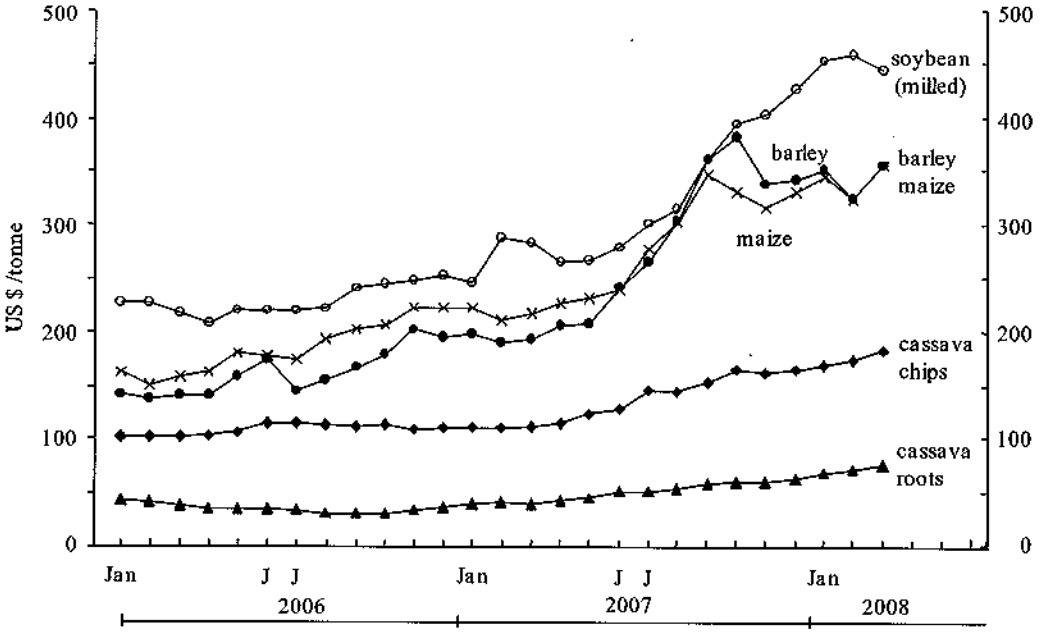

Figure 5. Change in the price of milled soybean, barley, maize, dry cassava chips and fresh cassava roots from January 2006 to March 2008
Sources: *Thai Trade Center, the Netherlands (soybean, barley, maize) and Thai Customs Department (cassava products).*

3. Starch and Derivatives

Table 12 indicates that most countries foresee the greatest future potential for cassava in the area of starch and starch-based products. This is due to the increasing demand for starch in processed food, in the paper and textile industry, as well as a very large potential demand for biodegradable plastics. In most of these markets cassava has to compete with maize, wheat, and potato. Up until 2009 Thai cassava starch was very competitively priced in comparison with maize, wheat or potato starch in the US market. Thus, for products where cassava starch could substitute for these other starches in terms of starch characteristics, there is little doubt that cassava starch was the cheapest source. However, in cases where specific starch characteristics, such as low-amylose content, are required, as in the production of biodegradable plastics, cassava starch may lose its competitive edge to waxy (low-amylose) maize or potato starches. Intensive research is

under way to breed for low-amylose cassava or to produce these varieties through genetic transformation. On the other hand, cassava starch is characterized by a neutral taste and odor, and the transparency, smoothness and viscosity of the gel, making it particularly suitable for many processed food items. Native cassava starch is also very resistant to acid conditions, it is intermediately resistant to freezing but very unstable during heating (sterilization), making it suitable for some and unsuitable for other applications (Dufour *et al.*, 2000).

Table 13. Approximate prices of various feed ingredients and the final cost and protein content of feed mixes in Thailand in March, 2008.

	Protein (%)	Price (baht/tonne)	Price (US$/tonne)
Ingredients			
-Maize	8.5	7,480	238
-Cassava chips or pellets	2.5	5,200	166
-Soybean meal	44.0	16,820	536
-Cassava chips (85.5%) + soybean meal (14.5%)	8.5	6,884	219
-Cassava leaf meal-1	20.0	6,500	207
-Cassava leaf meal-2	25.0	8,125	259
Feed mixes			
-Milk cows:			
Maize (82%) + soya (18%)	14.9	9,161	292
Cassava chips (70%) + soya (30%)	15.0	8,686	277
Cassava chips (56%) + leaf meal-1 (24%) + soya (20%)	15.0	7,836	250
Cassava chips (59%) + leaf meal-2 (24%) + soya (17%)	15.0	7,877	251
-Pigs:			
Maize (76%) + soya (24%)	17.0	9,722	310
Cassava chips (65%) + soya (35%)	17.0	9,267	295
Cassava chips (61%) + leaf meal-1 (7%) + soya (32%)	17.0	9,009	287
Cassava chips (62%) + leaf meal-2 (7%) + soya (31%)	16.9	9,007	287
-Chickens:			
Maize (73%) + soya (27%)	18.1	10,002	318
Cassava chips (63%) + soya (37%)	17.9	9,499	302
Cassava chips (60%) + leaf meal-1 (5%) + soya (35%)	17.9	9,332	297
Cassava chips (60%) + leaf meal-2 (6%) + soya (34%)	18.0	9,326	297

[1] 1 US$ is 31.404 baht in March 2008.

4. Fuel-Ethanol

Due to the dramatic increases in world oil prices in 2006 and 2007 and the growing concern about global warming as a result of the production of greenhouse gases, especially from car exhausts, many governments are looking for alternative energy sources, especially renewable and domestically produced bio-fuels. These include mainly ethanol, made

mostly from maize, wheat, sugarcane or molasses and cassava, as well as bio-diesel, made mostly from soybean and palm oil. The fuel ethanol is usually mixed with gasoline in a ratio of 1:9 or 2:8 to produce "gasohol" E-10 and E-20, respectively. However, "flexi-fuel" cars can run on E-85, while "total-flex" cars, made in Brazil, can run on anything between pure gasoline and pure ethanol (E-100).

In the US and Canada most fuel-ethanol is made from maize or wheat, in Brazil it is made almost entirely from sugarcane; in Argentina from sugarcane and maize; in Europe mainly from wheat, rye and barley, in China from maize and wheat; and in Thailand from sugarcane (or molasses) and cassava. While India is presently not producing much fuel-ethanol, it is likely that in the future it will use both maize and sorghum. China, on the other hand, is phasing-out fuel-ethanol production from maize and wheat and is switching to sweet sorghum and cassava. In Indonesia there are also plans for the construction of fuel-ethanol factories, mainly on Sumatra and Sulawesi islands

The choice of crops to be used depends mainly on what crop is readily available for year-round production, and at a competitive price. **Table 14** shows that in the US sugarcane would produce the highest ethanol yield per ha, but cassava fresh roots or molasses would be the cheapest raw materials for production of ethanol. But, since none of these are abundantly available, maize is the preferred raw material. In contrast, **Table 15** shows that in 2006 in Thailand molasses and dry cassava chips were the cheapest raw materials for production of ethanol, followed by fresh cassava roots. Since dry chips can be readily stored and cheaply transported, while the supply of molasses is limited and seasonal, cassava dry chips are considered the most promising raw material for ethanol production in Thailand.

Table 14. Ethanol yield and raw material costs of various crops potentially used for ethanol production in the US.

	Yield (t/ha)	Market price (US$/t)	Gross income (US$/ha)	Ethanol yield (liter/t)	Ethanol yield (liters/ha)	Raw material costs US$/1000 l	Valuable co-products
Maize	8.5-9.0	70-100	595-900	385-400	3,272-3,600	175-260	DDGS[1)]
Wheat	2.5-4.9	114-118	285-578	378-390	945-1,911	292-312	Gluten, yeast, bran
Sugarcane	70-75	15-20	1,050-1,500	90-100	6,300-7,500	150-222	Bagasse, yeast
Molasser	3.2-3.4	35-40	112-136	250-300	800-850	116-160	-
Cassava							
-fresh roots	20-30	20-30	400-900	160-180	3,200-5,400	111-187	DDGS[1)]
-dry chips	9-13.5	60-70	540-945	330-400	2,970-5,400	150-212	DDGS[1)]

[1)]DDGS = distillers dry grain with solubles

***Source:** adapted from Shetty , 2006, by R. Howeler.*

Table 15. Raw material costs per liter of ethanol produced from various crops potentially used for ethanol production in Thailand in 2006.

Crop	Planted area ('000 ha)	Production ('000 t)	Yield (t/ha)	Conversion ratio (kg/liter ethanol)	Price of raw material (US$/t)	Raw material cost (US$/1000 l ethanol)
Maize	1,258	4,461	3.55	2.7	104	281
Rice	9,761	25,608	2.62	-	-	-
Broken rice	-	-	-	2.7	150	405
Sugarcane	1,065	62,828	58.99	14.3	17	243
Molasses	-	3,000	-	4.0	37	148
Cassava						
-fresh roots	1,101	18,265	16.59	6.5	26	169
-dry chips	-	-	-	2.5	62	155

Source: *adapted from Sriroth and Piyachomkwan, 2005, by R. Howeler*

Table 16 shows a breakdown of processing cost of ethanol using either molasses or fresh cassava roots as the feedstock. Processing costs for cassava are clearly higher than for molasses due to the higher costs of enzymes and energy. **Table 17** shows that while cassava was the cheaper source of raw material for ethanol production as compared to maize in both the US and Thailand in 2006, the lower processing cost of maize as well as the greater value of its high-protein by-products, results in a lower total cost of production of ethanol from maize as compared to cassava in the US, but a much lower production costs for cassava as compared to maize in Thailand in 2007. However, due to the high price of cassava and low price of molasses and sugarcane in 2007, ethanol production from cassava became uneconomic, while that produced from molasses was only barely economic due to a decrease in the price of ethanol (**Figure 6**). Thus, in different countries different crops may have a comparative advantage, while this may also change from year to year. It seems, however, that in southeast Asia, where cassava yields are relatively high and production costs are relatively low, cassava will have a cost advantage over most other crops. Moreover, cassava can be grown on poor soils and under drought conditions where other crops may perish. Also, cassava roots – either fresh or as dry chips – are available during most of the year, and the waste water ("stillage") and solid residues resulting from cassava processing into ethanol are much less polluting than those from molasses; they are also used to produce valuable by-products such as biogas and animal feed.

Thus, it appears that the production of fuel-ethanol opens a huge new market for cassava. According to **Table 18** the efficiency of conversion of starch to ethanol varies considerably among varieties and with plant age. Average figures of 160 to 180 l/t fresh roots are often used to calculate the raw material requirement. Naturally, varieties with a

higher starch content require less raw material per liter of ethanol produced, which in turn reduces ethanol production costs (**Table 19**).

Table 16. Processing cost of ethanol from molasses and cassava in Thailand in 2007.

	Molasses	Cassava	Molasses	Cassava
	(baht/liter)		(US$/1000 liter)[1]	
1. Labor	1.0	0.50	31.05	15.52
2. Chemicals	0.25	1.50	7.76	46.57
3. Energy	1.35	2.00	41.91	62.09
4. Maintenance	0.25	0.30	7.76	9.31
5. Insurance	0.15	0.15	4.66	4.66
6. Administration	0.50	0.30	15.52	9.31
7. Water	0.05	0.05	1.55	1.55
8. Depreciation	0.97	1.00	30.11	31.05
9. Waste water treatment	0.65	0.50	20.18	15.52
10. Benefit from biogas	-[2]	-0.30	-[2]	-9.31
Total	**5.17**	**6.00**	**160.50**	**186.27**

[1] 1 US$ = baht 32.21 in 2007

[2] already substracted from energy costs

Source: *Phetphirum, 2008.*

Table 17. Cost of production of ethanol using either dry maize grain, fresh cassava roots, molasses or sugarcane as the raw material for ethanol production under US and Thai conditions in 2006 and 2007, respectively.

	USA (2006)		Thailand (2007)			
	Maize	Cassava	Maize	Cassava	Molasses	Sugarcane
Crop yield (t/ha)	11	35	3.8	22	2.82	60
Crop price ($/tonne)	81	25	257	51	70	21
Ethanol yield (liters/t raw material)	379	180	379	166	250	70
Raw material costs ($/liter ethanol)	0.21	0.14	0.67	0.31	0.28	0.30
By-product credit ($/liter ethanol)	-0.063	-0.004	-0.063			
Processing costs ($/liter ethanol)	0.16	0.21	0.16	0.19	0.16	0.16
Ethanol production costs ($/liter)	0.31	0.35	0.83	0.50	0.44	0.46

Note: Ethanol price in Thailand in 2007: US$ 0.48-0.55/liter

Source: *adapted from Shetty, 2006, by R. Howeler*

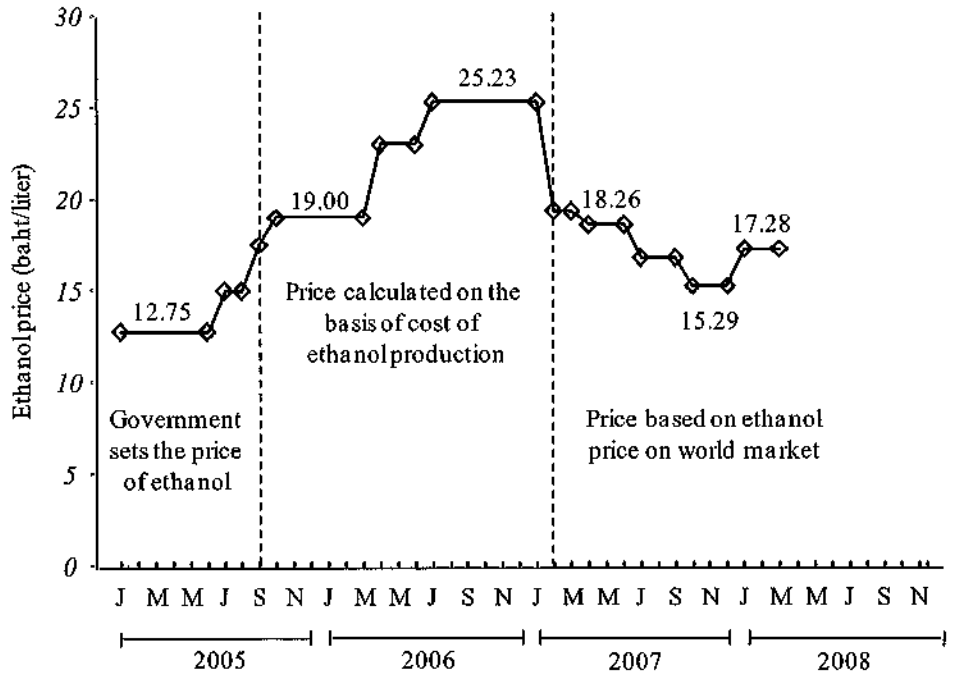

Figure 6. Change in the price of fuel ethanol in Thailand from 2005 to 2008.

Table 18. Cassava varietal differences in root yield, starch content and ethanol conversion efficiency when harvested at 12 and 18 months after planting in Thailand.

Months at harvest Variety	Root yield (t/ha)	Starch content (%)	Ethanol conversion (l/t fresh roots)	Ethanol yield (l/ha)
12 months				
Rayong 5	30.1	25.5	147	4,425
Rayong 9	30.9	30.8	208	6,427
Rayong 72	34.1	23.5	145	4,944
Rayong 90	31.2	27.5	174	5,429
Kasetsart 50	31.2	25.6	154	4,805
18 months				
Rayong 5	43.3	23.5	139	6,019
Rayong 9	48.7	29.3	194	9,448
Rayong 72	40.6	20.9	135	5,481
Rayong 90	41.0	25.6	155	6,355
Kasetsart 50	45.9	23.8	137	6,288

Source: *Charoenrath et al., 2006.*

Table 19. Ethanol production costs using two Thai cassava varieties in 2007.

	Rayong 9	Rayong 90
Starch content (%)	30	27
Fresh root requirement (t/1000 l)[2)]	4.81	5.7
Fresh root price (US$ /t) [1)]	50.84	48.05
Cost of raw material (US$/1000 l)	244.54	276.29
Ethanol processing cost (US$/1000 l) [3)]	186.27	186.27
Total cost of ethanol production (US$/1000 l)	430.81	462.56

[1)] Baht 1.64/kg ($ 50.84/t) fresh roots at 30% starch with 0.03 baht ($ 0.93) reduction for every 1% reduction in starch content

[2)] ***Source:*** *Charoenrath et al., 2006.*

[3)] ***Source:*** *Phetphirum, 2008.*

Similarly, in China the current installed capacity for cassava processing into starch and derived products, including hydrous ethanol, will require about 13 mil. tonnes of fresh roots in 2005/06. This is likely to increase by another 7.2 mil. tonnes to a total of 20 mil. tonnes fresh roots with the production of 1 mil. tonnes (1.2 bil. liters) of fuel-ethanol from cassava in the next 3-4 years. This is still only a fraction of the 5 mil. tonnes of fuel-ethanol that China is expected to need when all cars are running on gasohol E 10.

Since the cassava harvested area can not expand to keep up with increasing demand, this will require major increases in cassava yields, from the current levels of 20-22 t/ha in Thailand (**Table 20**) and 18-19 t/ha in China to about 28-30 t/ha in both countries. This will require major efforts to develop new higher yielding varieties with a higher starch content and a higher conversion efficiency to ethanol (from the current 160-180 liters/tonne fresh roots to at least 200 l/t), as well as improved agronomic practices that will allow these varieties to reach their full yield potential. Both the Thai and Chinese governments are fully committed to support the necessary research and extension activities, while the private sector will also need to contribute to support the research and to work closely together with cassava farmers to make this a reality. In 2010 the required yield increases have not yet materialized; in fact, yields in Thailand were markedly reduced in 2010 due to the damage caused by the mealybug attack, resulting in a short-fall in root supply and marked increases in the prices of fresh roots, dry chips and starch (**Figure 7**).

Table 20. Cassava production, harvested area and yield in Thailand from 2004/05 to 2009/10 and expected results of 2010/11.

Parameters	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11[1)]
Harvested area ('000 ha)	986	1,071	1,174	1,184	1,327	1,168	1,120
Production ('000 tonnes)	16,938	22,584	26,916	25,156	30,088	21,941	19,988
Yield (t/ha)	17.18	21.09	22.92	21.26	22.68	18.78	17.84

[1)] expected

Source: *Office of Agric. Economics (OAE) of Thailand, 2010.*

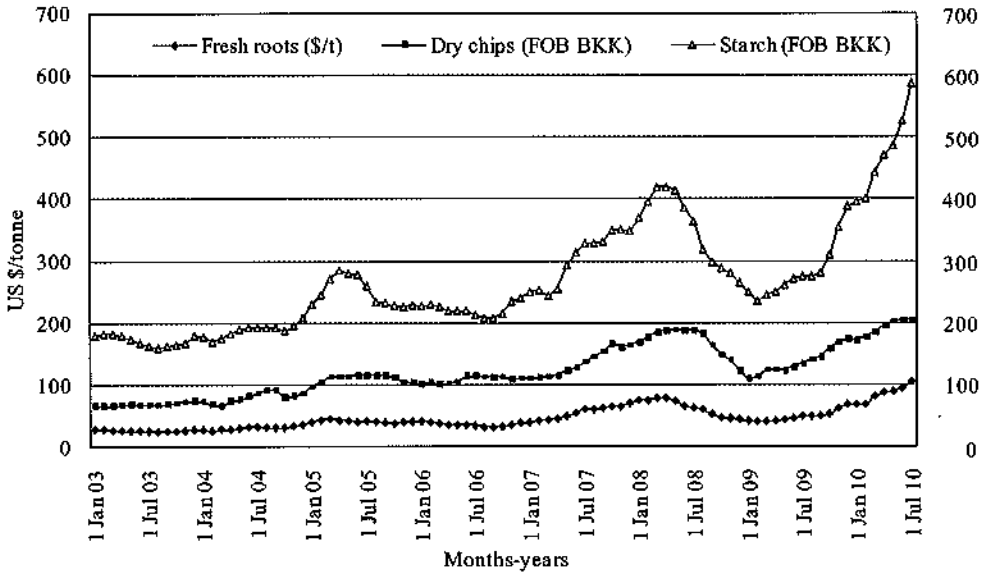

Figure 7. Change in the price of fresh cassava roots, dry chips and starch in Thailand from January 2003 to July 2010.
Source: *Thai Tapioca Trade Association Annual Reports 2008 and 2009.*

MAINTAINING A COMPETITIVE EDGE

To keep cassava-based products competitive in domestic as well as world markets is a real challenge. While cassava has many favorable attributes in the area of production, it also has some negative attributes, especially in terms of post-harvest handling due to its high water content and rapid deterioration. The content of cyanogenic glucosides in the roots is an important consideration in the use of cassava for direct human consumption, but is of less importance for production of processed food, animal feed or starch. The low content of protein in cassava roots increases the efficiency of starch extraction, but also

means the absence of a valuable high-protein by-product, as is the case for maize starch. Finally, since cassava cannot be grown in temperate climates, it has never received the same research attention in developed countries as for instance maize, rice, wheat, soybean and potato. Research on cassava had been minimal until the early 1970s when the international research centers – CIAT in Colombia and IITA in Nigeria – received the mandate for cassava research and development, which in turn triggered the formation of many national cassava research programs. Nevertheless, the number of researchers working on cassava, and the research budgets dedicated to this crop, are minimal in comparison with those for most of the competing crops.

Still, cassava thrives in Asia because of the ability of farmers, processors, traders, researchers and policy makers to adapt to rapidly changing physical, biological, economic and social conditions. To maintain this competitive edge will require special attention in three areas: 1) improving the production system in order to reduce the cost of raw material while maintaining reasonable profit margins for farmers; 2) adding post-harvest value by the development of new products and more efficient processes; and 3) stimulating higher demand for cassava-based products by market development. While the development of new markets was an important activity a few years ago, it now seems less urgent as demand for cassava in Asia seems to far outstrip supply. With the rapidly increasing use of cassava as a renewable energy source to replace fossil fuels – both for production of ethanol in the transport sector and for production of many chemicals, such as biodegradable and non-degradable plastics (Samai Jai-In *et al.*, 2010) – the demand for cassava roots are expected to remain very high in the near future. Unless cassava yields can be markedly improved there will continue to be a shortage of supply. In case of Thailand, the government may encourage the use of cassava for the production and export of ethanol and other value-added products and restrict the export of less valuable products like dry chips and pellets. **Figure 8** shows that this could markedly reduce the export of cassava chips from Thailand to other countries, especially to China, which in turn may stimulate more cassava production in neighboring countries in Asia.

While this cassava "boom" in Asia is a welcome development, which is likely to benefit many cassava farmers and improve their livelihoods, it may also stimulate a rush to expand cassava planting to less suitable areas, especially to steep slopes, which may cause serious erosion and soil degradation, or trigger further and more rapid deforestation in those areas where land is still available. To prevent this long-term detrimental effect on land and forest resources, it is essential to increase investments in cassava research – both at the national and international level – so as to obtain increases in production without having to increase the planting area. This will require that governments start considering cassava as a strategically important crop, similar to rice, maize, rubber and sugarcane, and markedly

increase investments in research in cassava breeding, soil fertility management and erosion control, as well as in integrated pest and disease management, coupled with increased efforts in farmer participatory research and extension in order to enhance adoption of new technologies and increase cassava yields, to the benefit of both cassava farmers and society at large. This will be the only way to prevent future environmental destruction and make the current cassava "boom" into a truly new "Green" Revolution in Asia.

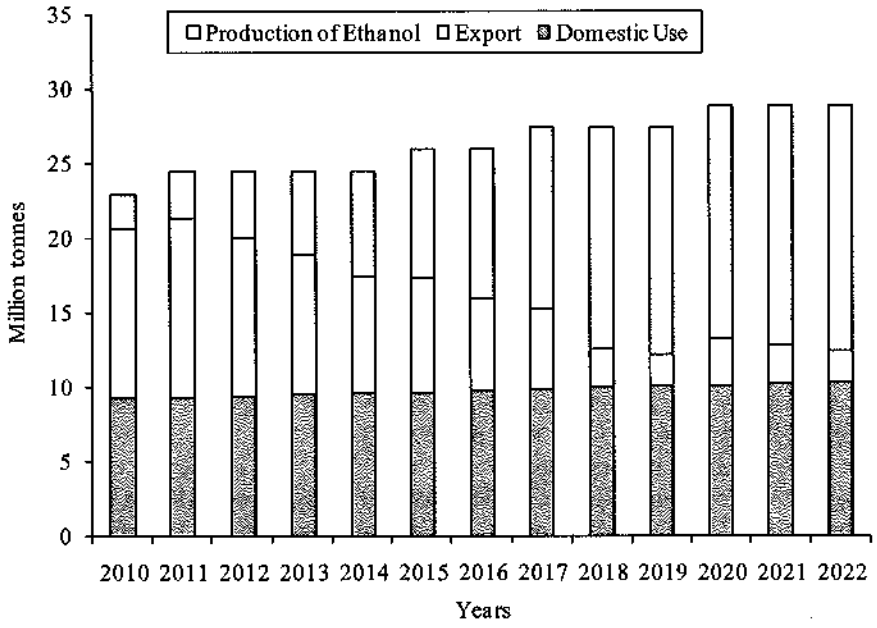

Figure 8. Estimated use of fresh cassava roots in Thailand for domestic use, ethanol production and export from 2010 to 2022.
Source: *Dept. of Alternative Energy Development and Efficiency; www.dede.go.th*

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INSTITUTIONAL COLLABORATION TO DEVELOP CASSAVA FOR THE BENEFIT OF THE CASSAVA SECTOR IN THAILAND

Morakot Tanticharoen[1],

Cassava (*Manihot esculenta* Crantz) is one of the most important economic and subsistence crops of many countries in Asia, South America and Africa. Instead of being recognized as a staple food crop as in other regions, in Thailand cassava plays a crucial role as an industrial crop, making Thailand ranked as the world-leading producer and exporter of cassava-derived products. Important ones are chips, pearls, native starches, chemically modified starches and those derived from utilizing biotechnology, such as MSG, glucose, fructose, sorbitol, lactic acid and citric acid, which find diversified applications in food, non-food and feed industries locally and worldwide. Significantly for Thailand, cassava can also be used to produce bioethanol, an alternative eco-friendly fuel for fossil petroleum substitution.

Regarding the crop's significance to the country's socio-economics, supportive and collaborative efforts among all stakeholders, in particular farmers, processors, end-users, policy makers, technology developers and non-profitable cassava organizations formed as "Cassava Cluster", are an important engine driving an enormous potential of cassava via various mechanisms. These include collaborative research which has significantly contributed to the improvement of cassava varieties, cultivation practices, modification processes and conversion technologies to produce high-value, industrially-oriented products.

At the National Science and Technology Development Agency (NSTDA), a research program on cassava has been established since 1995. During the first decade, most research activities focused on the development of core competencies including characterization of cassava root and starch properties of new improved varieties, improvement of native starch processing, establishment of quality control systems in starch factories, benchmarking of water and energy consumption in the starch manufacturing process, and effective waste water utilization by the biomethylation process. In the second era, the research activities on cassava still continue and further expand to develop novel cassava cultivars with superior characteristics as desired by the industry. With the implementation of advanced tools in plant molecular biology, the CASS-MOL BIOTECH collaborative research group targets to achieve a comprehensive understanding of the genetic control and functions of known key genes involved in starch biosynthesis of cassava. In addition, transcriptomic and proteomic analyses are performed to generate a large repertoire of genetic information, which is of immense value for future functional genomic studies. The efficient genetic transformation system for Thai cassava cultivars is also being established to serve as a platform for gene function testing to characterize important genes controlling vital economic traits. The wealth of knowledge gained from these efforts will help open new avenues for cassava research and make the selection and development of novel elite cassava cultivars a faster and more accurate process.

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Current collaborative research on developing zero-discharge technology and bioenergy production for the cassava industry are of great significance to alleviate the current environment and energy crisis. Starting in the 1980s, BIOTEC initiated a research program to manage and utilize waste water from the cassava manufacturing process as a renewable energy source: biogas. BIOTEC plays an important role in promoting the implementation of biogas technologies in several high-potential industrial sectors, including the cassava sector. BIOTEC has conducted R&D on the high-rate Anaerobic Fixed Film (AFF) Reactor as one of the major biogas technologies available nowadays. Further, BIOTEC is under a collaboration with the private sector under the project called "Research and Development on the Tapioca Starch Production Process to Increase Efficiency and Optimize the Utilization of Natural Resources, Water, and Energy: A Near-Zero Discharge Starch Factory" to be a pioneer and an industrial-scale pilot plant for the improvement of the cassava starch production process using engineering and process optimization skills. The collaboration leads to gain scientific and engineering knowledge to reduce the production loss and capital costs and to improve the process efficiency for different units of operation in the starch production line to steer the factories toward a zero discharge concept.

TRADITIONAL AND NEW USES OF CASSAVA ROOTS IN INDONESIA

J. Wargiono[1] and N. Richana[1]

ABSTRACT

In general, cassava roots in Indonesia are being used for food, feed and industrial purposes, which includes products such as chips/gaplek, flour, starch, and sweeteners such as high-fructose syrup, dextrose, maltose and sorbitol, while the new utilization of cassava roots focuses on the new demand for fuel-ethanol.

Factors causing the increased utilization of cassava roots for food are: (1) rice production can not satisfy the increasing demand, (2) cassava is more nutritious than rice due to its higher micro-nutrient content, (3) it is a staple food in remote areas, (4) it has functional properties that are highly suitable for certain foods. About 70% of the national cassava production is still used for food and this has been increasing at a rate of 1.8% per year.

During the last ten years the domestic demand for chips, flour, starch, and sweeteners has increased by 50%, 34%, 25% and 15%, respectively, while production of chips, flour and starch decreased at 34%, 22%, and 25% during the same period. This indicates that demand far outstrips supply and that cassava production needs to be increased.

Utilization of fuel-ethanol as an alternative source of energy is one way to solve the energy crisis and slow down the decrease in national fossil fuel supply of 5.74% per year during the last ten years. Annual demand for fuel-ethanol, to be mixed at 10% with gasoline for transportation, based on Presidential decree No. 5/2006, is estimated to be 1.4 million kl (1.12 million tonnes) which will require 8 million tonnes of fresh cassava roots. It means that cassava production has to be further increased to meet this additional demand for fuel ethanol.

Cassava production can be increased through both increases in yield by intensification and through increases in planted area. In Indonesia the target is to achieve a 5% annual increase in production through intensification and another 15% through increases in area. Sumatra and Kalimantan islands are suitable locations for increasing production through area expansion due to their wet climate and the availability of 5.7 million ha of under-utilized land. By 2025, it is projected that 18.7 million tonnes of fresh cassava roots will be needed for food, 6.1 million tonnes for dry chips, 2.6 million tonnes for starch, 7.9 million tonnes for sweeteners and 23.4 million tonnes for fuel-ethanol, for a total requirement of 67.2 million tonnes, which is over three times the current level of production.

INTRODUCTION

In Indonesia, the annual rate of growth of the utilization of rice, maize and cassava as staple foods during the last ten years were 1.37, 3.02% and 3.39%, respectively. Rice and maize production satisfies only about 90% and 70% of their respective demands, while cassava production exceeds its demand as food. This means that cassava is potentially a staple food alternative to substitute for rice and maize. Its demand for food will increase since the production of both rice and maize is insufficient to meet current demand.

Traditionally, cassava roots are also used for animal feed and for industrial purposes such as the production of dry chips, flour and cassava starch. Starch is an intermediate product to be used as raw material of downstream industries, such as fructose syrup, sorbitol, MSG, etc.

Since the growth of cassava production is below that of cassava usage for food, and this demand accounts for about 70% of national production, the availability of cassava as

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an industrial raw material can, therefore, not keep up with increasing demand. The decreasing availability of cassava fresh roots for industries due to the increasing demand for food, has affected the export of products like chips, flour and starch. On the other hand, the domestic demand of these products increased (FAO, 2005). To solve this problem we need to increase cassava production in order to meet the increasing demand for both industrial purposes and food.

An entirely new utilization of cassava roots is its use as a raw material in the fuel-grade ethanol (FGE) industry. The demand for FGE for mixing with gasoline at 10% (E10), based on Presidential Decree No.5/2006, was estimated at 1.4 million kiloliters in 2007 and will increase at a rate of 7.07% per year. Assuming a factory-gate price of Rp 350/kg fresh cassava roots and Rp 4,500/l FGE, the development of FGE industries is financially feasible based on NPV>0, R/C>1, and the internal rate of return being higher than the commercial bank interest rate (Wargiono, 2008). FGE industries are expected to be developed due to their various internal and external supporting factors. Investors are therefore committed to develop FGE industries. It means that both traditional and new uses of cassava have the potential to be further developed, and cassava production could be increased significantly in line with the increasing demand.

To meet the demand, both as raw material for the traditional and FGE industries as well as for food, national cassava production will need to increase at least 40% during the coming years.

Traditional Utilization of Cassava Roots

Traditionally, cassava roots in Indonesia are used for food, animal feed and for industrial processing into food and non-food products.

1. Cassava roots for food

Cassava is the third main staple food, after rice and maize, for most low- to medium-income people in Indonesia. As production of rice and maize satisfies only about 90% and 70%, of food demand, respectively, the demand of cassava for food is likely to increase. Besides, cassava used as food is nutritionally better than rice due to its higher content of both macro- (except protein) and micro-nutrients, as well as food fiber, while its glycemic index is considerably lower than that of rice, making it a very functional food (**Table 1**). For that reason, about 70% of cassava production in Indonesia is used as food and this demand will increase by 3.63% per year (Statistic Indonesia, 2006).

Based on its superior quality (except in protein content) cassava is used as the main staple food for many communities in remote areas, as well as for low- to medium-income groups. Traditionally, the preparation of *tiwul* as a staple food was relatively simple: put 1 kg of cassava flour in a bamboo winnowing basket, add one liter of water, make small balls by kneading → make many small balls homogeneous in size (similar to rice grains) by turning around on the basket, steam for about 30 minutes and the *tiwul* is ready to eat.

Malnutrition and anemia resulting from inadequate levels of energy and micronutrients in the diet are serious public health problems in Indonesia. **Table 1** shows that the rice in the diet could not supply sufficient vitamin A and C, while only 4.2% of calcium and iron and 33.6% of the micro-nutrient requirement could be supplied. On the other hand, cassava eaten as staple food is able to supply both vitamin A and C, and more than 60% of calcium and iron required in the diet. It means that malnutrition resulting in

anemia and vitamin A deficiencies, which is affecting one million and nine million people in Indonesia, respectively (WNPG, 2004), could be reduced by eating cassava as a staple food.

Dietary fiber, which consists of soluble fiber and non-soluble fiber, takes longer to transit the digestive tract, where some is fermented by intestinal microbes into fatty acids. The function of soluble fibers is to slow down starch digestion, thus decreasing the blood glucose level, and the need for insulin, which is involved in the transfer of glucose into body cells to produce energy. Non-soluble fiber also helps to reduce colon cancer, diverticulosis as well as vizier. It means that introducing cassava in the diet is not only suitable for diabetic consumers, but also increases the health of various digestive tract organs.

Since the utilization of cassava for food is of first priority, and the growth rate of food demand is higher than that of production, cassava production has to be increased to meet the demand for both food and industrial purposes.

Table 1. Nutrient characteristics of staple food crops in terms of calories, vitamins and minerals.

Food crops/ recommendation[1)]	Amount (g)	Protein (g)	Vit.A (si)	Vit.C (mg)	Ca (mg)	P (mg)	Fe (mg)	DF[2)]	DS[2)]	GI[2)]
Recommended	1,269 (cal)	36	356	53	474	356	7.71	-	-	-
Rice	326	22	0	0	20	456	2.59	5.4	70.0	56.0
Cassava[3)]	748	6	2,881	225	247	299	5.2	7.0	62.1	37.0
Maize	352	32	14	1,795	35	901	9	-	-	-

[1)] Nutrition recommended in the diet
[2)] DF = digestible fiber; DS= digestible starch; GI= Glycemic index
[3)] Fresh roots
Source: WNPG, 2004.

2. Cassava used for traditional industrial purposes

For traditional industries, such as dry cassava chips, flour, starch and sweeteners, their raw material supply depends on the total national cassava production, and on the demand for food, which has been increasing annually at a rate that is 45% higher than that of production. Consequently, the processing of these traditional cassava products has decreased annually by 19% due to insufficient availability of the raw materials (Statistik Indonesia, 2006). The products of these traditional industries, such as cassava chips, flour, and starch, are either exported to international markets or used as the raw material for downstream industries, such as maltodextrin, glucose syrup, fructose syrup, sorbitol, monosodium glutamate, textiles, paper, cosmetics, drugs, etc.

The impact of decreasing production by these traditional industries due to the insufficient supply of cassava roots has decreased the export of these products and increased the importation of these product to meet the domestic demand. This problem could be solved by increasing cassava root production to satisfy the demand of these traditional industries. To meet the demand for food, feed, and these traditional industries, as well as the expected future use of fuel-grade ethanol (FGE), it is estimated that fresh cassava root production by 2025 will need to increase to 67.17 million tonnes (**Table 2**).

Table 2. Projection of cassava fresh root production in Indonesia to meet the demand for food, feed and various industries from 2010 to 2025.

	Fresh root equivalent ('000 t)				Growth (%/year)		
Indicators	2010	2015	2020	2025	2010-2015	2015-2020	2020-2025
National production	24,512	38,289	53,424	67,165	8.26	7.00	5.00
Uses:							
-Food	14,521	15,883	17,373	19,004	1.81	1.81	1.81
-Feed	344	348	351	355	0.02	0.02	0.02
-Industrial purposes							
-Chips	937	1,702	3,793	6,109	15	12.5	10
-Flour	343	553	890	1,433	13	13	13
-Starch	1,847	3,015	4,922	7,969	10	10	7.5
-Sweeteners	1,255	2,021	2,902	4,166	10	9.5	9.5
-FGE	2,970	11,838	19,455	23,359	32	10.4	3.7
-Others + waste	2,295	2,929	3,738	4,770	4.9	4.0	4.0

Source: *Wargiono, 2008.*

Increasing cassava root production can be achieved through both intensification in production and by increasing the growing areas. To guarantee fresh root availability as raw material for industries, cassava has to be planted continuously during the wet season (at least six months) and harvested throughout the year. The cassava can be harvested from 7 to 12 months to meet the demand for a continuous supply of raw materials. Areas which have more than six wet months during the wet season are suitable to increase production through both intensification and extensification. Besides, currently unused land is needed for increasing the planted area from the current 1.2 million ha to about 2.2 million ha by 2025, while also increasing yields from 16 t/ha to 30.5 t/ha by 2025. **Table 3** shows that Kalimantan and Sumatra are suitable areas for developing industries, especially for cassava starch and downstream industries such as sweeteners, sorbitol, MSG, etc. While production of dry chips and cassava flour could be developed in dryer areas such as Java, Sulawesi and East Nusa Tenggara islands. Increasing cassava production successfully through both intensification and extensification depends on the contribution to the income of both farmers and government.

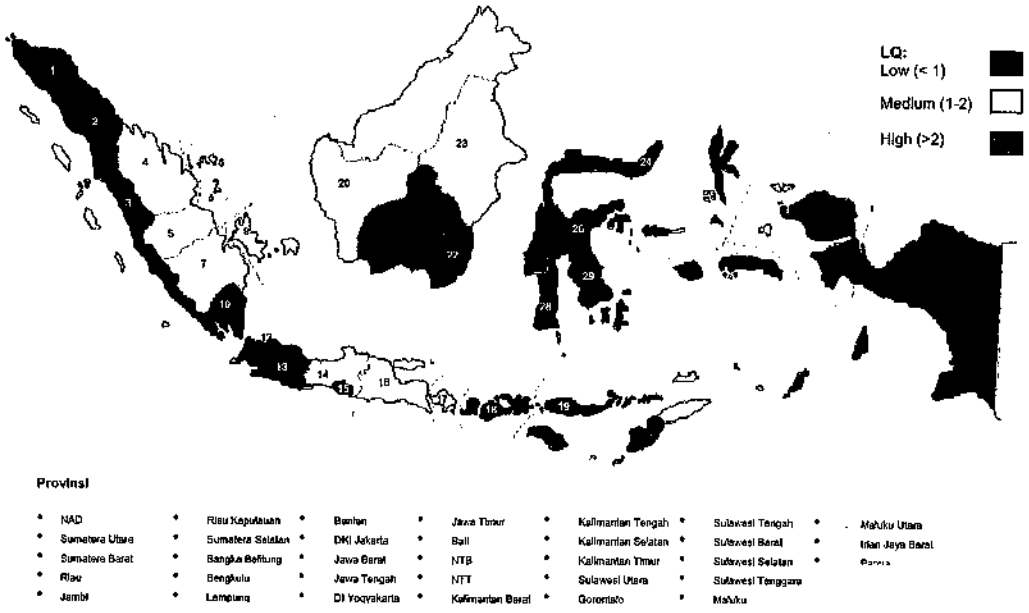
Table 3. Suitable regions based on land and climate to develop cassava as raw material for industries.

Region	Soil type ('000 ha)			TNUL land[1)] ('000 ha)	Dominant climate
	Inceptisol	Alfisol	Ultisol		
Sumatra	10,598	-	8,008	2,156	wet
Java	4,231	1,053	4,463	111	dry
Kalimantan	11,025	-	20,400	3,633	wet
Others	5,803	976	2,336	1,163	dry

[1)]TNUL= temporarily not used land.

Source: *Adimihardja and Mappaona (Eds.), 2004.*

A location quotient (LQ) could be used to describe the contribution of cassava farming to the regional economy. The LQ of cassava-based provinces could be divided into three categories: low (<1), medium (1-2), and high (>2). Provinces with medium to high LQ are characterized by the dominating presence of commercial cassava farming (Wargiono, 2008). Commercial farming systems are characterized by farmers who are responsive to yield and price change and adopt recommended technologies in order to obtain high profits. The benefit-cost (B/C) ratio of commercial cassava farming systems is generally >1. The B/C ratio of >1 is an indication that cassava farming is financially feasible and can be developed to contribute more than 40% of farmers' income (Ditkabi, 2008). Therefore, increasing production through both intensification and extensification in areas with medium to high LQ, i.e. where there is temporarily not used land and with a suitable climate, will be the first priority. Based on this criteria 39 districts in seven provinces of Sumatra island and 35 districts in four provinces of Kalimantan island have potential for further development of cassava to be used as raw material for both traditional and FGE industries (Wargiono, 2008) (**Figure 1**).



Gambar 6. Sebaran Location Quotient (LQ) ubikayu per provinsi.

Figure 1. Suitability of provinces for the development of FGE industries, based on their LQ status.

Traditional industries which use fresh cassava roots and derived product as raw material include those producing chips, flour, starch, sweeteners, sorbitol, MSG, cracker/crisp etc. The traditional industries are mostly concentrated on Java and Sumatra islands (**Table 4**). The decrease in the export of cassava chips, flour and starch and the increasing deficit to meet domestic demand for these products indicate that these industries were not able to produce sufficient products due to the inadequate supply of the raw material to meet demand.

Table 4. Currently existing traditional cassava-based industries.

Industries	Number of factories
Dry chips	13
Pellets	11
Cassava flour	1
Cassava starch	54
Sweeteners	8
Sorbitol	1
MSG	1
Crackers/crisps[1)]	27

[1)] Such as krupuk and kripik
Source: Hafzah, 2003.

(a) Dry chips and flour industries

During the last ten years, cassava chip production decreased while domestic demand for chips increased 33.9%; the export of dry chips and cassava flour decreased 21.64% and 25.37%, respectively, while the import of cassava flour to meet domestic demand increased 33.9% (Statistik Indonesia, 1996-2005). This indicates that chip production needs to be increased both through a greater supply of raw material to the existing 24 chips and pellets factories and to develop new chipping and drying industries.

Since fresh roots have to be processed within three days after being harvested, the simple processing of fresh roots to dried roots (*gaplek*) by each farmer (home-scale industries) is a popular alternative for most farmers that are located in areas that are far from markets or industries. However, most chips produced by these home industries are of low quality. On the other hand, high quality chips are needed for both exported chips and for use as raw material in downstream industries. Therefore, the development of medium- to large-scale chip industries will not only enable an improvement in chip quality, but will also provide a local market for fresh roots. The existence of these medium- to large-scale chip industries would eliminate the need for processing fresh roots by home-scale industries that produce low-quality chipping and drying due to the alternative of selling fresh roots directly to these chipping and drying industries.

The capital that need to be invested for a chips industry with a capacity to process 100 t fresh roots/day, will be Rp 1.344 million (about US$ 150,000) both for building and for operational costs, including raw material at Rp 400/kg (about $45/t) fresh roots. Financial analyses shows that Rp 1,281/kg (about $140/t) dry chips could be produced; this is feasible as its NPV is positive, B/C ratio is higher than one and the IRR is higher than the commercial bank interest (**Table 5**). Because chips can be processed into cassava flour, the chips industry could be combined with the cassava flour industry. By combining these industries transportation cost of chips as raw material for the flour industry is eliminated resulting in a lower price of the flour produced, making the product more competitive in domestic and international markets.

Chips can be stored for more than six months (Wargiono, 2008), which means that the chips are available for the cassava flour industries during the whole year even though these industries should be developed mainly in areas with dry climates, such as Java, East Nusa Tenggara (NT) and Sulawesi islands (**Table 6**).

Table 5. Financial analyses of various cassava-based industries*.

Indicators	Chips	Starch
Total costs (Rp'000,000)	11,794	14,160
Yield (kg/100 kg fresh roots)	35	25
Price of product (Rp/kg)	1,123	1,890
Net income (Rp'000,000)	13,650	18,500
Net benefit (Rp'000,000)	1,856	3,840

* Raw material 100 t/day fresh roots at Rp 400/kg; 1 US$ = Rp 9,000.

Table 6. Projected priority areas for the development of cassava-based industries in Indonesia.

Industries	Java	Sumatra	Kalimantan	Sulawesi	East NT
Chips	***	*	*	**	***
Flour	***	*	*	*	***
Pellets	**	**	**	*	**
Starch	*	***	***	*	-
Sweeteners	*	***	***	*	-
Sorbitol	**	**	*	*	*
MSG	*	**	*	*	*
Crackers/Crisps	**	**	**	**	*
Ethanol	*	***	***	*	-

*** = high priority; * = low priority.

(b) Cassava starch industry

During the last ten years, cassava starch production decreased 9.5%, while domestic demand for cassava starch increased 10.2% (Statistic Indonesia, 1996-2005). To meet the demand, cassava starch needs to be imported. Cassava starch imports have increased from 35 tonnes to 2,136 tonnes. This indicates that increasing cassava starch production, both through increasing production at the existing 54 starch factories and by developing new starch factories, is needed. The factors causing the decrease in starch production are: (1) raw material availability is less than demand; (2) low agro-ecological support; and (3) the starch price in the world market fluctuates widely. Cassava starch is used for various food and non-food industries, so the starch factories should be built in areas that are environmentally most suitable, such as Sumatra and Kalimantan.

The capital that need to be invested for a cassava starch factory with a capacity to process 100 t fresh roots per day will be Rp 14,100 million (about US$ 1.5 million) for the buildings, machinery and operational costs, including raw materials at Rp 400/kg fresh roots. The factory will be able to produce dry starch at Rp 1,890/kg (about $ 210/t) and is economically viable to be developed in Sumatra and Kalimantan because of a positive NPV, the B/C ratio is more than one, and the IRR is higher than the commercial bank interest (**Table 5**). Traditionally, cassava starch is a raw material of both non-food and food industries such as sweeteners, noodles, cakes, biscuits and other downstream

industries. These downstream industries could make cheaper products by combining the starch and downstream industries in one area due to lower transportation costs.

Instant noodle industry

Consumption of instant noodles in Indonesia is increasing at a rate of 12.38% per year. PT Indofood Sukses Makmur is the biggest instant noodle company in the country, followed by PT Asia Inti Selera, PT Nissinmas, PT ABC President Food Enterprises, PT Mie Barokah, followed by another 25 smaller instant noodle companies (Richana, 2003). These companies produce about 9.2 million packs/year of instant noodle. The cassava starch demand of these industries is about 0.045 million tonnes, corresponding to about 0.20 million tonnes of fresh roots. In order to obtain a monthly supply of starch, the instant noodle industries should cooperate with small-scale cassava starch factories such as ITTARA by providing credit to farmers for the purchase of fertilizers and for land preparation costs.

Cake and biscuit industries

In the cake and biscuit industries cassava starch is mixed with wheat flour, at about 10-20% for cakes and at 30-40% for biscuits. The annual demand for wheat flour is about 4 million tonnes, which is totally imported; therefore, mixing wheat flour with cassava starch is a way to reduce the production cost of cakes and biscuits. The demand for cassava starch in these industries is about 90,000 tonnes/year. Demand for these products increased at an annual rate of 14.9% (Richana, 2003). This means that the cake and biscuit industries have good future prospects, and demand for cassava starch could be increased as well. Household-scale cake and biscuit industries could be developed in the villages. For that reason, cassava starch should be just as available as wheat flour in local markets.

Sweetener industries

The industries, that produce products such as glucose, fructose, sorbitol, and organic acids like MSG, citric acid and enzymes, can use both fresh and dry cassava roots as the raw material. As most of these products are currently imported, domestic production should be increased to meet the demand.

The demand for cassava starch as raw material of the sweetener industry that produce glucose, fructose and sorbitol is about 0.17 million tonnes and is increasing annually at a rate of 9.17% (Statistik Indonesia, 2000; Capricorns, 1998). But most of these products are still being imported. The demand for glucose syrup is 40% higher than current domestic production; this is similar for glucose, fructose, maltose, mannitol and sorbitol. Demand for glucose as the raw material for the production of candy, soft drinks, traditional medicines and the biscuit industries also tends to increase (Statistik Indonesia, 2000). Domestic production of these products should be increased urgently to meet the domestic demand.

Glucose syrup can be produced by hydrolyzing starch with either acid or α-amylase enzyme. Cutting the starch chain using acid will produce a mixture of dextrin, maltose and glucose (Richana, 2003).

Imported gluco-amylose and α-amylase enzymes for producing glucose and fructose syrups could well be substituted by other enzymes produced domestically (Richana *et al.*, 1999; Lestari *et al.*, 2000). **Table 7** shows that the amylose content of cassava starch is lower than that of arrowroot or maize starch, but the yield of cassava roots is much

higher than those of maize and arrowroot. **Table 7** shows that the amylose content of cassava starch is similar to that of maize but its glucose syrup yield is slightly lower than that of maize starch. However, the availability of maize can not meet the domestic demand (Statistic Indonesia, 2005). Moreover, cassava starch will probably be the main raw material for the domestic production of glucose and fructose syrup due to its greater domestic availability.

Table 7. The yield of glucose syrup from different starches.

Starch type	Amylose content (%)	Glucose syrup yield (%)
Maize	29.84	89.1
Arrow root	34.80	83.5
Cassava	29.86	86.0
Sago	33.28	83.3

***Source:** Richana, 2000.*

(c) Home and small-scale industries

Various home- and small-scale industries use cassava roots and derived products as raw material for making fermented roots, crisps, crackers, *rengginang* and other traditional foods. Traditional crackers and crisps are produced by about 27 small-scale industries and are consumed domestically and exported. These industries, mostly located in both urban and remote areas, are the only local markets for the sale of fresh roots since other fresh root-based industries have not developed yet.

New Utilization of Cassava Roots

The utilization of bio-energy as a renewable alternative energy source is a way to solve the problem of decreasing fossil energy supply. The supply of fossil energy in Indonesia is decreasing at about 6% per year, while domestic consumption of gasoline for transportation is 18.37 million kl which could be mixed with fuel grade ethanol (FGE). By implementing the E10 policy of gasoline mixed with 10% ethanol for transportation, the demand for FGE will increase annually by 7.1%. In 2007 the demand for FGE was estimated at 1.84 million kl, which is equivalent to 11.0 million tonnes of fresh cassava roots. To satisfy the FGE industry demand for raw material, cassava root production has to be increased by about 56% during the next five years in order to satisfy the demand for food, feed and all other cassava-based industries (**Table 2**).

An adequate supply of raw materials could be realized if the FGE industries are located in areas with a wet climate that have sufficient availability of unused land. By 2025, the amount of fresh cassava roots needed as raw material for the FGE industries is projected to be 23.36 million tonnes (**Table 2**). Sumatra and Kalimantan islands are environmentally the most suitable areas for development of FGE industries because of the availability of land and their rather wet climates (**Figure 1**).

In principle it should be possible to plant cassava during the six months of the wet season and to harvest during the whole year, in order to supply the feedstock for the FGE industry on a continuous basis (**Figure 2**).

The capital that need to be invested for an FGE factory with a capacity to process 100 t fresh cassava roots per day, will be Rp 15,284 million (about US$ 1.7 million) for the

buildings, machinery and operation costs including raw material at Rp 400/kg fresh roots. The factory will be able to produce FGE at Rp 3,057/l (about US$ 0.34/l), and produce a net income of Rp 22,499 million and net benefit of Rp 5,686 million. A financial analysis indicates that it is economically viable because of a positive NPV, a B/C ratio higher than one, and IRR higher than the commercial bank interest (**Table 8**).

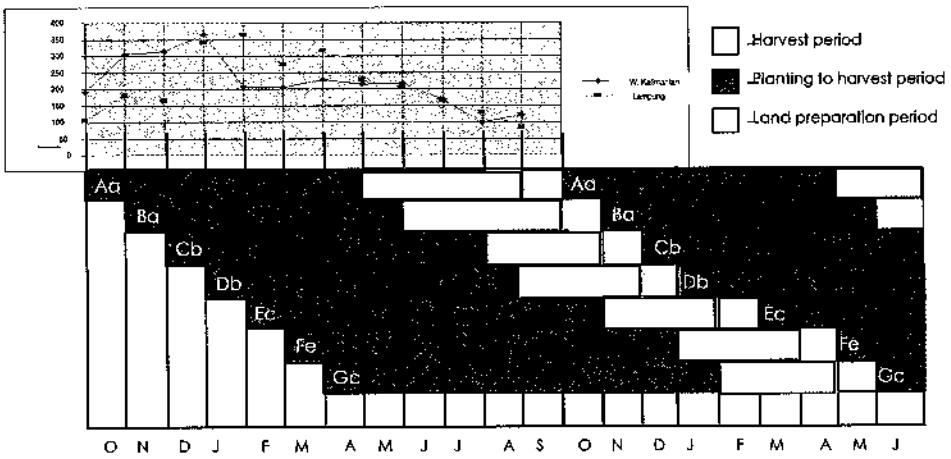


Figure 2. Time schedule for planting and harvesting of cassava based on the rainfall patterns in West Kalimantan and Lampung provinces of Indonesia to produce feedstock for FGE industries during the whole year.

Table 8. Financial analysis of the FGE industry.

Indicators	Input-Output
- Total costs (Rp'000,000)	15,284
- Ethanol yield(l/100 kg fresh roots)	20
- Price of product (Rp/l)	3,057
- Net income (Rp'000,000)	22,449
- Net benefit (Rp'000,000)	5,686

A SWOT analysis indicate that the FGE industries in Indonesia can be developed with good prospects due to their high potential from the production and economic stand point, and for marketing aspects as well.

To be economically and environmentally most viable, the FGE industries should be located in areas which are environmentally most suitable, such as Sumatra and Kalimantan. Based on land availability for cassava farming to supply the 23.4 million tonnes of fresh roots to the FGE industry (**Table 2**), at least 10,000 ha per district in about 38 districts of Sumatra and 35 districts in Kalimantan are potential areas for the development of FGE industries in Indonesia (Sensus Pertanian, 2005).

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HARMONIZING THE SUPPLY OF CASSAVA TO MEET THE INCREASING DEMAND FOR FOOD AND VARIOUS OTHER USES IN INDONESIA

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ABSTRACT

During the past 40 years the cassava harvested area in Indonesia has declined from 1.5 to 1.3 million ha, but cassava yields have significantly increased from 7.5 to 15.5 t/ha. Therefore, total production has increased from 11.3 to 19.6 million tonnes. However, the increase in production is still not able to meet the rapidly increasing demand. Previously, the demand for cassava was primarily for human consumption as well as for export as dry chips for animal feed to European countries and Japan. The greater domestic demand for starch and starch-derived products, such as sorbitol, maltose, glucose and fructose syrup, has required the importation of starch from Thailand. Various food products made from fresh roots, dried flour as well as starch also contributed to the increased demand. Recently, the growth of the renewable fuel industries (ethanol) for domestic use and export (China, Korea and Japan) also require huge amounts of raw material in the form of fresh roots or dried chips. Consequently, the resulting increase in the price of fresh cassava roots has benefited many farmers who had never experienced this previously.

To meet the greater demand, the yield level of cassava has to be increased substantially. On the other hand, expanding the planting area is also an appropriate solution. However, the expansion of the cassava area should avoid the logging and destruction of forested areas. Instead, grasslands or unused land that was previously in forest could be used to cultivate cassava under an agroforestry system. Intercropping cassava with associated crops such as cereals and grain legumes should be undertaken more widely in attempts to achieve greater harmony in cassava development programs. Applying better crop and soil management practices is a must for achieving a better image of cassava development in harmony with economic and ecological considerations.

Keywords: cassava, Indonesia, supply, demand.

INTRODUCTION

Cassava is not a native crop of Indonesia; it was introduced during the early colonial era after Columbus found the new world "America". The introduction of cassava into Indonesia occurred around the middle of the 18th century, entering through Maluku (Cock, 1985). From the Maluku islands cassava was distributed throughout the other islands of Indonesia, including Java. During the Mataram Kingdom cassava was propagated in Pogung Raharjo in Sleman, Yogyakarta, and was distributed throughout the island of Java (1880-1920); therefore, in East Java cassava is also known as Pogung. In the early 20th century cassava started to be used for large-scale cultivation for the export of dried peel for animal feeding in Europe by the Dutch government in Indonesia. During the First World War and thereafter, cassava was able to safe people in Java living nearby cassava plantations from famine. From that experience, in the mid 20th century the cultivation of cassava in Java was progressively developed for use as food, for the starch industry and for export. From the early 20th century (1905), as part of the first transmigration program, cassava was distributed to 105 households from Central Java to take to Lampung on Sumatra island. Furthermore, in conjunction with the transmigration

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program, cassava was recognized as having greater adaptability to various sub-optimal conditions, and was thus distributed from Java throughout the country (Widodo, 1993).

During the early days of independence in the early fifties (1945-1955) cassava was again able to reduce a severe famine due to post-Second World War and internal conflicts caused by an unstable political situation. Since cassava was frequently saving people from hunger, and has flexibility of storage in the form of dried peeled chunks, called *gaplek*, Mr. Mukibat, a farmer in Ngadiluwih, Kediri, tried to improve its productivity by grafting the wild cassava (*Manihot glaziovii*) on top of ordinary cassava (*Manihot esculenta*). In the beginning, this grafting method of cassava was intended to avoid stealing due to food insufficiency. After harvesting the grafted cassava, Mr. Mukibat and family were very surprised to see a 5-10 fold yield increase over ordinary cassava. After that, the Mukibat method was quickly disseminated. During the 1960s the Mukibat method was an effective way to produce more food from the starchy roots of cassava in order to reduce food shortages.

In line with the green revolution in cereal production by introducing early maturing rice varieties, the cassava Mukibat system was able to increase food production significantly. By the intensive management of the cassava Mukibat system in home gardens cassava could produce more than 50 kg/individual plant/year. In addition, by implementing the Mukibat system and growing cassava in home gardens the roots could be harvested piecemeal. Cassava could thus be harvested over a longer period (>2 years). Unlike ordinary cassava, which had to be harvested at the end of the dry season and then processed into a dried form to be stored, the Mukibat cassava could be kept in a fresh form in the field and harvested when required.

Widodo (1986) reported that the cassava planted area decreased significantly due to the conversion of uplands, cassava's domain, into irrigated areas for lowland rice. Consequently, to satisfy the demand, which tended to increase, cassava planting moved into dry marginal and more risk-prone areas. By the 1970s the expansion of cassava outside of Java developed progressively, especially in order to meet the increasing demand from the starch industry. Entering the third millennium, the demand for cassava tended to increase, even though the harvested area tended to stagnate or even decline. Recently, due to the lower availability and the incredibly high price of fossil fuels, the use of cassava as a raw material for production of bio-fuel (ethanol) is being promoted, as it is considered more ecologically friendly, and is a renewable source of energy. Therefore, a higher level of productivity of cassava, as well as the expansion into other appropriate regions, is urgently required. Significant simultaneous increases in yield and in the harvested area will contribute to a boost in the national production (**Table 1**). If this occurs, then there will be no conflict between the demand for food, feed, the existing processing industries and for bio-fuel.

INCREASING DEMAND

The initial move of cassava cultivation from Maluku to Java was meant for large-scale plantations to meet the demand for feedstuff in Europe. This coincided with a period of food scarcity, which forced poor farmers in Java to use cassava as a source of carbohydrate food. The plantation of cassava during the Dutch colonial period emphasized the use of bitter cassava with an HCN content of >100 ppm. From the beginning the export of cassava to the European market was aimed to fulfill the demand for animal feed, so

shipping in the dried form of *gaplek* was considered sufficient. Processing cassava into *gaplek* was very simple: by peeling the skin and cutting the roots into smaller pieces, these would dry faster during sun-drying. This simple way of preparation could be done directly by farmers. It seems that the method to prepare *gaplek* was taught by the Dutch to farmers in Java in order to fulfill the market demand for *gaplek* in Europe.

Table 1. Trend in cassava area, yield and production in Indonesia during the past 40 years.

Years	Harvest area (ha)	Yield (t/ha)	Production (tonnes)
1968	1,503.000	7.56	11,356,000
1973	1,429.000	7.80	11,186,000
1978	1,383.000	9.30	12,902,000
1983	1,221.000	9.90	12,100,000
1988	1,303.000	11.87	15,471,000
1993	1,401.600	12.30	17,285,400
1998	1,205.400	12.20	14,696,200
2003	1,244.500	14.90	18,523,800
2008*	1,341.607	15.50	20,794,607

Source: *BPS 1970-2006; *www/bps.go.id*

The production of *gaplek* by farmers who chronically suffered from food scarcity, stimulated people to prepare a palatable food from a dirty raw material (during the processing of *gaplek* the peeled roots were sun dried directly on the soil). Unlike fresh cassava that will easily deteriorate in around 3-4 days, cassava in the form of *gaplek* could be stored for up to 12 months to secure against food insufficiency. From *gaplek* several food preparations could be made. The most common food preparation that is still widely practiced by rural households is *tiwul*, which is a staple food other than rice for low-income communities. *Tiwul* is processed from *gaplek* flour. Processing *tiwul* is as follows: flour of *gaplek* is mixed with hot water which will form granules when the mixture is swirled on a bamboo tray; these granules are steamed for about 15-20 minutes. *Tiwul* is the most popular staple food derived from *gaplek*. It can be consumed directly after cooking or is dried as a storable instant *tiwul* (Gintine *et al.*, 1989a). *Tiwul* is eaten like rice, with several side dishes to meet the local taste. Instant *tiwul* is a popular food, not only for the poor but also for middle-income communities.

Other than *tiwul*, there is a dish called *gatot* that is prepared from *gaplek*; its preparation is faster than that of *tiwul*. *Gatot* can be prepared by soaking *gaplek* in water for more than six hours to make it soft; these are then sliced into small pieces and steamed. Unlike *tiwul* which is a staple food, *gatot* is only used as an additional snack, mostly eaten with shredded coconut. *Tiwul* can also be used as a snack, by mixing in palm sugar during preparation, and then mixing this with shredded coconut to improve the taste. Fermented food could be generated not only from fresh cassava, but also from *gaplek*. However, the best quality fermented food from cassava is made from fresh cassava without any physical or microbial deterioration. On the contrary, during the drying process *gaplek* suffers some physical deterioration. Therefore, fermented products made from *gaplek* are not as attractive as compared to those made from fresh cassava, especially with respect to color.

The color of fermented fresh cassava can be white or yellow, depending on the original color of the flesh in the fresh form. But, fermented food made from *gaplek* has a color that looks dirty, grey, brown to dark (blackish). Because of this, there is an increasing demand for products made from fresh cassava instead of *gaplek*. Improvements in the processing of traditional foods, as well as recent innovations in making new products from cassava, have made cassava-based products very popular due to the lower price of cassava, either fresh or as *gaplek*, as compared to other raw materials used in food processing, such as wheat, rice, maize etc.

Table 2. Quality standard of dried cassava (*gaplek*) in Indonesia based on SNI No. 01.2905-1992.

Parameters	Categories			
	Super Quality	Quality I	Quality II	Quality III
Water content (% w/w maximum)	14	14	14	14
Starch content (% w/w maximum)	70	68	65	62
Fiber content (% w/w maximum)	4	5	5	5
Sand content/silica (% b/b maximum)	2	3	3	3

w/w = weight/weight

During the Dutch colonial period, when cassava was used mainly for export to Europe in the early 20th century, it was estimated that 90% of total production was exported, and the remaining 10% was used for local consumption. Due to the famines caused by the First and Second World War the proportion of cassava for domestic consumption increased. In the early days of independence (1945-1968) Indonesia was the largest exporter of cassava in the world. But, after 1968 this position was taken over by Thailand. However, as cassava production decreased due to the conversion of uplands into irrigated lowland areas for rice, demand for cassava remained high. This demand was mainly satisfied by an increase in productivity, from 7.56 t/ha in 1968 to 8.71 t/ha in 1988, and to 15.6 t/ha in 2008. Consequently, this increase in productivity contributed to a marked increase in production which is currently over 20 million tonnes per year.

In 2003 about 47% of cassava production was used for food, 2% for feed and 38% for "other" uses, which includes processing into non-food products. The remaining 13% is listed as "waste", such as peel and solid residues from processing, which are mostly used for animal feeding (FAOSTAT, 2010). The apparent consumption level of cassava was about 41 kg/capita/year (FAOSTAT, 2010), the highest level in Asia except for East Timor. The consumption level of cassava in rural areas was 4-5 times higher relative to urban areas (Setyono *et al.*, 1992). According to ICBS (1999), about 6% of households in rural areas consumed roots (predominantly cassava) every day and 21% two to five times per week; in urban areas this was 2% and 16%, respectively. Cassava is consumed either as a staple food or in the form of various snacks. As snacks, the fresh roots are generally boiled or steamed, deep-fried or fermented to prepare various types of foods, such as *ubi rebus, ubi goreng, getuk, tape, lemet* and *keripik*. There are at least 90 different kinds of traditional foods that can be prepared from fresh cassava (Setyono *et al.*, 1992). These traditional foods are popular in both rural and urban areas; however, more different types of snacks are found in rural areas.

In addition to direct consumption, cassava can also be processed into intermediate products, such as *gaplek*, starch and flour (**Figure 1**). Starch is mainly produced for commercial purposes, both for food (*kerupuk* or cracker, sweeteners, thickener, filler, binder or stabilizer) and non-food industries (sorbitol, maltose, glucose, mono-sodium glutamate and other chemical products, for paper, textile, pharmaceuticals etc.) (Setyono *et al.*, 1992). Starch is extracted from the roots with water. This process requires a lot of water. Therefore, the starch industry can only be developed in those areas where water is easily available. Widodo (1993) reported that Lampung province could supply only about 60% of the raw material required for the starch industries in the province. Moreover, Widodo (1993) and Widodo and Hartojo (2001) concluded that the huge amount of water (8,000 l for 1 t of fresh cassava roots) required for the extraction process in the starch factories was an environmental problem. In fact, starch production has great prospects, but the effects on the environment should be well-managed. Widodo and Hartojo (2001) concluded that to be ecologically, economically and socially friendly the large-scale starch industry should be spread over a wider geographical area. It does not mean that the big starch factories should be immediately stopped. But, stronger environmental regulation for building new large-scale starch factories should be considered. The building of smaller scale factories may be another alternative.

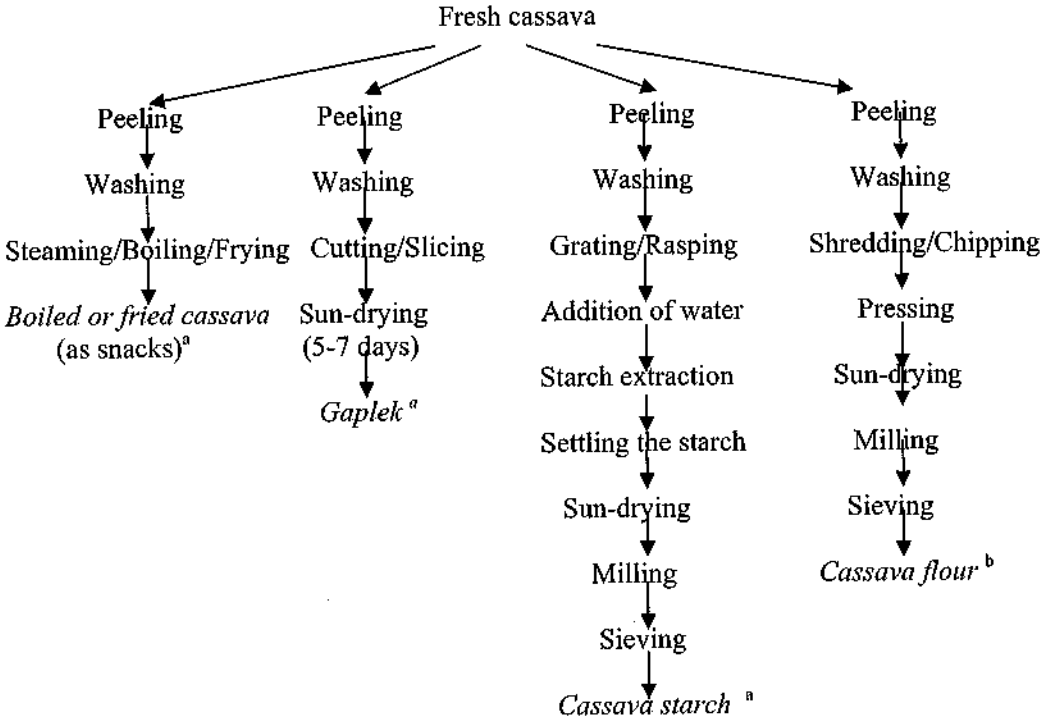

Figure 1. Flow chart for the preparation of cassava snacks, gaplek, starch and flour.
Source: *[a] Barret and Damardjati, 1984; [b] Damardjati et al., 1996.*

The Cassava Starch Industry and its Consequences

Widodo (1993) reported that the fish and shrimp ponds on the eastern coast of Lampung province were polluted by waste water from the cassava starch industry. This was particularly due to the poor waste management in the large-scale cassava starch factories. Commonly, the liquid waste from the starch extraction process was released directly into the rivers and ended up down-stream in fishery ponds. Currently, about 25% of the fresh cassava roots produced nationally is required as raw material for starch processing. It means that almost 5 million tonnes of fresh roots are processed into starch. The starch industry generally uses the more bitter, high (>100 ppm) hydrogen cyanide (HCN) cassava cultivars. In the starch extraction process the HCN is released and part of it may end up in the waste water. In terms of food safety, the natural presence of cyanogenic glucosides in cassava roots is of concern because of their potential toxicity. The amounts of HCN, a highly toxic compound, produced after the release of cyanogenic glucosides varies in different cultivars from 1 up to 1000 mg/kg (Bradbury, 1990). Cassava roots containing <50 mg HCN/kg fresh roots are considered "sweet" cultivars, while the "bitter" cultivars have >50 mg HCN/kg. Cassava roots with >100 mg HCN/kg are not safe for direct consumption as it may cause acute poisoning and death (Coursey, 1973, *in* Richana and Suarni, 1990). Therefore, the sweet cultivars are mostly used for fresh consumption of cassava roots. However, the bitter cultivars, with relatively high HCN content, tend to have higher yield potential and starch contents (Setyono *et al.*, 1992; Ginting *et al.*, 1999). These characteristics are desired by starch and flour processors as well as by most farmers. On the other hand, different processing methods of cassava roots result in different levels of cyanide reduction (Coursey, 1973, *in* Bradbury, 1990). Hence, the use of cassava roots for food should combine effective processing methods to reduce the HCN content with the selection of cultivars with high yield potential and low cyanide content.

Cyanide Toxicity: Warning in Food Safety

Although cassava was introduced to Asia almost four centuries ago, accidents resulting in human death due to cyanide toxicity still occur, particularly during famines. There are two cyanogenic glucosides present in cassava roots, namely linamarin, which accounts for 95% of the total cyanogen content, and lotaustralin (Balagopalan *et al.*, 1988, *in* White, 1994). The hydrolysis of linamarin by the β-glucosidase and linamarase (at optimum pH of 5-6), results in the production of acetone cyanohydrin. This can be further decomposed to free-cyanide (HCN) and acetone, either spontaneously or enzymatically by hydroxynitrile lyase at pH greater than 4.0 (optimum pH is 5.0) and temperatures greater than 30°C (White *et al.*, 1994). HCN, which is known to be highly toxic, is volatile with a boiling point of 25.7°C (Nweke and Bokanga, 1994) and is also soluble in water (Oke, 1994). Liberation of free cyanide only occurs from tissues that are physically damaged by crushing or maceration during processing, indicating that the enzymes and the substrate are located in different compartments in the cell (White *et al.*, 1994). Information on the conditions required for such chemical and biochemical changes are important in enhancing HCN reduction during processing.

The lethal dose of cyanide was reported to be 0.5-3.5 mg HCN/kg body weight. The human body is able to detoxify as high as 100 mg of HCN in 24 hours by rapid conversion of cyanide to the much less toxic thiocyanate (Montgomery, 1980 *in* Bradbury,

1990). However, high levels of cyanide ingestion may cause acute cyanide intoxication, which particularly may occur in cassava-eating populations due to the consumption of food in which removal of HCN was insufficient during cooking. The predominant symptoms include nausea, vomiting, dizziness, weakness and sometimes collapse, which occasionally leads to death (Rosling, 1994). The conversion of cyanide to thiocyanate uses the sulfur-containing amino acids, cystein and methionine; hence, consumption of low protein foods, which is a common situation in cassava eating populations, would enhance the toxic effects (Rosling, 1994).

Table 3. Quality standard of cassava starch[1)] (SNI, 1994) and flour[2)] (SNI, 1996) in Indonesia.

Quality Standard	Starch/Tapioca			Cassava flour
	Quality I	Quality II	Quality III	
Water content (% w/w maximum)	15	15	15	12
Starch content (% w/w minimum)	-	-	-	75
Ash content (% w/w maximum)	0.6	0.6	0.6	1.5
Fiber and others (% w/w maximum)	0.6	0.6	0.6	4
Acidity (ml 1N NaOH/100 g, maximum)	3	3	3	3
HCN content (ppm, maximum)	-	-	-	40
Whiteness (%) ($BaSO_4$ = 100%)	min. 94.5	min. 92.0	< 92.0	min. 85
Viscosity (° Engler)	3 – 4	2.5 – 3	< 2.5	-
Smoothness (screening 80 mesh) (%)	-	-	-	min.90
Heavy metal *:				
- Pb (mg/kg, maximum)	1.0	1.0	1.0	1.0
- Cu (mg/kg, maximum)	10.0	10.0	10.0	10.0
- Zn (mg/kg, maximum)	40.0	40.0	40.0	40.0
- Hg (mg/kg, maximum)	0.05	0.05	0.05	0.05
- As* (mg/kg, maximum)	0.5	0.5	0.5	0.5
Microbial contaminants*:				
- Total plate count (colony/g, maximum)	1.0×10^6	1.0×10^6	1.0×10^6	1.0×10^6
- *E. coli* (APM/g)	10	10	10	< 3
- Yeast/fungi (colony/g, maximum)	1.0×10^4	1.0×10^4	1.0×10^4	1.0×10^4
Added chemicals (sodium bisulfite)	-	-	-	as standard SNI 010222-1995
Characteristic:				
- Odor	-	-	-	Specific
- Flavor	-	-	-	Specific
- Color	-	-	-	White
Other substances	-	-	-	None

w/w=weight/weight * used especially for food.
***Source**: 1) SNI, 1994,; 2) SNI, 1996.*

Thiocyanate has been observed to be a potential goitrogenic agent that may aggravate iodine deficiency, resulting in goiter, the enlargement of the thyroid gland, and cretinism, a severe form of mental retardation (Bokanga *et al.*, 1990). These conditions are not solely caused by an overload of thiocyanate in the human body due to long ingestion of cyanide, but are also caused by low intake of dietary iodine (Delange *et al.*, 1994).

Long-term ingestion of cyanide from cassava may also cause neurological disorders, such as tropical ataxic neurophathy, that usually occurs among adult males and results in an uncoordinated gait, called ataxic, as well as epidemic spartic paraparesis, a spastic paralysis of both legs that mainly affects women and children (Rosling, 1987 *in* Bradbury, 1990). Above facts show that cassava-related disorders are often related to food insecurity, agro-ecological crises and severe social economic circumstances. In addition, the safe limit has not been set for individual cyanogens that might be present in cassava products. HCN is always present in small amounts due to its volatility; hence, the presence of linamarin and its intermediate product, cyanohydrins, may further act as the main sources of dietary cyanide. Banea *et al.* (1995) found negligible amounts of HCN in the stiff porridge derived from cassava flour, whereas cyanogenic glucosides and cyanohydrins remained. Studies in animals showed that linamarin may break down, resulting in HCN in the gut if suitable glucosidases are present in the gut microflora. It can also be absorbed and excreted unchanged in the urine. Cyanohydrins yield cyanide rapidly in the alkaline environment found in the small intestine (Cook *et al.*, 1982, *in* Banea *et al.*, 1995). These cyanogens may also become toxic as well; hence, establishment of the safe levels for consumption of these cyanogens consumption seems to be warranted.

Table 4. Chemical and physical properties of cassava flour and two cassava-based composite flours.

Criteria	Cassava flour*	Cassava composite flour **	
		A	B
Water content (%)	11.11	9.91	10.28
Carbohydrate (%)	84.64	78.73	78.27
Protein (%)	1.65	9.08	8.89
Fat (%)	0.65	0.53	0.63
Ash (%)	1.50	1.75	1.93
Fibre (%)	1.63	-	-
Amylose (%)	22.68	23.51	23.14
Gel consistency (mm)	38.67	52.00	51.30
Water absorption value	172.78	89.13	103.12
Water dilution value	7.45	1.10	1.13

Note : A = 60% cassava flour + 20% mungbean flour + 20% wheat flour
B = 60% cassava flour + 20% pigeon pea flour + 20% wheat flour
Source : **) Marzempi, 1995; **) Richana dan Damardjati, 1990.*

The safe level for consumption of cassava products has been established as low as 10 mg HCN equivalent per kg dry weight by the Codex Alimentarius of FAO/WHO (1988) *in* Rosling (1994). This level would allow consumers to have an intake of 5 mg in 24 hours. However, Rosling (1988) as quoted in Lynam (1994) estimated that ingestion of 5-100 mg HCN per 24 hours was still safe even at low levels of protein intake, and ingestion of >100 mg can be detoxified under normal dietary intake by adult subjects. The upper level for cassava for breeding purposes was set at a level 30 times higher (100 mg HCN/kg fresh weight or approximately 300 mg HCN/kg dry weight) than the established safe level, probably taking into account the HCN removal during processing prior to consumption. This suggests that the set safe level may actually be too low, and a higher level as cut-off

point may need to be established. The safe level should be based on cyanide detoxification rates in humans with a necessary safety margin for natural toxins, degree of cyanide release from ingested cyanogens, expected daily consumption and degree of cyanogens removal during processing (Rosling, 1994).

Cyanide Pollution from the Starch Industry

Several processing techniques show different levels of cyanide reduction in cassava root products. Activities like crushing or physically damaging the root tissues, using large amounts of water and dehydration, which are normally involved during processing, result in the enzymetic break-down of the cyanogenic glucosides to cyanohydrins, followed by degradation of the cyanohydrins to HCN. HCN will readily disappear due to its volatility and rapid disolution in water (Nambisan and Sundaresam, 1985). According to Richana and Suarni (1990), soaking of peeled cassava roots in water (1:3 w/v) for 20 hours reduced the HCN content about 37%. This level was found to be higher (50%) for the bitter varieties relative to the sweet varieties (25%). Subsequent drying of the soaked roots to obtain *gaplek*, followed by milling into flour resulted in a still higher cyanide reduction level of 70%, and up to 81% for the bitter varieties. The HCN content found in *gaplek* and cassava flour was below 50 mg/kg (dry basis), suggesting that soaking and drying are efficient methods to reduce the HCN content. In addition, shredding of peeled cassava roots and subsequently pressing out the water with a hydraulic press reduced the HCN content by 33% (Suismono and Wibowo, 1991). These steps are performed during cassava flour preparation (**Figure 1**), particularly for the bitter varieties. Nambisan and Sundaresan (1985) also reported that crushing the fresh roots and subsequent sun-drying was the most effective method, which may reduce the HCN content by >95%. This is due to the efficient hydrolysis of the cyanogenic glucosides as maximum contact between the enzyme and the substrate is obtained.

In the processing of cassava fresh roots into starch (**Figure 1**), the HCN released from bitter cultivars is seemingly dissolved into the water. Unfortunately, up to the present the mode of action of HCN in the water is not clearly understood. Water pollution due to liquid and solid waste from the starch extraction industry is not merely caused by the release of the waste into the water ways, which leads to the rapid increase of biological and chemical oxygen demand (BOD and COD), but it seems that the release of large amounts of HCN into the rivers is also a problem. Measurements of HCN in the liquid waste pond as well as in the rivers nearby the factories revealed a level of 0.025 ppm. As mentioned previously, 5 million tonnes of fresh cassava roots are processed for starch in Indonesia yearly, and bitter cultivars having >100 ppm HCN are generally preferred. The water required for starch extraction is about 40 billion liters, and the HCN liberation into free water is about 500 tonnes yearly. It is a serious problem which justifies further research. There is a possibility to use HCN as a phyto-chemical insecticides. Bellotti and Riis (1994) reported the effectiveness of the use of HCN to control insect pests in the crop. It may be useful to initiate applied research on integrated pest management oriented towards a more sustainable approach. However, if HCN can not be used as a phyto-chemical, in order to avoid the high levels of HCN in waste water and the pollution of rivers and ponds, research in crop genetic improvement to develop cassava varieties with low levels of HCN should be conducted urgently.

DEMAND FOR BIOFUEL

The price of fossil fuel has recently increased dramatically due to rapid increases in demand and the limitation of oil reserves. In attempts to provide renewable fuel that is more ecologically friendly, the use of ethanol to partially replace gasoline is considered appropriate. In the early eighties (1982) an ethanol plant using cassava was established in Lampung in order to anticipate the future limited availability of fossil fuel. During the Dutch colonial period ethanol was produced from molasses (sugarcane), and several ethanol plants were established in East Java. Considering the experience from some developed countries that up to 85% of gasoline can be replaced by ethanol, Indonesia has started to use a blend of 5% ethanol with 95% gasoline. Indeed the government has a target to use 10% ethanol to produce "gasohol" (blend of gasoline and ethanol). Unfortunately the capacities of the existing ethanol plants are still low. Although in several areas of Java small- to medium-scale ethanol plants have been established, the ethanol produced is hydrous alcohol with 95% ethanol, which is not suitable as fuel-ethanol; to be suitable the hydrous alcohol needs to be further dehydrated until the ethanol content is 99.5%. The most serious problem is in providing sufficient raw material from cassava as well as from molasses. This phenomenon is similar to that faced by China and Korea in their ethanol plants, which also have difficulties in supplying the raw material. For that reason, both countries are importing *gaplek* from Indonesia. This is affecting the price of fresh cassava which has increased significantly, as there is competition for raw material between the starch industry and ethanol plants, as well as the fresh market and for feedstuff.

Table 5. Chemical composition and conversion rates of cassava into ethanol

Cassava cultivars	Root dry matter content (%)	Total sugar content (% wet basis)	Starch content (% dry basis)	Conversion into ethanol (kg fresh roots/liter)[1)]
Adira-4	39.51	40.93	80.31	5.20
Malang-6	43.07	39.12	80.46	5.51
UJ-3	41.34	36.22	79.57	5.43
UJ-5	46.31	43.47	80.24	5.52

[1)] Ethanol content 96% (distillation efficiency assumed 95%)
Source: *Ginting et al., 2006.*

Compared to the starch industry, the ethanol plants are more ecologically friendly, because there is no liberation of HCN to open water ways such as from some starch factories. The amount of water required for ethanol processing is less than for starch extraction processing, so the pollution consequence is smaller, especially if the solid waste is used for animal feed. Yudiarto (2007) has recommended small-scale ethanol processing at the household level using 50 kg cassava roots with a starch content of 28% to produce 7.5 l ethanol. The procedures is as follows:

1. 50 kg of cassava roots are peeled, washed and meshed and put into a drum, adding 40-50 l of water followed by boiling.
2. Add 1.5 ml α–amylase enzyme and keep the temperature at 90°C for 30 minutes.
3. Bring to boiling at 100°C for 30-60 minutes, and then cool down to a temperature of 55-60°C.

4. Add 0.9 ml gluco-amylase enzyme, and maintain the temperature at 55-60°C during three hours.
5. Cool down to <35°C, then add 1 g yeast, 65 g urea and 14 g NPK. Let the fermentation process continue for 72 hours in the closed drum, but allow the release of carbon dioxide. The success of the fermentation process can be detected from the aroma of fermented cassava as well as the bubbling of CO_2 gas released and the pH level >4.
6. Move the liquid containing 7-9% ethanol to the evaporator drum.
7. Heat the evaporator drum until vapor produced enters the still. Then, condense the vapor into liquid by running cooling water through the outside mantle of the still.
8. Keep the temperature at the upper part of the still 79°C until liquid ethanol comes out from the bottom. The temperature can be controlled by adjusting the heating source or the reflux water in the still.
9. The liquid containing 90-95% ethanol will flow out gradually from the still.
10. Remove the liquid waste from the drum through an outlet. Both the liquid and solid waste can be used as feed for animals (goats, cows etc).

In the past the starch industry tended to build ever larger factories that ultimately resulted in many problems, such as the sustainability of raw material supply as well as pollution of the environment from waste. Therefore, for ethanol production the industry is considering to operate at small- to medium-scale rather than at large-scale. Large scale factories will purify this to high-quality fuel-grade ethanol with 99.7% ethanol that small- and medium-scale factories cannot reach. So, there are many opportunities for rural communities to gain a better income. The potential of cassava to be converted to bio-fuel is in line with the Millennium Development Goals (MDGs), particularly goal one, that is to reduce poverty and to alleviate hunger.

Second generation ethanol production that will utilize the solid waste from starch factories seems an appropriate way to reduce the problem of raw material competition. Thus, the solid waste, consisting of fiber (lignin, cellulose and hemicelluloses) and starch will be broken down into glucose through a delignification process. Although at the laboratory level this second generation ethanol has been successfully produced, to implement its production at an economic scale needs much further research and development (Soerawidjaya, 2008).

In East Nusa Tenggara province there exist a traditional technology for producing ethanol using the liquid substance generated from sugar palm (*Arenga pinnata*). The liquid is then fermented and distilled to produce flame-able ethanol of 60-70% purity. This indigenous knowledge should be taken into consideration by investors with interests to use cassava or other raw materials for ethanol production. In some of those areas, aside from sugar palm and cassava, farmers also grow sorghum but with insufficient management. Planting cassava and sorghum without soil tillage, no fertilizer application and no weeding, results in very low productivity. Indeed those three crops – sugar palm, cassava and sorghum – can all be utilized as sources of food, feed and energy while conserving the environment and the traditional landscape of sugar palm trees in the tropics.

Cultivation Progress

Although in early cassava experiments fertilizers were used and recommended, during the Dutch colonial period there are no reports indicating that farmers were informed about fertilizer use for cassava. This is probably so because during that period chemical fertilizers were not readily available. Fortunately, organic fertilizers were available, both animal and green manures. The farmers' habit continued this traditional practice until the early sixties. As a result of the green revolution, in which fertilizer application was promoted to support the potential of the new high-yielding varieties of cereals (particularly rice), cassava farmers also started using chemical fertilizers, at least as a source of N (urea and/or ammonium sulfate) to obtain better crop growth and yield. Based on research results about fertilizer application for cassava it was recommended that for every 1 t of fresh roots farmers should apply 2.3 kg N, 0.5 kg P, 4.1 kg K and 0.6 kg Ca (Veltkamp and de Bruijn, 1996); however, in general farmers apply only N. The reason for this is that the application of N has a distinct and direct effect on the color of leaves, which become a darker green color accompanied by more rapid top growth. The effect of other nutrients is slower and farmers cannot wait until the harvest to know the real effect on root production. A Field School on integrated cassava crop and resource management held in several districts of East Java, showed that better and significant yield increases could be obtained by applying a compound fertilizer such as Ponska (N-P_2O_5-K_2O-S = 15:15:15:10).

Compared with most other food crops, cassava has a longer growth duration. For this reason, farmers in general do not plant cassava in monoculture, but tend to practice intercropping with other crops, like cereals, legumes, chili pepper etc. Intercropping of cassava is widely practiced by farmers, in South America, Asia as well as in Africa. It seems that intercropping cassava is a practice that was not developed by research institutes or universities, but was initiated from indigenous knowledge. Research institutes and universities then improved the existing cassava intercropping systems using more quantitative methodologies (Leihner, 1985). Up to three cycles of intercrops can be planted during one growth cycle of cassava, of around one year. The first intercrop, usually upland rice or maize, is planted together with cassava. After the first companion crop is harvested, a second crop is planted between cassava rows. A third crop can possibly be inserted, if rainfall is adequate and space between the rows of cassava is wide enough. Besides cassava row arrangement, the lower leaves of cassava could be removed to increase light interception for the intercrop (Widodo, 2005).

The cassava plant population under intercropping can be the same as under monocropping by adjusting the planting arrangement. Using more appropriate crop and resource management practices, the yield of cassava under intercropping was not significantly different from that under monocropping. For instance, adequate soil tillage and weeding after the harvest of the first intercrop is necessary. Fertilizer application under intercropping must be based on the nutrient requirements of each crop in order to prevent competition for nutrients between the crops. In upland areas of East Java the rainy season is only about six months and the cassava population is kept below 10,000 plants/ha, similar as in monoculture. Intercropping cassava with maize at a population of 80% of monoculture maize is often practiced. After the maize harvest, cassava is managed like any cassava monoculture crop.

Intercropping cassava is mainly practiced by farmers in Java and Lampung as well as in transmigration areas where Javanese have settled. On the other hand, where cassava is planted in large-scale plantations for fulfilling the raw material needs of starch factories, cassava is planted only in monoculture. Although intercropping is generally recognized as being economically more profitable and technically feasible, in large-scale cassava plantations farmers prefer to cultivate cassava in monoculture. The reason is that intercropping requires more labor and is considered more complicated, so cassava intercropping at large-scale is not always feasible.

Because of the need to supply the daily demand of raw material to the starch factories in the form of fresh roots, the factories promote the planting and harvesting of cassava year-round. For that reason, large cassava plantations are found mainly in the humid tropics with adequate rainfall for at least nine months. Unlike cassava in small farmers' fields, in large plantations soil tillage, i.e. plowing, harrowing and ridging is done by tractor. The sustainability of large-scale cassava plantations depends on the level and stability of crop and resource management. In Musi Banyuasin in South Sumatra which was started in 1980, a cassava plantation in an area of around 2500 ha could not be sustained due to many complicated factors. Heavy rainfall (>3000 mm/year) in an undulating area induced severe soil erosion, while a decreasing pH (4.2-4.8) and nutrient depletion were serious problems, which prevented the maintenance of high yield levels above 30 t/ha of fresh roots. Poor growth of cassava during the early stages of crop development, triggered excessive weed growth, especially *Axonopus sp.*, *Boreria sp.* and *Mikania sp.*, which competed with cassava for light and nutrients. After about 20 years the plantation was not able to supply the demand of the factory. Moreover, the market demand for starch is growing progressively. A similar decline in productivity in large-scale cassava plantations was also experienced in Lampung and in North Sumatra. For that reason, a partnership between the factory and farmers in the form of nucleus estate smallholders (NES) was developed, in the cassava starch industry.

Expansion of the Cassava Growing Area

In order to meet the increasing demand for cassava, in 2007 the government decided to expand the cassava harvested area by 850,000 ha, distributed in various districts throughout those provinces with conditions for the establishment of cassava. Unfortunately, of the target of 850,000 ha less than 10% or 57,000 ha could be achieved. The main problems relate to the shortage of planting material, and also poor infrastructure (access roads) for distributing the planting material and inputs. Unlike crops using sexual seed for multiplication, in cassava the multiplication rate is not as quick as in cereals and legumes. Therefore, the expansion of cassava into new areas requires more time, and it is more costly to establish plantations in large areas.

The raw material requirement of the large-scale cassava starch factories varies from 600 up to 2,000 t of fresh roots daily. This large amount is difficult to supply, except during the peak harvest period. Consequently, in the outer islands (outside of Java), the cassava starch factories are mainly supplied by large cassava plantations, where continuous planting is practiced to maintain the daily raw material supply. In Sumatra, Kalimantan and Sulawesi, cassava plantations have been established in previously forested areas. This fact is now strongly opposed by environmental groups. Since 1998 there has been an euphoria of freedom, called the "reformation", which had a detrimental effect on forests.

Many forested areas were occupied by people who converted it into agricultural land for growing food crops, especially cassava. In many forested areas of Java cassava was planted intercropped with upland rice, maize, or groundnut. The crop's low input requirement as well as its high adaptability to grow in marginal environments encouraged farmers to plant cassava. Although the price was low, it was still economically profitable according to poor farmers. To conserve the forest as an important global resource, it is not recommended to grow cassava in forest areas where the slope is >30%. Only by practicing alley cropping systems in sloping and undulating areas, soil erosion can be prevented or at least reduced to acceptable levels.

Aside from Java and Sumatra, arable land in Kalimantan, Sulawesi, Nusa Tenggara, Maluku and Papua have been visited by investors to determine the possibility of cassava development in order to meet the huge demand for the food, feed, starch and ethanol industries. Unfortunately, due to poor road access and lack of other infrastructure facilities as well as labor scarcity, most foreign and domestic (from Java and Lampung) investors hesitate to open new cassava areas in the eastern parts of Indonesia. In addition, there is a large effort under way to increase cassava production in Java and Lampung to meet the increase in domestic demand and from abroad, especially from China and Korea, which like to import *gaplek* for ethanol production. That was the main reason to revitalize the Mukibat system (**Table 6**). Starting about five years ago, the Mukibat system was resurrected and disseminated in many districts of Java and Lampung in order to meet the huge demand for cassava roots.

Table 6. Advantages and disadvantage of Mukibat and ordinary cassava (based on field observation 2007/08).

Items	Mukibat	Ordinary cassava
Multiplication rate	1:1*	1:10
Spacing (cmxcm)	200x150	100x100
Population	3,300	10,000
Cost (of each seedling in Rp)	1,000	125
Land preparation	Mound	Flat, ridge or mound
Intercropping	Only able to intercrop with one crop due to heavy shading from cassava plants	Arranged in double rows permit 2-3 associated crops
Replanting risk (%)	>30, broken due to wind, failure of grafting union, termites etc.	<8, due to poor cutting quality, time lag from harvest till planting, erratic rainfall etc
Organic fertilizer requirement (t/ha)	≥5 kg/plant (15-20 t/ha)	Applied if available
Cost of production (Rp/ha)	15,000,000	5,200,000
Yield level (t/ha)	>80	15-40
Cost/kg fresh root (Rp/kg)	187.5	130-347

*After harvest the Mukibat graft can be used again as planting material, this is called *randan* meaning 'widow'. This "widow" graft can be reused 1-4 times. The highest yield is obtained from the first widow planting (risk <5%); US$ 1.0 = Rp 9,230.

The large-scale implementation of the Mukibat system is being evaluated for its technical and economic feasibility by farmers. From experiments conducted by Brawijaya University from 1974 to 1984, it was concluded that the Mukibat system had many advantages; however, most cassava farmers think that it is very laborious. With insufficient nutrient application (organic manure especially), and planting in shallow soil, the yield of Mukibat cassava is comparable to that of ordinary cassava, but the risk is higher for the Mukibat system. Farmers in Banyuwangi, in one of the eastern districts of East Java, due to the high demand of cassava as a snack food in Bali, prefer the Mukibat system as the best way to sustain their supply. In these areas, a sweet and yellow-fleshed local variety is used as the rootstock and *Manihot glaziovii* as the scion. This system is widely used by farmers for more then 15 years without any support from the government or investors. In Pacitan, a southwest district of East Java, and Wonogiri, a southeastern district of Central Java, investors from China as well as domestic developers have promoted the use of Mukibat in large areas designated for ethanol production or for export as *gaplek* to an ethanol plant in Guangxi, China.

Using good quality cuttings from the new high-yielding cultivars is one of the best ways to achieve higher productivity. To earn additional cash income, farmers do not necessarily need to expand the harvested area. Proper soil tillage, the use of organic and inorganic fertilizers to prevent soil nutrient exhaustion by nutrient removal in the roots of the previous harvests is very important. Maintaining a cassava plant population at 10,000/ha, similar to that used in monoculture, but with a plant arrangement of 200 cm between rows and 50 cm between plants in the row provides space for twice planting of intercrops. This kind of intensive management can be practiced by farmers and prevents the forest area from being destroyed by illegal logging.

New High Yielding Varieties

Widodo (1995) suggested the need to develop high-yielding sweet, low HCN cassava cultivars in order to provide safer food for the people that use cassava as a staple food and simultaneously reduce the pollution by the release of toxic waste from cassava into the environment. About 463 cassava cultivars have been collected in Indonesia, which include local and newly released varieties as well as breeding lines (Antarlina and Harnowo, 1992). Since in Indonesia a high proportion of cassava is used for human consumption and a smaller part is used for industrial purposes, most farmers grow local, mainly sweet, varieties, which also have good taste and cooking quality characteristics, even though the potential yield is relatively low. In cassava producing areas, such as South Malang, about 48% of farmers grew local varieties, mostly sweet varieties, such as Randu, Putih, Tapak Lumut, Mantel, Sumatra, for direct consumption, 33% grew improved varieties, mostly bitter varieties, such as Sembung or Faroka for *gaplek* and starch preparation, and 19% of farmers planted both types of varieties (Ginting *et al.*, 1993). This shows a need for the availability of improved varieties with high yield potential, low cyanide content and good cooking quality.

A level of 100 mg HCN-equivalent per kg fresh roots has been used as an upper limit for low cyanide varieties in breeding programs since 1954 (Hahn, 1985, *in* Rosling, 1994). Regarding improved varieties that have been released in Indonesia from 1978 till 2002, some of these have high yield potential with low cyanide content (<50 mg/kg), such as Darul Hidayah, Malang 1 and Malang 2 (**Table 7**), while the rest have relatively high cyanide contents. Since 1997, studies on breeding and selection of cassava cultivars for high yield

potential (>35 t/ha) as well as good taste and cooking quality and with an HCN content below the level found in Adira 1 (27.5 mg/kg) have been pursued at ILETRI. Currently, about ten cassava clones have been selected (Ginting *et al.*, 1999; Sundari *et al.*, 2000; Hartojo *et al.*, 2000) that meet above criteria, and these will be further developed and ultimately released after passing a series of stability and adaptability tests.

Table 7. Improved cassava cultivars released in Indonesia from 1978 to 2002.

Variety	Year of release	Yield potential (t/ha)	Starch content (%)	HCN content (mg/kg fresh roots)
Adira 1[1]	1978	22	29.50	27
Adira 2[1]	1978	22	25.00	124
Adira 4[1]	1987	35	27.25	68
Malang 1[1]	1992	36.5	26.30	<40
Malang 2[1]	1992	31.5	25.75	<40
Darul Hidayah[2]	1998	102.1	21.50	<40
UJ-3[2]	2000	25-38	26.00	>100
UJ-5[2]	2001	39.7	27.00	>100
Malang 4[3]	2001	36.4	26.50	>100
Malang 6[3]	2001	38.5	25.50	>100

Source: *[1] Anonymous, 1993; [2] Anonymous, 2000; [3] Anonymous, 2002*

Different levels of cyanogenic glucosides are naturally present in cassava cultivars and different processing methods can have different effects on cyanide reduction. To guarantee food safety, it is highly recommended to be careful in the choice of cassava cultivars and to utilize effective processing methods for the preparation of a particular product. Cassava food products (mostly snacks) obtained through boiling, steaming or frying should be derived from cassava cultivars with HCN content <50 mg/kg as cyanogens can not be completely removed through such processing methods. This is particularly important for many traditional food processors who normally prepare snacks from cassava. They sometimes find it difficult to obtain sufficient raw materials of fresh cassava with low cyanide content due to seasonal availability in the markets. Using cultivars with relatively high cyanide content and processing these with normal processing methods could result in cassava toxicity, ranging from the milder forms to severe ones. Hence, awareness and knowledge on effective processing methods, such as soaking the peeled roots overnight and changing the soak water several times prior to cooking as well as discarding the boiling water, are very essential.

Conversely, cassava cultivars with relatively high cyanide content can be used for the preparation of *gaplek*, starch and flour as a combination of soaking, slicing/shredding, pressing and sun-drying is performed, which are known to be very effective in reducing the cyanide content, as discussed previously. The national standard requirement for *gaplek* flour and cassava flour was set at a maximum level of 50 mg and 40 mg HCN per kg fresh roots, respectively, while there is no maximum standard level for starch (Purwadaria, 1989;

SNI, 1991; SNI, 1992). Through processing steps shown in **Figure 1**, lower levels of HCN relative to the set maximum level can normally be achieved.

The starch industry is not so dependently on the quality of the fresh cassava roots used as raw material, especially as related to HCN content. But since the starch extraction process will liberate HCN from the fresh roots into the waste water, which may cause pollution of rivers and ponds, low-HCN varieties are recommended for use as raw material.

Minimizing Waste for a Better Environment

Following the green revolution approach, productivity and production increases are important goals, but many problems may be encountered at this stage, so called "first generation" problems. Subsequently, after these problems have surfaced efforts are made to minimize yield losses by improving processing, storage and distribution; these are called "second generation" problems. Unfortunately, attempts to alleviate the first and second generation problems resulted in detrimental effects of pollution of the environment. These "third generation" problems need to be tackled immediately, because the need for a clean and healthy environment is crucial, not only for the present but also for future generations. It means that in attempts to optimize the starch extraction processes by using large amounts of water, the third generation problems should be tackled using a holistic and integrative approach.

Several new high-yielding and high-starch cultivars have been developed, but due to the existing practice of optimizing the efficiency of starch extraction, this may have resulted in environmental problems. Widodo *et al.* (2002) reported that the age of plants at harvest is one of the determinant factors to achieve a high starch content and reduce wastes. When the price of cassava is high, due to lack of supply, a young crop of <8 months old is sometimes harvested to meet the high demand. In fact, this practice will increase the water requirement for starch extraction, and simultaneously produces more liquid as well as solid wastes. From research results we know that waste water could be reduced and re-used for further processing, but this is expensive and too sophisticated, so this is seldom practiced, either in small- or large-scale factories. Several large-scale starch factories were equipped with waste water treatment ponds, but these facilities are more like monumental showrooms, which are operated only during the visits of guests or policy makers, while in the daily operation waste water is directly released to the river or large ponds without any treatment. At the national level, the processing of 5 millions tonnes of cassava requires 40 millions m^3 of fresh water which will be converted into waste water. This amount of water could fill an irrigation channel of 40,000 km length and 1 m width to a depth of 1m.

It seems that in both small- and medium-scale starch factories the management of waste water would be easier. In Ngadiluwih as well as in Mojo Kediri, waste water from starch extraction is used for irrigating and fertilizing crops such as papaya, sugarcane, cassava, maize, peanut, and even rice. According to farmers the use of liquid waste from cassava starch extraction was able to reduce the use of inorganic fertilizer. This practice is especially useful during the dry season when there is a water shortage for irrigation. The large-scale starch factories could do the same by providing mobile tanks for distribution of waste water to dry areas.

Waste Utilization from the Starch Industry

The characteristic bad smell surrounding cassava starch factories is an indication of air pollution, whether from small-, medium- or large-scale factories. This smell is a problem particularly for people who are not familiar with the starch industry. Fortunately, the permanent residents in the area generally do not care about the smell. In Ponorogo, in an area near a large-scale starch factory, people living 1.5 km from the factory complained about the smell and water pollution. Street demonstrations were undertaken to stop the operation of the factory. On the other hand, farmers and cassava traders were not allowed to stop. The factory must continue, because cassava fresh roots need to be processed. To solve this conflict, Widodo and Hartojo (2000) proposed to compromise by processing the waste into useful by-products.

The bad smell is mainly due to the formation of butyric acid and other organic acids. In fact, citric acid can be produced by inducing the fermentation process of solid waste (pulp). Furthermore, after the solid waste is removed, the citric acid produced can be used as the substrate for single cell protein which is a nutritious feed. Widodo and Hartojo (2000) proposed that the solid waste, particularly the peel and neck of the roots could be inoculated with chicken or cattle manure, or with urea or ammonium sulfate to be processed into organic fertilizer (**Table 8**). Improving the existing cassava starch industry into being more ecologically responsible is an important objective. By integrating the cassava starch industry with animal husbandry as well as various other enterprises, it is possible to create more employment opportunities and generate more income (Widodo, 1986; 1996). To use waste and other biomass from cassava as second-generation feedstock for production of ethanol needs to be further studied, and ultimately the waste from ethanol production can be used for animal feed. Biogas is an inexpensive source of energy, generated by fermentation of animal manure, which can help the community. Ultimately, the animal manure, after its biogas liberation, can be utilized as a source of fertilizer to sustain the cassava production system.

Table 8. Effect of the application of various organic fertilizers produced from solid waste of cassava starch processing from a large-scale factory after five weeks of decomposition in Ponorogo in 2000 on soil fertility parameters.

Treatments	C org (%)	N (%)	C/N	pH	P (%)	K (%)
Check (no treatment)[1)]	10.43	0.40	26.07	7.39	0.15	0.64
Added EM-4 100 cc/l water	8.63	0.45	19.18	7.12	0.09	0.48
Added Urea 5%	7.72	0.65	11.87	6.50	0.22	0.48
Added Ammonium Sulfate 5%	8.03	0.85	9.45	5.70	0.14	0.48
Added cattle manure 50%	8.95	0.70	12.78	6.85	0.12	1.06
Added chicken manure 50%	8.24	0.65	12.67	6.70	0.26	6.27

[1)] Before the treatment: C organic =15.74%; N = 0.28%; pH = 7.4; each treatment box contained 10 kg waste + additives; EM-4 = Effective Micro-organism as a source of liquid bio-fertilizer

SUMMARY AND CONCLUSIONS

Based on the historical facts of cassava development in Indonesia after about four centuries of cultivation and utilization, several conclusions can be drawn:

1. In the beginning the objective of cassava cultivation was to earn foreign exchange by exporting cassava to Europe for production of animal feed. Fresh roots, which are characterized by being a voluminous and perishable product, requires immediate conversion to a dried form (such as *gaplek*) to avoid its rapid deterioration; this is also a simple way to prepare the material for export.
2. Utilization of cassava from fresh roots or dried *gaplek* and starch, triggered by food scarcity conditions, promoted the spontaneous development of various local food products. The increase in domestic demand, mostly for direct consumption and food-related industries, was able to absorb the increased supply and even required the importation of some products to supplement the supply.
3. Cassava starch processing is one way to convert cassava fresh roots into a value-added intermediate product, which can be further processed into various final products. The starch industry requires a lot of water and often releases HCN into waste water, and ultimately into rivers. The existing traditional technology is not ecologically friendly, and results in complaints from the local community around the processing plant.
4. Bio-ethanol can be produced from fresh or dry cassava. The current level of production of fresh cassava has been completely allocated for specific usages, and any increase of cassava production can be directed to supplying the raw material of small- to medium-size ethanol plants by also incorporating other raw materials, such as from sugar palm, sorghum etc..
5. Second generation ethanol production can use the waste of starch factories, but this will need to be integrated with animal husbandry to reduce raw material competition and to create a better and healthier environment without major pollution.

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CURRENT SITUATION OF CASSAVA IN VIETNAM

Hoang Kim[1], Nguyen Van Bo[2], Hoang Long [3], Nguyen Trong Hien[2], Hernan Ceballos [4] and Reinhardt Howeler[5]

ABSTRACT

In 2008 cassava production in Vietnam was about 9.40 million tonnes, up from only 1.99 million tonnes in 2000. This was the result of both area expansion, from 237,600 ha to 555,700 ha, and marked increases in yield, from 8.36 t/ha in 2000 to 16.91 t/ha in 2008. Vietnam has made the fastest progress in the application of new technologies in breeding and new variety propagation in Asia. This progress has been achieved as a result of many factors, of which the success in breeding and application of new technologies were the main contributing factors. Cassava yields and production in several provinces have more than doubled due to the planting of new high-yielding cassava varieties in about 500,000 ha, mainly KM94, KM140, KM98-5, KM98-1, SM937-26 and KM98-7 varieties, and the adoption of more sustainable production practices. Cassava chips and starch are now being produced competitively, and cassava markets are promising. The combination of widespread production of fresh cassava roots and the processing of cassava into chips, starch and ethanol has created many jobs, has increased exports, attracted foreign investment, and contributed to industrialization and modernization of several rural areas.

Key words: cassava, Vietnam.

INTRODUCTION

Cassava production in Vietnam was about 9.40 million tonnes in 2008, up from only 1.99 million tonnes in 2000. This was the result of both area expansion, from 237,600 ha to 556,000 ha, and marked increases in yield, from 8.36 t/ha in 2000 to 16.91 t/ha in 2008. Cassava is now an important source of cash income for small farmers. The situation has changed because of the development and adoption of more sustainable cultivation techniques and new high-yielding varieties, as well as the rapidly growing market demand. Cassava has become a cash crop in many provinces and cassava markets are promising for export of cassava chips to China.

Vietnam has made the fastest progress in the application of new technologies in breeding and new cultivar propagation in Asia. Such progress has been considered as a result of many factors, of which the success in breeding and application of new technologies were the main contributing factors. The combination of widespread production of fresh cassava roots and the processing of cassava into chips, starch and ethanol has created many jobs, has increased exports, attracted foreign investments and contributed to industrialization and modernization of several rural areas. The Ministry of Agriculture and Rural Development (MARD) has planned to maintain the cassava area

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around 450,000 hectares from 2011-2015, and efforts are being made to increase the fresh root yields from 16.90 to 20 t/ha in 2011 and to 23-24 t/ha in 2015 by using new technologies, especially in breeding (MARD 7256/TB-BNN-VP 25 12 2009).

To meet the rising demand for cassava roots we have carried out a study on the development of high yield and good quality cassava cultivars for different ecological zones in the whole country, in collaboration with the Vietnam Academy of Agricultural Sciences (VAAS) and Nong Lam University (NLU), and with the International Center for Tropical Agriculture (CIAT), linking the poor to global markets of the IFAD/ICRISAT Project "Harnessing water-use efficient bio-energy crops for enhancing livehood opportunities of smallhoder farmers in Asia, Africa and Latin America". This paper describes the current situation of cassava in Vietnam and its potential as a bio-fuel, while Hoang Kim *et al.*, (2010) describes the progress made in cassava breeding and selection of new cultivars.

CURRENT SITUATION OF CASSAVA IN VIETNAM AND ITS POTENTIAL AS A BIO-FUEL

1. A New Future of Cassava for Food, Feed and Bio-fuel

Cassava (*Manihot esculenta* Crantz) ranks as the world's fifth most important food crop, after maize, rice, wheat and potato. Cassava originated in South America and was later introduced to Africa and Asia. The crop is now being cultivated in 105 countries in a range from 30°N to 30°S. This crop is a staple food crop for many poor farm families around the world. It is also a source of on-farm and commercial animal feed, as well as starch for the food, candy, alcohol, noodle and pharmaceutical industries (**Figure 1**).

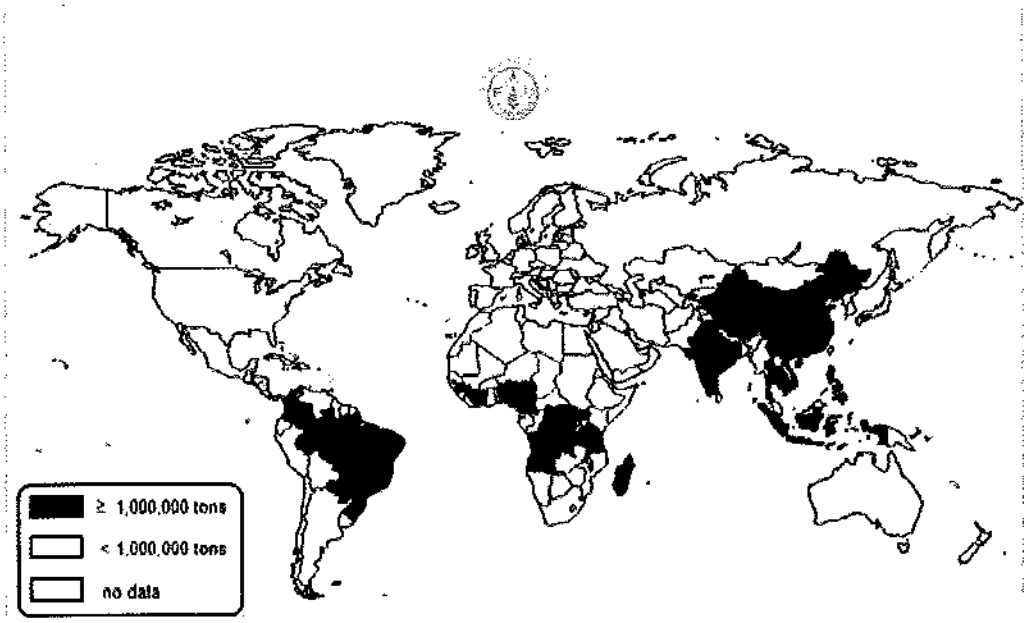

Figure 1. Cassava production in the different countries in the world in 2008.
***Source**: FAO 2010 adapted by Hoang Long*

Global production of cassava was around 232.95 million tonnes in 2008 (**Table 1**) and about 51% of that was produced in Africa, 34% in Asia and only 15% in Latin America and the Caribbean (LAC). Cassava production in Asia increased at a high rate of 3% annually during the late 1970s and early 80s, slowed down during the 90s and has been growing quite rapidly again at 3.3% per year during the past ten years (Howeler and Fahrney, 2008).

Table 1. Area, yield and production of principle food crops in the world and in Vietnam in 2008.

	In the World			Vietnam		
Food crops	Area (million ha)	Yield (t/ha)	Production (million tonnes)	Area (million ha)	Yield (t/ha)	Production (million tonnes)
Maize	161.01	5.10	822.71	1.12	4.02	4.53
Rice	158.95	4.30	685.01	7.41	5.22	38.72
Wheat	223.56	3.07	689.94	-	-	-
Potato	18.19	17.26	314.14	-	-	-
Cassava	**18.69**	**12.46**	**232.95**	**0.56**	**16.90**	**9.40**
Barley	56.77	2.77	157.64	-	-	-
Sweet Potato	8.17	13.47	110.12	0.16	8.16	1.32
Sorghum	44.91	1.46	65.53	-	-	-
Yam	4.92	10.49	51.73	-	-	-
Millets	37.40	0.95	35.65	-	-	-
Oats	11.33	2.27	23.10	-	-	-
Rye	6.77	2.62	13.26	-	-	-

Source: FAOSTAT 2010, calculated by Hoang Long

Impact simulations indicate that root and tuber crops will play economically important and increasingly diversified roles in developing country food systems over the next decades (Scott *et al.*, 2000). Cassava has one of the highest rates of CO_2 fixation and sucrose synthesis for any C3 plant. It is a dry-land crop and has a high water use efficiency. It is also a suitable feedstock for ethanol production across much of Asia, Africa and Latin America. Bio-fuels are gaining importance ever since fossil fuel prices began skyrocketing due to geo-political issues, and also because of growing concerns about environmental pollution. Considering these issues, various developed and developing countries are formulating policies for mandatory blending of ethanol and bio-diesel (produced from various oil crops) with gasoline and diesel, respectively. This has resulted in a huge demand for the raw materials used for producing these bio-fuels. In China, Nigeria, Thailand, Indonesia, Vietnam, Philippines and Cambodia cassava is seen as the most suitable crop to use for the production of fuel-ethanol.

Cassava is also the third most important food crop in Vietnam (**Table 2**) and is a water-use efficient bio-energy crop. Cassava has become an important source of cash income to small farmers. Cassava chips and starch are being produced competitively.

Table 2. Area, yield and production of principle food crops in Vietnam 1995- 2008.

Crop		1995	2000	2005	2006	2007	2008
Rice	Area ('000 ha)	6,766	7,666	7,326	7,324	7,305	7,414
	Yield (t/ha)	3.68	4.24	4.88	4.89	4.86	5.22
	Production ('000 t)	24,963	32,529	35,790	35,826	35,560	38,720
Maize	Area ('000 ha)	556	730	995	1.031	1.150	1.125
	Yield (t/ha)	2.11	2.74	3.51	3.70	3.75	4.02
	Production ('000 t)	1,177	2,006	3,500	3,819	4,310	4,530
Cassava	Area ('000 ha)	277	238	426	475	496	556
	Yield (t/ha)	7.97	8.36	15.78	16.37	16.53	16.91
	Production ('000 t)	2,211	1,986	6,716	7,783	8,193	9,396
Sweet potato	Area ('000 ha)	304	254	205	181	180	162
	Yield (t/ha)	5.53	6.33	7.56	8.00	8.05	8.16
	Production ('000 t)	1,685	1,611	1,550	1,454	1,450	1,320

***Source**: FAOSTAT 2010, calculated by Hoang Long.*

China imports annually about 500,000 tonnes of cassava starch, and 3.5 million tonnes of cassava dry chips, equivalent to about 12 million tonnes of fresh roots; this is 1.5 times the current Chinese annual cassava production (Tian Yinong, 2010; Li Kaimian *et al.*, 2010). Continued improvements, such as the development of better cassava varieties and agronomic practices, are expected to increase the yield of the crop. Moreover, an additional 670,000 hectares of hillside waste lands in Guangxi are suitable for growing the crop, adding to the existing 270,000 hectares of cassava. The region will also be able to obtain a stable supply of cassava, mainly from Thailand, Vietnam and other neighboring producer countries.

Vietnam has recently developed an E10 policy which will require the production of 100 to 150 million liters per year. The Prime Minister has approved "the scheme on bio-fuel development to 2015 and the vision to 2025", which aims to produce bio-fuels and partly replace traditional fuels. This will contribute to energy security and environmental protection. PetroVietnam plans to build three cassava-based ethanol plants in the northern (Phu Tho), central (Quang Ngai) and southern part of Vietnam (Binh Phuoc). Each plant will cost $80 million and will use cassava as the feedstock. They are expected to open in 18 months (in 2011) with a total annual capacity of 300 million liters per year. The combination of widespread production of fresh cassava roots and the processing of cassava into chips, starch and ethanol has created many jobs, has increased exports, attracted foreign investment, and contributed to industrialization and modernization of several rural areas.

2. Current Production and Use of Cassava in Vietnam

In Vietnam about 66% of cassava is grown on Utisols, 17% on Inceptisols, 7% on Oxisols, 4% on Alfisols, 2% on Entisols and 3% on Vertisols (Howeler, 1992). The soil pH generally varies from 4.5 to 6.0. In North Vietnam, cassava is grown mainly in areas with hilly topography and about 68% of the cassava growing area has a rocky soil while 12% have sandy soils, respectively (Pham Van Bien *et al.*, 1996). In South Vietnam cassava is grown mainly on sandy-grey soils, which tend to be flat and poor in nutrients. The Central

Coastal and the Southeastern regions, account for about 60% of the total cassava area of the South. More than 30% of cassava is grown in the Central Highlands and in Dong Nai and Binh Phuoc provinces of the Southeastern region on red yellow soils with a hilly topography. Due to these marked differences in cassava soil characteristics (**Figure 2, Figure 3, Figure 4, Figure 5, Figure 6**), research in the north should concentrate on erosion problems and soil fertility enhancement, whereas in the south research on cassava should focus on variety improvement, soil fertility enhancement and soil conservation by using intercropping systems.

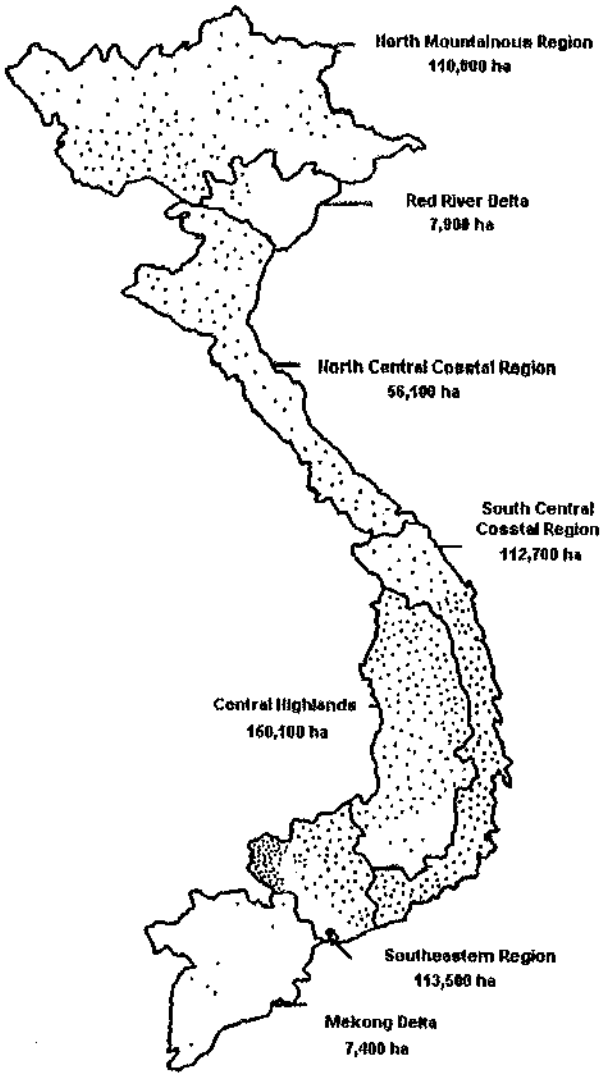

Figure 2. Cassava production area in agroecological zones in Vietnam in 2008. Each dot represents 1000 ha of cassava.
***Source**: Vietnam General Statistics Office 2008, adapted by Hoang Long.*

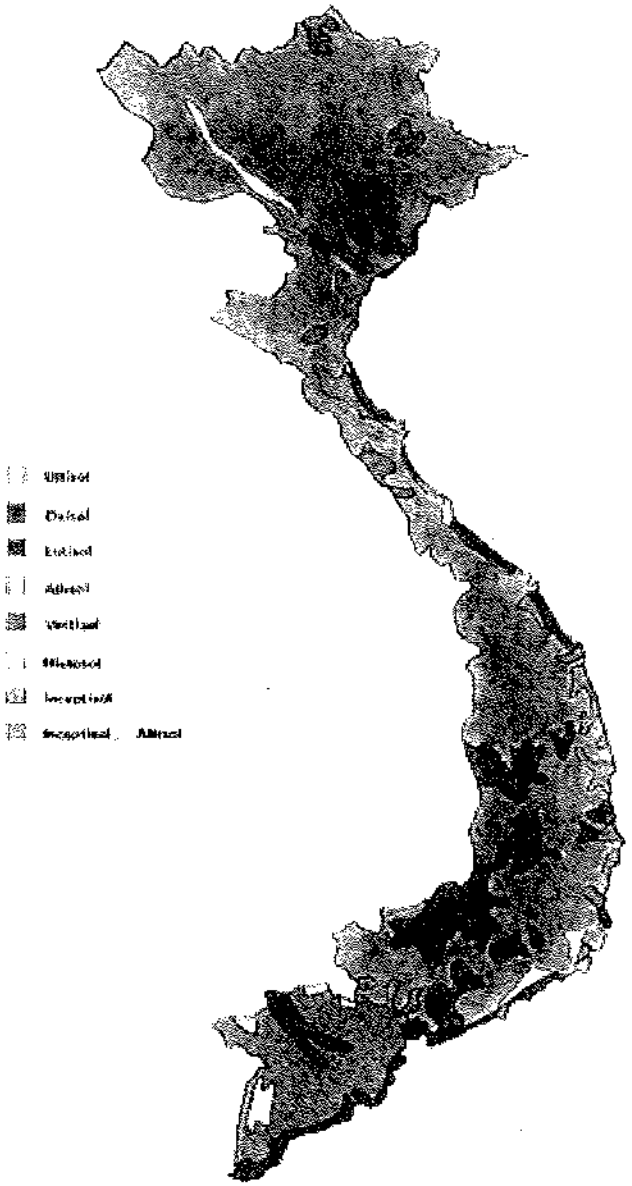

Figure 3. Soil map of Vietnam, adapted from FAO World Soil Map by R.H. Howeler
***Source**: Hoang Kim, Pham Van Bien and R.H.Howeler 2003.*
http://www.fao.org/docrep/009/y1177e/Y1177E05.htm#ch4

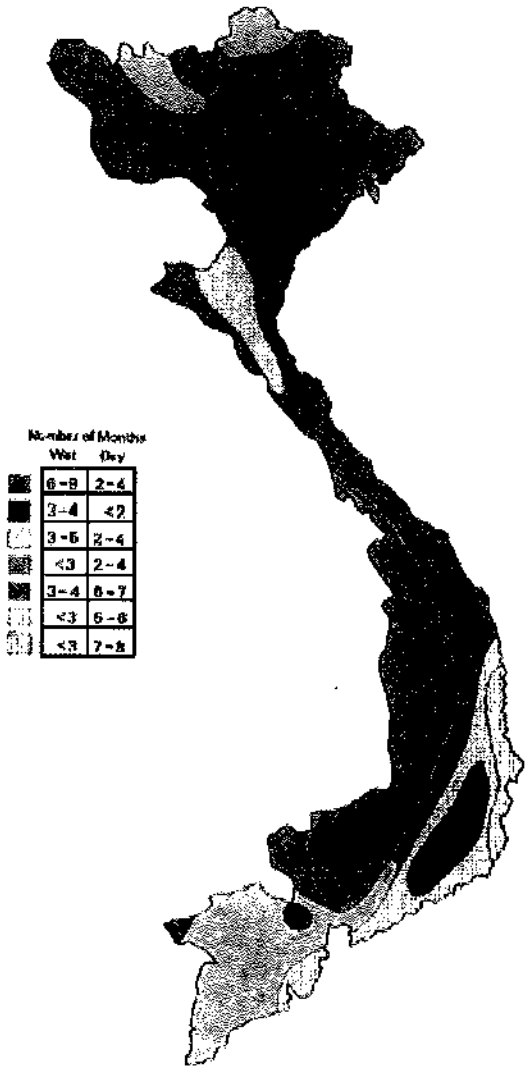

Figure 4. Agro-climatic map of Vietnam adapted from Agro-climatic map of SE Asia by Huke 1982.
***Source**: Hoang Kim, Pham Van Bien and R.H.Howeler 2003.*
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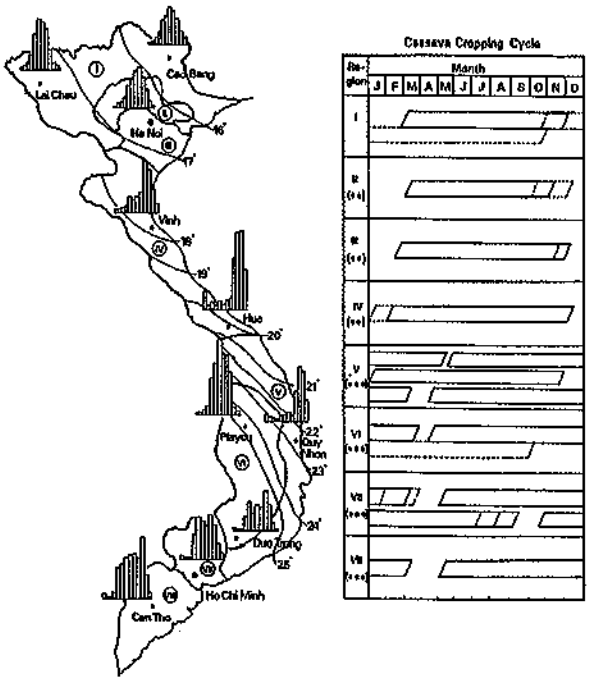


Figure 5. Cassava cropping times in eight agro-ecological regions of Vietnam
***Source**: Hoang Kim, Pham Van Bien and Reinhardt .Howeler 2003*
http://www.fao.org/docrep/009/y1177e/Y1177E05.htm#ch4

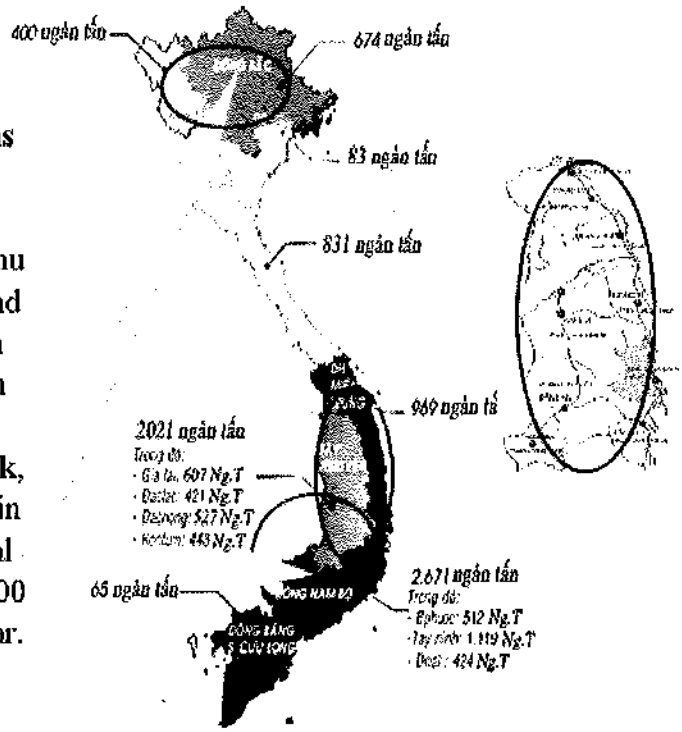
In 2009 the cassava planted area has reached 560,400 hectares (**Table 3**), of which about 78% is located in the Central Coast, Central Highlands and the Southeastern regions. It can be seen that cassava production in Vietnam has gradually shifted to the Central and the Southeastern regions in recent years, especially to Gia Lai, Kon Tum, Dak Nong and Dak Lak provinces in the Central Highlands; to Tay Ninh, Dong Nai, Binh Phuoc and Binh Thuan provinces in the Southeastern region; and to Quang Nam, Quang Ngai, Binh Dinh and Phu Yen provinces in the South Central Coast. The three regions all have increased the areas of cassava production to different degrees. Prominent among the three regions is the Central Highlands with a significant increase in the period from 2000 to 2009 (**Table 4**).

The cassava farm size in Vietnam is small and cassava farms in the Southeastern Region are on average double the size of those in North Vietnam. The cassava area per farm for all of Vietnam is on average 0.27 ha, with extremes for the Southeast (0.85 ha) and the North Mountainous Region (0.20 ha). When farms are classified according to size, 31.6% of the sampled farms are smaller than 0.6 ha, 35.5% are between 0.6-1.05 ha, and the remaining 33% are larger than 1.05 ha (Pham Thanh Binh *et al.*,1996).

During the 1980s and 1990s cassava production in Vietnam was in decline. But in the past nine years (2000-2009) cassava production increased from 1.99 million tonnes in 2000 to 9.45 million tonnes in 2009. This was achieved through both area expansion, from

237,600 ha in 2000 to 560,400 ha in 2009 and marked increases in yield from 8.36 t/ha in 2000 to 16.87 t/ha in 2009. New high-yielding cassava varieties (**Table 5**) and more sustainable production practices have increased the economic effectiveness of cassava production. In 2009, new varieties, mainly KM94, KM140, KM98-5, KM98-1, SM937-26, KM98-7 were grown in more than 500,000 ha. This corresponds to more than 90% of the total cassava area in the country.

Petrovietnam plans to build three tapioca-based ethanol plants in Phu Tho, Quang Ngai and (Binh Phuoc. Each costing $80 million which will **use cassava as feedstock,** is expected to open in 18 months with total annual capacity of 300 million liters per year.



Site selection for Cassava Vietnam Biofuel Project
(Nguyen Van Bo', Hoang Kim and Keith Fahmey 2008)
http://cassavaviet.blogspot.com

Vietnam Academy of Agricultural Sciences (VAAS)

Figure 6. Three cassava-based ethanol plants to be built in Phu Tho, Quang Ngai and Binh Phuoc provinces.
Source: http://www.gso.gov.vn/default.aspx?tabid=390&idmid=3&ItemID=8785

Table 3. Cassava planted area ('000 ha) in regions of Vietnam from 1995 to 2009.

Regions	1995	2000	2005	2006	2007	2008	2009
Red River Delta	10.9	9.9	8.5	8.4	8.8	7.9	7.9
North Mountainous	80.4	82.1	89.4	93.7	96.5	110.0	110.0
Central Coast	94.0	83.8	133.0	140.3	151.2	168.8	170.0
Central Highlands	32.6	38.0	89.4	125.9	129.9	150.1	150.0
Southeastern	49.3	16.1	98.8	100.9	102.9	113.5	115.0
Mekong Delta	10.2	7.7	6.4	6.0	6.2	7.4	7.5
Total of Vietnam	**277.4**	**237.6**	**425.5**	**475.2**	**495.5**	**557.7**	**560.4**

Table 4. Cassava production ('000 tonnes) in regions of Vietnam from 1995 to 2009.

Regions	1995	2000	2005	2006	2007	2008	2009
Red River Delta	79.0	87.9	92.4	93.7	102.9	102.1	105.5
NorthMountainous	606.3	678.5	986.8	1,070.8	1,132.3	1,328.0	1,330.0
Central Coast	602.1	645.9	1,855.9	2,167.6	2,359.9	2,808.3	2,810.0
Central Highlands	283.7	351.5	1,446.6	2,058.8	2,090.4	2,356.1	2,400.0
Southeastern	560.8	154.3	2,270.5	2,327.4	2,434.4	2,694.5	2,700.0
Mekong Delta	79.6	68.2	64.0	64.2	72.9	106.8	110.0
Total of Vietnam	**2,211.5**	**1,986.3**	**6,716.2**	**7,782.5**	**8,192.8**	**9,395.8**	**9,455.0**

Table 5. Harvested area and yield of cassava varieties currently in use in Vietnam[1)].

Variety	Harvested area in 2008		Fresh root yield (t/ha)		Starch content (%)	Starch yield (t/ha)	Fresh root production ('000 t)
	('000 ha)	(%)	Mean	OFT [2)]			
KM94	420	75.54	16.9	33.0	28.7	9.5	7.098
KM140	30	5.40	20.0	35.0	28.7	10.0	600
KM98-5	25	4.50	20.6	34.5	28.5	9.8	515
KM98-1	18	3.24	20.3	32.2	27.6	8.9	365
SM937-26	15	2.70	19.8	32.2	28.9	9.3	297
KM98-7	8	1.44	17.0	31.6	27.5	8.7	136
HL23	6	1.08	13.5	16.5	25.3	4.2	81
XVP	15	2.70	12.0	15.1	26.5	4.0	180
Others	19	3.40	6.5	14.9	25.4	3.8	124
Total	556	100.00	16.9				9.396

[1)] Nguyen Van Bo *et al.*, 2008; updated Dec. 20, 2009.

[2)] Results of sixty cassava OFT (four rows of cassava 1.00 x 1.00 m x 5 plants/row) and RYT (four rows of cassava 1.00 x 1.00 m x 8-10 plants/row) conducted by VNCP (2001-2008).

According to the Ministry of Agriculture and Rural Development, in the 2009-crop, Vietnam had about 560,400 ha of cassava under production, 9.45 million tonnes of cassava were harvested, up 2,700 ha and an increase of 59,200 tonnes over 2008. Cassava yields and production in many provinces have doubled, stimulated by the construction of new large-scale cassava processing factories. The cassava output in each region/province has been closely related to the planted area and yield, which greatly depends on the application

of new high-yielding cassava varieties in each province, and the adoption of more sustainable production practices. While twenty years ago there were no medium- or large-scale cassava starch factories in Vietnam, there are now 60 cassava processing factories in operation with a total processing capacity of 3.2-4.8 million tonnes of fresh roots/year. Total cassava starch production in Vietnam was about 800,000- 1,200,000 tonnes, of which 70% was exported and 30% used domestically.

Vietnam is now probably the second largest exporter of cassava products, after Thailand, with 2.00-4.00 million tonnes of cassava dry chips and about 0.4-0.8 million tonnes of cassava starch exported (**Tables 6** and **7**). Mainland China remains the biggest importer of Vietnamese cassava and accounted for 90% of the cassava's export income. South Korea and Taiwan were the second and third largest importers. Demand has soared, largely due to demand from China, which mainly uses the dry chips to produce ethanol. The total export in 2009 was estimated to be around 4 million tonnes of cassava chips and more than 350 thousand tonnes of cassava starch and flour (**Table 6**). Prices of cassava chip exports fell to a low of $135 per tonne at the beginning of 2008, but have since risen to between $180 and $195 a tonne in December 2009.

Table 6. World trade of cassava products in millions of tonnes 2006-2009.

Market Region	2006	2007	2008[1)]	2009[1)]
World Exports	**10,245**	**10,922**	**9,150**	**12,118**
Flour and starch	***4,852***	***4,686***	***4,265***	***4,651***
Thailand	4,616	4,416	3,963	4,316
Vietnam and others	236	269	302	335
Chips and pellets	***5,629***	***6,506***	***5,187***	***7,802***
Vietnam	1,041	1,317	2,000	4,000
Thailand	4,348	4,824	2,848	3,450
Indonesia	132	210	170	160
Others	108	156	169	191

[1)] Data for 2008 and 2009 are estimates and forecasts, respectively.
***Source**: Cassava: FAO Food Outlook, December 2009.*

A case study of the cassava production costs in central provinces of Vietnam in late 2007 found that on average labor costs accounted for 59.9% of cassava production costs. In some regions, like in Binh Dinh and Gia Lai provinces, this was 52.8% and 68.7%, respectively (Table 8).

The average labor requirement for cassava production in Vietnam is about 125 mandays/ha. The second largest cost item is fertilizer, constituting 41.8% in Binh Dinh and 24.7% in Gia Lai, depending on farmers' investment in fertilizers. With the selling price of fresh roots of 900 VND/kg, farmers can earn 10.72 to 11.20 million VND/hectare. The total variable cost of cultivation in Feb 2008 was about US$ 455-567/ha. At an average root yield of 22.0 t/ha the production cost would be US$ 20.68-25.79/t fresh roots. Gross income is US$ 1,155-1,237/ha. Net income is US$ 670-700/ha.

Table 7. China import of cassava chip (mt/ ha) in year 2009.

Item	Total	Thailand	Vietnam	Indonesia	Laos	Others
Jannuary	259,886	145,530	89,223	25,133	0	0
February	344,823	149,787	185,408	9,055	0	0
March	581,164	196,733	382,441	0	1,920	70
April	686,062	253,379	432,200	0	350	133
May	564,353	250,451	313,868	0	0	34
June	420,310	237,863	182,397	0	0	50
July	513,421	354,192	159,229	0	0	0
August	471,532	369,218	102,314	0	0	0
Sebtember	522,240	452,406	51,206	18,628	0	0
October	533,645	472,365	48,374	12,906	0	0
November	505,113	453,794	18,154	33,165	0	0
December	616,875	526,944	45,746	44,185	0	0
Total 2009	**6,019,424**	**3,862,662**	**2,010,560**	**143,072**	**2,270**	**287**

***Source**: Boomee Watanaruangrong, personal communication.*

Table 8. Production costs and returns per ha in two central provinces of Vietnam in early 2008.

		Binh Dinh			Gia Lai		
Economic item	Unit	Amount	Unit price ('000đ)	Total cost ('000đ)	Amount	Unit price ('000đ)	Total cost ('000đ)
- Land preparation	manday	34	40	1,360	34	40	1,360
- Planting	manday	6	40	240	6	40	240
- Weeding	manday	40	40	1,600	40	40	1,600
- Harvesting	manday	40	40	1,600	45	40	1,800
Labor costs				***4,800***			***5,000***
Planting material	stems	2500	1	*	2500	1	*
- Farmyard manure	tonne	7	200	1,400			
- NPK 20-20-15	kg	400	6	2,400	300	6	1,800
Packing	unit	6	60	360	6	60	360
Other	unit	20	6	120	20	6	120
External input costs				**4,280**			**2,280**
Gross income	**t/ha**	**22**	**900**	**19,800**	**22**	**840**	**18,480**
Total variable cost				**9,080**			**7,280**
Net income/ha				**10,720**			**11,200**

Note: 1US$= 16.000 dong in Feb. 2008

According to farmers' information: 32% of fresh roots was being chipped and dried by farmers for export; 27% was sold for cassava starch processing, 22% was sold to processing households, who process starch for domestic utilization, and 19% was used for animal feeding or for home consumption.

CONCLUSIONS

Vietnam is a classic example of how cassava can contribute to rural industrialization and development. Previously, people were reluctant to grow cassava because they thought that cassava caused soil degradation and produced low profits. But in reality, one hectare of cassava can produce 60-80 tonnes of fresh roots and leaves. The situation has changed because of the adoption of more sustainable cultivation techniques and new high-yielding varieties, and the large and growing market demand. Cassava has become a cash crop in Vietnam. Cassava chips and starch are now being produced competitively, and cassava markets are promising. The combination of widespread production of fresh cassava roots and the processing of cassava into chips, starch and ethanol has created many jobs, has increased exports, attracted foreign investment and has contributed to industrialization and modernization of several rural areas.

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CASSAVA RESEARCH AND DEVELOPMENT STRATEGIES IN INDIA

K. Abraham and S. Edison[1]

ABSTACT

Cassava, or tapioca as it is more commonly known in India, was introduced more than three centuries ago from Brazil. It has helped the southwestern part of the country to overcome a famine situation because of non-availability of sufficient rice. Although rice and wheat are important staple foods in India, the role of cassava as a food security crop is getting realized and soon it will be reinstated as a food security crop, especially for that part of the population below the poverty line, people living in coastal areas and the tribal population in many provinces. However, currently the crop is getting more and more industrial uses and is now being effectively utilized for the production of modified starches, starch derivatives, convenient foods and adhesives, besides the conventional production of sago and starch. The starch and sago industry in India is concentrated in Tamil Nadu, where nearly 800 small-scale factories employing about 500,000 laborers turn around a business of nearly Rs 5000 crores per year. The starch, sago and some of the products like wafers are also being exported to a number of countries, in particular to Bangladesh, Malaysia, Indonesia and Sri Lanka.

Some varieties bred many years ago in CTCRI, i.e. H-226 and H-165, are still very popular in the industrial cassava belt of Salem district in Tamil Nadu, as well as in Samalkot district of Andhra Pradesh. Nearly 70% of the area under cassava in these two states is covered by hybrids released by CTCRI. Another distinct component is the popular use of edible cassava varieties like M4, Sree Vijaya, Sree Jaya etc in the southern province of Kerala where cassava is mostly considered as a food crop. The overall area under cassava in India is nearly 270,000 ha with an annual production of around 9 million tonnes and the average yield is about 33 t/ha. However, the Salem belt in Tamil Nadu registers yields of 35-40 t/ha, thanks to the adoption of high-input technologies such as irrigation, fertilizers and good disease control. This area also benefits from a good climate and fertile soils. Over the years, this essentially peninsular crop of India has now spread to non-conventional areas like Gujarat, Rajasthan, Nagaland, Bihar, Orissa, Chhattisgarh, Jharkhand, Tripura and Madhya Pradesh. New factories have become established for the last 3-4 years in the above zones, producing sago and trying to produce other industrial products as well.

CTCRI, together with the All-India Coordinated Research Programme (AICRP) on Tuber Crops, has released nearly 23 varieties of cassava, which are available as location-specific cultivars for adoption. A massive program on production and distribution of high-quality planting material has been undertaken under the government of India-sponsored Mega Seed Project, and large quantities of planting material are produced and distributed to the various user agencies, such as the Department of Agriculture, State Agricultural Universities, progressive NGOs and industrial units. The success story of high yields of cassava in India is attracting attention all over the world, especially in African and Latin American countries. CTCRI is developing quite a few collaborative programs with different countries to enhance the adoption of technologies used in India for their further transfer to developing countries.

INTRODUCTION

Cassava research started in India during the year 1944 in the Tapioca Research Station of the Kerala State Government which was established in Trivandrum. Even before the beginning of organized research, cassava became an important food crop of Kerala, and a life-saving food of the state, during periods of famine. The crop became popular as a

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substitute for rice, when rice became scarce, especially during the world war period. As the crop was introduced in the 17th century by the Portuguese, it had become familiar to the people and was widely cultivated; so, the need was felt for research on this crop and the first research station came into existence.

From 1944-1963 cassava research was under the Tapioca Research Station of the Kerala State Government. During those years the Tapioca Research Station made an exhaustive collection of indigenous germplasm, in the form of farmers' varieties, which resulted from seedling and clonal selections as well as natural mutations of the material. These had spread out in cultivation during the approximately 250 years since its introduction. Exotic germplasm of the crop was also introduced during this period, especially clones from Malaysia. Among them the clone Malayan 4 or M 4, became very popular due to its excellent and stable culinary qualities and negligible cyanogen content. Malayan 4 is still in cultivation in various parts of Kerala state and it is preferred by the buyers for table purpose. M4 is cultivated in different pockets throughout the state under various local names. It is a tall, non-branching variety, but its efficient use in conventional breeding is highly restricted due to its limited flowering. During the early years of research, the Tapioca Research Station had also made significant contributions in the basic studies on the crop, like cytology, polyploidization and mutation.

In 1963, the Central Tuber Crops Research Institute (CTCRI) was established under the Indian Council of Agricultural Research (ICAR) in Trivandrum, which took over the materials from the state-owned Tapioca Research Station and continued the research. CTCRI's mandate was to conduct exclusive research on root and tuber crops other than potato but during the initial years, and even later on, the major thrust has been on cassava. In addition to the genetic resources collected and maintained in the Tapioca Research Station, CTCRI made further exhaustive collections. During the earlier years, introductions from Colombia, Madagascar, Nigeria, Thailand, Ghana, Uganda, Malaysia, Indonesia, Sri Lanka, Senegal and Gabon were added to the CTCRI germplasm collection. During the past two decades germplasm materials in the form of sexual seeds and *in vitro* cultures were received from CIAT, Colombia, which have been utilized in the breeding program.

Its Origin as a Food Crop

For a long time after its introduction in Kerala, cassava remained essentially a food crop as well as a food security crop during times of famine. Its cultivation was mostly limited to Kerala, forming the food for that portion of the population below the poverty line: people living in the coastal regions and the various tribal populations. With the improvement in economic conditions and standards of living over the years, cassava has changed its role from a food security crop. At present it is used as a food crop by the poor and as a side-dish by the affluent, and its acceptability has become wider. Apart from Kerala, cassava is also cultivated in more than 10,000 ha in the northeastern states of Assam and Meghalaya, mainly as a food crop and to some extent for the production of sago.

Breeding High-yielding and Short-duration Varieties

The first and foremost task of CTCRI after its inception was to breed high-yielding varieties for general cultivation. By conventional breeding using indigenous and exotic

germplasm, the first three high-yielding hybrid varieties, i.e. H-97, H-165 and H-226, were released in 1971. These high-yielding varieties gradually spread in the southern peninsula, mainly to the adjoining states, especially Tamil Nadu, and the general production and productivity of cassava started to increase thereafter.

Over the last two decades, cultivation of cassava in Kerala as a monocrop in the uplands has declined and the cropping systems in Kerala started undergoing changes. Cassava is more and more being cultivated in low-lying areas as it is grown after the main crop of rice; for this production system, short-duration varieties became necessary. The three short-duration varieties, Sree Prakash, Sree Jaya and Sree Vijaya, which mature in 6–7 months, became very popular in the lowlands of Kerala as they performed very well after the harvest of rice, benefitting from the remaining soil fertility and moisture in the lowland soils.

Further breeding objectives were to have nutritionally superior varieties, drought resistant varieties and varieties suitable for upland and lowland cultivation. The variety Sree Visakham, released in 1977, is a carotene-rich variety with a compact root formation; it is high-yielding and rich in carotene (466 IU/100g). Sree Sahya is a hardy, drought-tolerant variety, which performs well even under prolonged drought. By producing inbreds in cassava the heterosis was utilized and the first such varieties were produced in the year 2000. The varieties Sree Rekha and Sree Prabha are high yielders with excellent cooking quality and are suitable for upland and lowland cultivation.

Its Use as an Industrial Crop

Cassava starch and flour production first commenced in Kerala and the neighboring state of Tamil Nadu during the Second World War. Sago production commenced in Tamil Nadu, with the technical know-how from Malaysia. Various factors, like the adaptation of the crop and its high yields, less humid non-rainy climate and highly fertile soils, as well as low labor costs soon promoted cassava as a commercial crop in Tamil Nadu for starch and sago production, and the number of cassava-based factories have increased from a few to more than 800 today. Cassava is cultivated in about 100,000 ha in Tamil Nadu and the ruling varieties are the hybrids produced by CTCRI, such as H-165 and H-226. Following the success of cassava in Tamil Nadu as a commercial crop, the state of Andhra Pradesh started sago production as a cottage industry by 1970, and at present there are about 70 cassava-based industries in Andhra Pradesh with a cultivated area of about 25,000 ha. In the states of Maharashtra and Gujarat also, several cassava processing factories have come up and the crop is cultivated in several thousand hectares.

CTCRI has made a significant breakthrough in breeding high-starch varieties of cassava by the production of triploid hybrids. Triploid hybrids are highly successful as industrial varieties because of their higher root yields (>35 t/ha), higher dry matter content (45-50%) and higher extractable starch content (>30%). Two triploid hybrid selections, i.e. 4-2 and 5-3, having higher root yields and higher extractable starch contents, have created an impact in the industrial areas of Tamil Nadu. The success of these two varieties is that they were selected by farmer participatory evaluations in the industrial areas. Both hybrids are preferred by farmers and factory owners alike. The farmers get additional income due to higher yields and higher starch contents and the factory owners obtain 5-6% higher starch recovery.

Management of CMD and Root Rots

Even though cassava mosaic disease (CMD) is very common among the varieties, they still have substantial root yields as many improved and local varieties are tolerant to CMD. The varieties H-165 and H-226, although not CMD-resistant, are performing very well, giving profitable yields in Tamil Nadu during the past four decades. In the absence of resistant varieties, rouging was practiced which had resulted in symptom-free plants. More recently, CMD-resistant lines from CIAT, carrying CMD1 gene and CMD2 gene, were received and they are extensively used in the breeding program. Farmer participatory evaluation of CMD-resistant hybrids has resulted in the isolation of superior selections suitable for hills and plains. The CMD-resistant hybrid selections also produce higher yields and have higher extractable starch contents. More recent breeding attempts are directed towards incorporating CMD-resistance into high-starch triploid hybrids. An integrated disease management strategy for cassava includes production of disease-free planting material through meristem culture, followed by multiplication of plants in vector-free zones.

Root rots caused by *Phytophthora* started appearing in areas of Tamil Nadu a few years back, and this problem has slowly spread. As the farmers grow cassava in the plains of Tamil Nadu with heavy irrigation, it was found that the water-logging in the shallow soils was causing the root rot infestation. This was mitigated by deep plowing the land to break the hard pan below the top soil, ridge planting, incorporation of *Trichoderma viride*, and also by awareness creation among the farmers about the adverse effects of excess irrigation.

Integrated Production Technologies

Agrotechniques and soil fertility management practices to maximize cassava root production were also developed in CTCRI. Apart from standardizing the ideal planting time, planting material size, plant population and intercultural operations, a nursery technique was developed for production of cassava in non-traditional and very dry areas, such as planting the healthy stakes closely at 5 cm so as to accommodate 400 stakes per m^2 for the better establishment of plants and thereby shortening the crop duration in the field during the short rainy season.

Standardization of soil fertility management practices for cassava in industrial areas of Tamil Nadu and Andhra Pradesh is currently in progress. N, P, K fertility maps of Salem and Namakkal districts of Tamil Nadu, and East Godavari district of Andhra Pradesh, were developed based on detailed soil surveys and analysis of soil samples. As the existing general fertilizer recommendations for cassava consist of fixed rates and timings of N, P and K, a more site-specific nutrient management (SSNM) technology was developed. In both Tamil Nadu and Andhra Pradesh SSNM practices for cassava and fertilizer calculation charts were developed. The results give a general NPK recommendation of 100:100:100 kg/ha of N, P_2O_5 and K_2O for Tamil Nadu and 100:100:125 kg/ha for Andhra Pradesh. For the rationalization of recommendations of NPK fertilizers and micro-nutrients, rapid appraisal of soil fertility in southern districts of Kerala is undertaken. Soil test-based fertilizer recommendations were developed for the districts of Thiruvananthapuram, Kollam, Pathanamthitta, Kottayam and Idukki of Kerala and Kanyakumari district of Tamil Nadu after assessing the nutritional status of the major cassava growing soils of these areas.

The research efforts in the recent past also led to the development of low-input technologies for cassava with thrust on genotypes adapted to low-input conditions, utilization of locally available organic wastes as soil amendments, green manuring *in situ* with cowpea, and utilization of bio-fertilizers. The cassava hybrid Sree Prabha, the land race Mankuzhanthan and the local variety Malayan-4 were found to be adapted to low-input conditions, producing satisfactory root yields in low-P soil, even in the absence of applied P. Monitoring the VA-mycorrhizal (VAM) association on cassava roots indicated that in the absence of P fertilization, the fungal colonization was higher on all genotypes. Green manuring *in situ* with cowpea is a low-cost soil fertilizer management practice that has agronomic and economic advantages. By practicing green manure *in situ* with cowpea, the application of farm-yard manure (FYM) can be eliminated and N and P application can be reduced to 50% of the recommended rates. Locally available organic manures like mushroom-spent compost, sawdust compost, press mud and coir pith compost, were found to be cheap and effective substitutes to FYM in cassava production.

Apart from these, integrated use of biofertilizers (*Azospirillum* and *Phosphobacterium*) with the recommended dose of FYM and K and with 50% of the recommended N and P rates produced substantial root yields (26.87 t/ha), almost equal to that achieved using the existing fertilizer recommendation. This suggests the possibility for reducing the N and P fertilizer doses to about 50%. An economic analysis indicate that the low-input technology package comprising of green manuring *in situ* with cowpea, the use of indigenous rock phosphate (Mussoriephos or Rajphos), and the use of biofertilizers (*Azospirillum* and *Phosphobacterium*) can save about Rs 3000/ ha (US$ 65) in the cost of production of cassava.

In cassava production, integrated use of VAM fungi and organic manures, such as vermi compost and coir pith compost were found to be beneficial when applied on an equal nutrient basis of 12.5 t/ha of FYM. Application of vermi compost at the rate of 3.8 t/ha, VAM fungi and NPK at 100:50:100 kg/ha resulted in cassava yields that were equal to those obtained with 12.5 t/ha of FYM + VAM fungi and NPK at 100:50:100 kg/ha. In another set of experiments, attempts were made to reduce the inorganic fertilizer dosage by giving greater emphasis to various locally available organic manures. It was found that application of organic manures, like FYM, coir pith compost, processed urban waste, VAM fungi and 25% of the recommended chemical fertilizers proved superior to the present recommendation for cassava, suggesting the possibility to reduce the rate of chemical fertilizers application by as much as 75%.

Conventional techniques were developed for the large-scale multiplication of VAM fungi. As VAM fungi cannot be cultured axenically, they are multiplied by inoculating the host plants grown in sterilized soil to produce a single-species culture, which is then used for further inoculation. The technology for storage consists of preparing an aqueous spore suspension of VAM fungi and adding two parts of the suspension to one part of steam-sterilized lignite powder and then storing this in a refrigerator at 21^{0}C. By this technique, the viability of spores could be maintained up to six months. The use of lignite also keeps the spores in close proximity of the emerging roots and this initiates spore germination. It also helps in retaining soil moisture and may act as a buffer minimizing the effects of soil pH and other factors.

Compatible and profitable cropping systems involving root crops and short-duration legumes were perfected. Groundnut, French beans and vegetable cowpea were

identified as ideal intercrops in rainfed cassava. In single-crop paddy fields, rice-short duration cassava sequential cropping was found to be very profitable. Management practices for intercropping cassava with coconut were also standardized. Cassava varieties H-165 and Sree Jaya performed well as intercrops in newly established coconut gardens in the state of Bhubaneswar.

Production and Distribution of Quality Planting Materials

In order to meet the increasing demand for planting material of high-yielding varieties of root and tuber crops, CTCRI has launched a program involving the Department of Agriculture, ICAR institutes, Agricultural Universities, Krishi Vigyan Kendra, NGOs etc. As a part of this program, location-specific testing and popularization of root crop varieties and the production and distribution of planting materials are undertaken. Many District Agricultural Farms in Kerala, Tamil Nadu, Orissa and Andhra Pradesh are involved in this program. A simple farmer-oriented technology aimed at rapid multiplication of cassava using 2-node cuttings was developed and large quantities of planting materials are being produced and distributed to farmers and several agencies.

Value Addition of Cassava

Many diversified and value added food products were developed from cassava, including cassava rava (semolina), yucca porridge, fried cassava chips with good texture, flour-based fried food products and snacks. A microbial process was developed to prepare fermented cassava flour with modified textural attributes and this technology has been patented. A solid-state fermentation technology was developed using *Trichoderma pseudokonigii* to enhance the protein content of cassava-based feed to 8-10%. Technologies for by-product utilization of solid cassava starch waste (*thippi*) as broiler feed were developed, with starter rations having 60% *thippi*- flour mix, and finisher rations having a 55% mix. Cassava based silage was also developed for 'round the year' use as cattle feed by mixing chopped cassava roots with cut paddy straw in a 9:1 ratio and ensiling the mixture in air-tight containers. It was found that 25% of the concentrate can be replaced with silage in dairy cows for increased milk yield.

Various types of modified starches, such as cross-linked, acetylated, cationic and inorganic starches, were developed from cassava.. Carboxymethyl starches and cold water-miscible starches were developed and transferred to industries. Production of ethanol from cassava starch and flour has also been patented and transferred to companies. The process for producing biodegradable plastics incorporating cassava starch was developed and transferred to private industries. The technology for the treatment and management of waste waters from cassava starch and sago factories has been implemented in Salem district of Tamil Nadu.

CONCLUSION

The success story of high yields of cassava in India has been the result of an integration of high-yielding varieties and the production technologies from the Central Tuber Crops Research Institute, the industrial importance of cassava as a raw material for starch and sago, and the large number of location-specific, improved varieties identified by the All-India Coordinated Research Programme of CTCRI, as well as the production and distribution of high-quality planting material. The varietal development of cassava in

CTCRI is taking a new direction, to produce very high-yielding, high starch, CMD-resistant varieties, especially by using the recent additions of CMD resistant genetic stocks. The rapid spread of cassava in non-traditional areas like Maharashtra and Gujarat in central India and Assam, Nagaland and Tripura in northeastern India, and the establishment of new factories for starch and sago production in those areas in recent years indicate that the use of cassava is gaining more importance in the industrial sector. This along with further value-addition and product diversification will also generate employment opportunities for the rural populations. Thus, the cassava research and development strategies in India are expected to add new dimensions to the whole cassava sector, including production, processing, utilization and export, in the near future.

A NEW FUTURE FOR CASSAVA AS AN ANIMAL FEED AND BIOFUEL IN CHINA

Tian Yinong[1]

ABSTRACT

Since carrying out the "reform and open-door" policy in the early 1980s, it is well known that China has achieved much progress in economic development. It is now the fifth largest economy in the world. But the rapid development of the economy also created big problems with respect to energy supply. Currently, the country consumes more than 350 million tonnes of mineral oil per year and nearly 50% of this is imported. The energy crisis has increased Chinese determination to develop an efficient bio-fuel industry. After several years of research, it was determined that cassava could become an important resource crop for bio-fuel production in southern China. During the next 5-10 years total production of bio-fuel using cassava as the raw material will be more than one million tonnes. This means that cassava research and production will need to enter into a new phase of accelerated development.

Being traditionally used mainly as a feed for animals, cassava will still play a very important role in the development of animal production in rural areas of southern China. The nutritional value of the feed has increased a lot by mixing cassava with maize, soybean and mungbean. So, farmers are now earning more money from animal feeding and much quicker than before.

INTRODUCTION

I. China's Economic Achievements Since the Reform and Opening-up Policy

Since the economic development policy of reform and opening-up in 1978, China's economy has achieved great progress in the past 30 years. In 1978, China's GDP[2] was only 364.5 billion RMB which ranked No.10 among the world's major countries, while GNI[3] per capita was 190 USD, which ranked as one of the world's lowest income countries. The reform and opening-up policy has continuously improved the economy and China's economy is on track for rapid further development. In these 30 years of reform and opening-up, China's economy has been growing rapidly, and its national power as well as international influence is turning from weak to strong (**Table 1, Figures 1** and **2**). During the past 30 years, the average economic growth rate per year was reached as high as 9.8%.

Table 1. GDP ranking of China in the world in 2004 and 2007.

	Country ranking in terms of GDP (trillion US$)						
	1	2	3	4	5	6	7
2004	US	Japan	Germany	UK	France	Italy	China
	10.9	4.3	2.4	1.8	1.7	1.5	1.4
2007	US	Japan	Germany	China	UK	France	Italy
	13.98	5.29	3.28	3.01	2.57	2.52	2.09

Source: *2000-2007 World Year Book.*

[1]Guangxi Subtropical Crops Research Institute, 22 Yongwu Road, Nanning, Guangxi, PR China
[2]GDP = gross domestic product
[3]GNI = gross national income

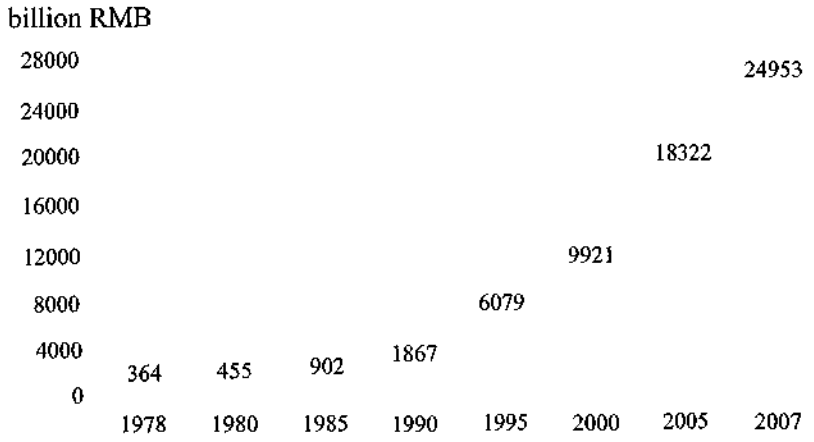

Figure 1. China's GDP between 1978-2007 (billion RMB)

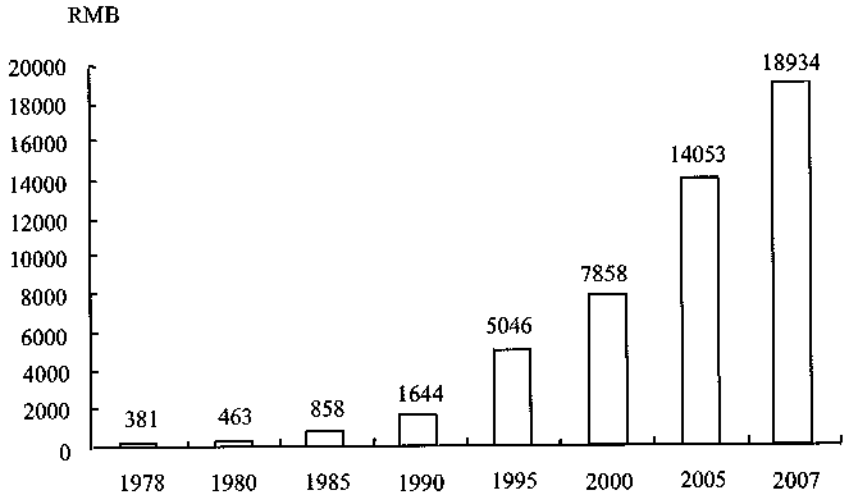

Figure 2. China's GDP per capita between 1978-2007 (RMB).

From 1979-2007, China's average fiscal revenue growth per year was 14.1%; the average urban per capita disposable income growth per year was 7.2%; and the average per-capita net income growth for rural residents per year was 7.1%.

The rapidly growing economy is accelerating the country's needs of energy, and energy shortages may affect the normal economic development; the country has therefore attached great importance to it and is looking for solutions. For a big developing country

like China, which is in a stage of rapid development, energy security is obviously very important because it is the guarantee of economic growth. For decades, China's economy has been growing at the rate of around 10%, while at the same time the total energy consumption has been increasing. From 1986 to 2004, China's average energy consumption growth rate per year was 5%, while at the same time China's actual GDP average growth rate per year was as high as 9%, which means China's total energy consumption and the efficiency of utilization were both increasing. However, China's energy efficiency rate of utilization is still very low and far below the world's average level. This is one of the important reasons why China's need of energy is dramatically expanding. Currently, the efficiency of utilization of energy in China is 33%, which means the energy such as coal and electricity consumed for every 1 US$ GNP is 3-4 times the world's average consumption. Compared by unit national income energy consumption in China is 10.6 times that of Japan, 8.3 times that of Germany, and 4.6 times that of the US. China's water consumption per ten thousand Yuan GDP is four times the world's average level, etc. The huge labor intensive industries with low added value and high energy consumption transferred from abroad has made China's energy waste problem become more serious, and the environment has been affected even worse. China's GDP is only a bit more than 4% of the world's total GDP, but its consumption of raw coal, iron ore, steel, aluminum, and cement has reached around 1/3 of the world's total consumption. In 2005, China's economic scale was 1/6 of the U.S., but its consumption of raw coal was 2 billion tonnes, which is almost two times that of the US. Because of this, the Chinese government is aware of the importance of developing renewable energy, and has taken some actions and achieved good results. Take wind energy as an example: in 1995, China's wind power generation installed capacity was only 38 MW, while the number reached 2,599 MW in 2006, which means that it has been increased more than 60 times within 11 years. Only within the year 2006, the new installed capacity was as high as 1,337 MW.

II. The Need for Energy During Economic Development

1. China's energy development

a. Production

In 1959 China's crude oil output was 3.733 million tonnes. In 1978, it was 0.1 billion tonnes, in 1988 0.137 billion tonnes, and in 1998 it was 0.16 billion tonnes; since then China has been among the big energy consuming countries. In 2008, China's oil output reached 0.19 billion tonnes.

B. Consumption and importation

From 1978 to 1990 was the period of steady growth of China's economy. The official statistics shows that China's oil consumption increased from 65 million tonnes in 1978 to 110.3 million tonnes in 1990, with an average increase of 1.58 million tonnes per year, and an average growth rate of 1.6% per year (**Table 2**).

During these twelve years, China had an oversupply of crude oil while its foreign currency reserve was in short supply. In the 1980s, 1/4 of China's crude oil was exported. Foreign currency reserves before 1993 were mainly from exporting oil. Since 1991, as the national economy was developing rapidly and steadily, the consumption of oil also entered a rapid growth phase. The consumption of oil increased from 0.118 billion tonnes in 1991 to 0.35 billion tonnes in 2008, with an average growth of 11.7 million tonnes and an annual rate of growth of 7.1% (**Table 2** and **Figure 3**).

Table 2. China's oil production and consumption from 1959-2008 (million tonnes).

	Output	Consumption	Importation
1959	6		0
1978	100	65	0
1988	137	110	0
1998	160	160	little
2008	190	365	180

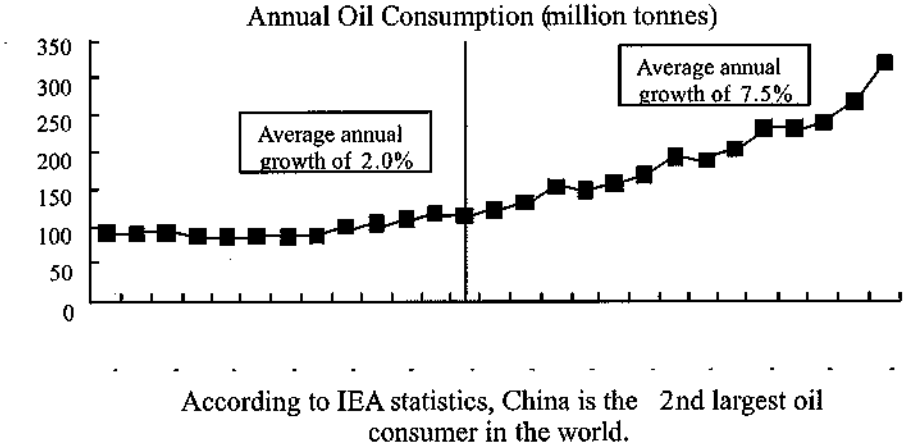

Figure 3. Annual oil consumption in China between 1978 and 2004.
***Source:** Annual report of fuel consumption in China, 2006.*

According to China's official statistics, China's total oil consumption was 0.267 billion tonnes in 2003, with domestic annual output 0.17 billion tonnes and imported oil almost 0.1 billion tonnes (**Figure 4**). In 2008, China's imported oil was more than 0.16 billion tonnes which is 7% of the world's total exported oil.

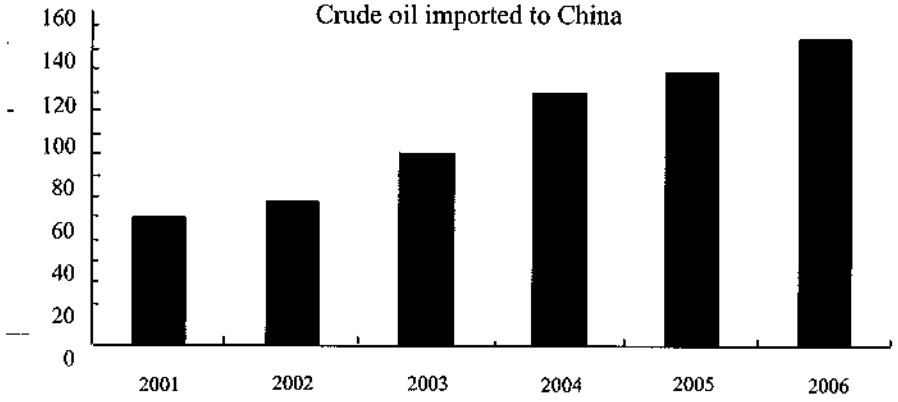

Figure 4. Annual importation of crude oil(million tonnes) in China from 2001 to 2006.

The predictions by the energy authorities show that by 2010, China's total oil consumption might be around 0.35 billion tonnes, of which domestic output is 0.18 billion tonnes and the other 50% will be imported from abroad; by 2020, China's estimated minimum oil need will be 0.45 billion tonnes, of which domestic output is estimated to be 0.18 billion tonnes and 0.27 billion tonnes will need to be imported, i.e. 60% of oil consumption will need to come from abroad. If the economy continues to grow from 2030 to 2040, the international energy authorities predicts that China's oil output will have only 0.1 billion tonnes left and 0.5 billion tonnes will need to be imported. This means that we will have to rely on foreign oil for 87% of our oil requirements.

Therefore, the development of biomass energy is greatly needed. Since the 1990s, the Chinese government has been planning to expand the ethanol industry with the hope of producing ethanol from stored grains to kill two birds with one stone, i.e. to solve the problem of difficulties in selling grains when food production greatly exceeded demand, and to develop ethanol production as fuel at the same time. Because of the dramatic increase in needs of energy and considering as well the food security problem at the end of the 20th century, the government adjusted the development strategy of bio-energy and organized related experts to conduct research and have discussions on raw material crops for bio-energy. The result was that the northern part of the country will focus on sweet sorghum while the south will focus on cassava and sugarcane. The bio-energy development plan with grain as the raw material will no longer be used.

The policy for the development of bio-fuel crops in China is now as follows:

- Non-food crops
- Cannot compete for land used for food crops(grown on marginal land only)
- Need to diversify the resources

III. Production and Utilization of Cassava in China

1. Production of cassava

Cassava was introduced to China in the 1820s. It was first planted around the Gaozhou area, in Guangdong province, and was later introduced to Hainan island. Now it is widely grown in the southern part of China, mainly in Guangxi, Guangdong and Hainan. Cassava has also been introduced and is planted in the southern parts of Fujian, Yunnan, Jiangxi, Sichuan and Guizhou provinces.

The "County Journal" (revised version) of 1889 of Gaozhou county, Guangdong province, records that "there is cassava coming from South Asia in the early Daoguang years (the first Daoguang was 1820)". Liang Guangshang and others believe that cassava was first introduced to Guangdong province around 1820, but the earliest book recording about cassava was the "Xinhui County Journal" compiled by Lin Xingzhang in 1840, which has a simple record on cassava's appearance, way of planting and usage. During the Taiping revolution (1851-1863), cassava was widely planted in eastern Guangdong province and entered into the markets. The album of "Cassava Planting Instructions" (Liang Yandong, 1900) published at that time had descriptions on cassava's appearance and characteristics, ways of managing the soil, ways of planting, harvest and variety, as well as processing. This means that people already had knowledge about cassava at that time. Looking back at the historical development of cassava in China, we believe that "there is cassava coming from South Asia in the early Daoguang years" as probably true as at that time quite a few people from southern China went to South Asia to live, so cassava might have been introduced to China during that period.

The earliest cassava experiments in China were conducted by the Agriculture and Forestry Experimental Farm of Guangdong province even before 1949. This farm had experiments on varietal collections, evaluation, of growing season (more than one year), starch making and nutrient analysis of roots from 1914 to 1919. From 1940 to 1944, Li Xikai, Huang Ruilun and others did intensive and specialized research on the distribution, content, and removal of cassava hydrocyanic acid, and made observations on varieties and planting methods at the "Sa-tang" Agricultural Experimental Farm in Liu-zhou city of Guangxi province, and published a monograph named "Research on Cassava Toxins". Liang Guangshang and others started varietal selection and cross breeding in Guangdong in

1957. After 1959, the Chinese Academy of Tropical Agricultural Sciences (CATAS) started to do research on cassava planting, multiplication, spreading, rotation, storage of planting material, breeding and the transfer of cassava to northern regions. Under the direction of professor Wen Jian, the first cassava variety, SC 6068, in China was developed at that time. Since then, cassava has been planted in Guangdong, Guangxi, Hainan, Fujian and Yunnan provinces (**Tables 3** and **4**).

Table 3. Cassava area, production and yield in the southern provinces of China in 2008.

	Area (ha)	Yield (t/ha)	Production ('000 tonnes)
Guangxi	240,000	18.90	4,530
Guangdong	85,000	18.71	1,590
Yunnan	35,000	10.57	370
Hainan	32,000	18.75	600
Total	**407,000**	**17.4**	**7,090**

Source: Office of Tropical Crops of the Ministry of Agriculture of China: Tropical Crops Production in China in 2008.

Table 4. Cassava area, production and yield in Guangxi from 2000-2008.

Year	Area ('000 ha)	Production ('000 t)	Yield (t/ha)
2000	264.2	4,488	17.0
2001	248.5	4,295	17.3
2002	250.6	4,973	19.8
2003	244.8	4,658	19.0
2004	251.6	4,870	19.3
2005	269.4	5,380	19.8
2006	284.0	5,770	20.3
2007	295.0	6,030	20.4
2008	240.0	4,530	18.9

2. Cassava products and their markets in China

As cassava is produced mainly in southern regions such as in Guangxi and Guangdong provinces of China, the cassava processing factories are mainly located in the cassava

planting areas of these two provinces. According to statistics from the Starch Association of Guangxi, there are now about 200 cassava processing factories in China, producing mainly the following three types of products: the first is native and modified starch, which is mainly used in textiles, paper making, medicines, food, construction materials, casting, light manufacturing, petroleum, energy, feed, agriculture, environmental protection, biological engineering, etc.; the second type is organic chemicals such as ethanol, polyethylene, acetic acid, epoxy ethane, sorbierite, neovaricaine, citric acid, etc., which are important raw materials for producing rubber, farm chemicals, fat, packaging, cosmetic products, and army necessities. As ethanol has become a fuel additive for gasoline, its potential market is huge; the third type is sweeteners, which includes various types such as glucose, fructose, maltose, oligose, fructose, etc., and these have now become popular ingredients, as they are considered health foods. Currently, other cassava processed products are being developed in the fields of ceramics, coal, daily necessities, and cosmetic products as well as in housing and forestry products.

In 2007, China produced 0.9 million tonnes of cassava starch (among which over 0.18 million tonnes of modified starch) and 0.45 million tonnes of cassava ethanol (**Table 5**). Of the 18 million tonnes of fresh cassava root equivalents required, 10 million tonnes were imported that year. Thirty percent of this, equivalent to 5.4 million tonnes of fresh roots, were used for producing feeds (including on-farm use), and the other 70%, equivalent to 12.6 million tonnes, were used for processing into starch, ethanol and sweeteners (**Figure 5**). Further processing products from ethanol are mainly biomass energy and biochemical products.

Table 5. Output of cassava-based products in China from 2004 to 2007 ('000 tonnes).

	2004	2005	2006	2007
Cassava starch production	580	700	800	900
- of which modified starch	120	140	160	180
Ethanol	290	350	400	450

In China, cassava starch is mainly used for further processing into noodles and modified starch, and its annual demand is over 1.5 million tonnes. Therefore, since China's cassava starch output was 0.9 million tonnes in 2007, much of the cassava starch requirements are met by importing. In 2004, over 0.5 million tonnes of cassava starch were imported from Thailand, Vietnam and Indonesia.

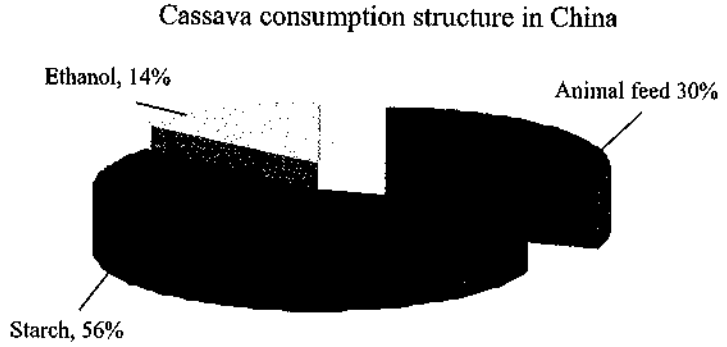

Figure 5. Cassava consumption in China in 2007 (in percent of fresh root equivalents)

The starch industry in China has been developing rapidly in recent years, with a total annual output in 2007 of about 0.9 million tonnes, of which cassava modified starch occupies around 20%, which is mainly used for paper making and the food industry (**Figures 6** and **7**). Currently, the product structure development of cassava modified starch is unbalanced as it is mainly used in the paper making industry. Modified starch for paper making occupies 85% of the total cassava modified starch, while textiles, food, construction materials, medicines etc occupies around 14%, and the others around 1%.

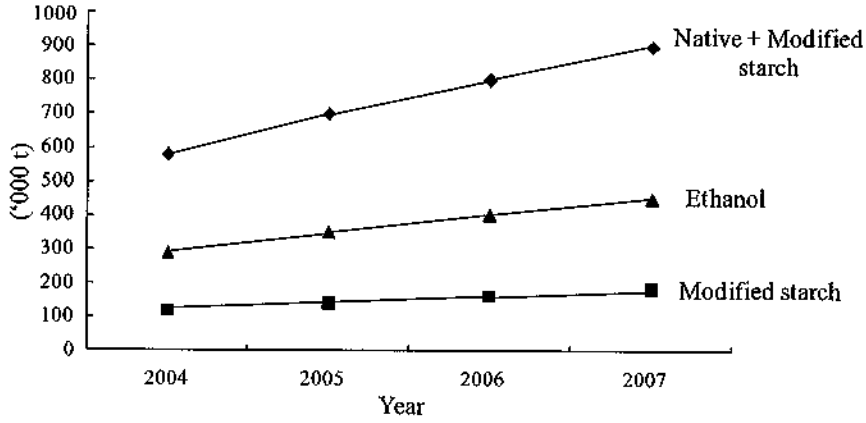

Figure 6. Growth of cassava starch and ethanol production from 2004 to 2007 in China.

The sweetener industry is also developing very fast. However, the manufacturers mainly use corn-starch to produce sweeteners and very few use cassava starch.

Cassava ethanol production in China is of more recent development. The annual production capacity of cassava ethanol in 2008 is about 1.2 million tonnes, which is used mainly in alcohol blending and in the local medicine industry. In 2008, with the completion

of the first cassava fuel-ethanol factory of COFCO in Beihai, Guangxi, with an annual production capacity of 0.2 million tonnes, China's actual output of cassava ethanol will increase dramatically. Guangxi province currently accounts for 70% of China's cassava processing and production capacity.

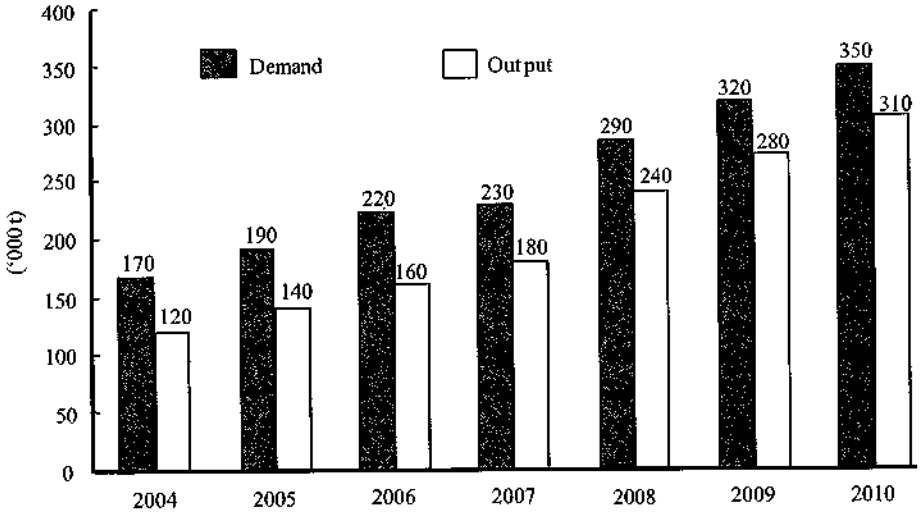

Figure 7. Trend in supply and demand of cassava modified starch in China from 2004 to 2007 and the estimation from 2008-2010.

3. Development trend of the cassava processing industry

Because of the high efficiency of utilization and at the lowest cost of production, the future of making ethanol from cassava is great. Ethanol is widely used in medicine, in the chemical industry, in food, fat, and the military industry with a huge potential market.

If cassava ethanol can be used as a renewable and clean source of energy, its potential market will be even bigger. Bio-fuel ethanol is currently the bio-energy with the world's largest production scale. Considering the annual per capita grain production of less than 400 kg in China, it is impossible to massively produce fuel ethanol from grain crops. Therefore, producing fuel-ethanol from "non-food" energy crops, including cassava, is the only way for biological energy development in China.

4. The bright future of producing ethanol from cassava resources

Ethanol is now the main product of cassava processing. As an important chemical, ethanol is widely used in many industries. If it can be used as a renewable and clean energy, the potential market will be huge. In recent years, the annual total ethanol output in China was about 2.5 million tonnes, with 2.3 million tonnes of domestic consumption and 0.2 million tonnes for export. In 2007 annual ethanol output using cassava as the raw material

in China was about 0.45 million tonnes. As the ethanol price in the international market is at least 30% higher than that in the domestic market, there is still a big profit margin for ethanol production in China.

China's current annual gasoline consumption by cars is about 57 million tonnes. If we mix 10% of fuel ethanol into the gasoline, it will require 5.7 million tonnes of dehydrated ethanol every year, while China has only 1.2 million tonnes of production capacity at present. Annual diesel fuel consumption is about 80 million tonnes. With the added ratio of 5%, bio-diesel fuel will requires 4 million tonnes of ethanol, while there is not yet any fuel ethanol for it in China. Therefore, the ethanol output in China is far behind the market demand, and the ethanol market is truly a "seller's market".

IV. Fuel Ethanol Production in China and its Future Development Plan

1. Development situation of the cassava ethanol industry

As an important chemical, ethanol is widely used in various fields including in medicines, alcoholic drinks, farm chemicals, for production of various organic chemical products, fuel, etc. Starting from 2001, with the development of the concept of biological energy and the completion of the fuel-ethanol technology, the production ability and output of ethanol in China has been improved. By the end of 2006, the total output of ethanol in China had reached 5.81 million tonnes, of which potable ethanol accounted for 71%. In 2007, China's ethanol industry's actual output was 6.36 million tonnes with a growth rate of 9.46% compared to 2006 (**Figures 8, 9** and **10**).

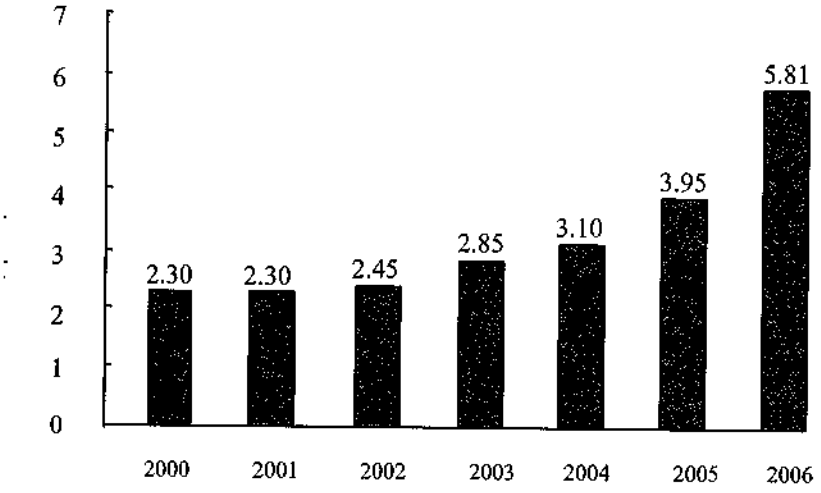

Figure 8. Total alcohol output (million tonnes) in China from 2000 to 2006.

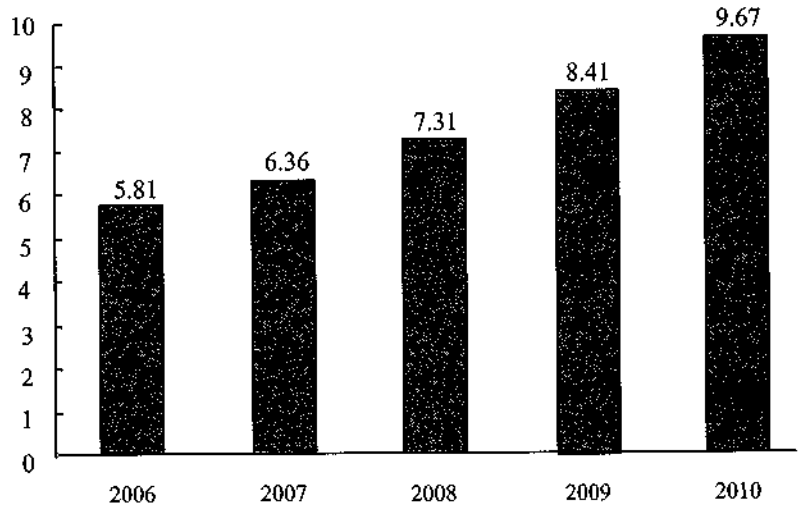

Figure 9. China's current and estimated future total alcohol output (million tonnes) from 2006 to 2010.

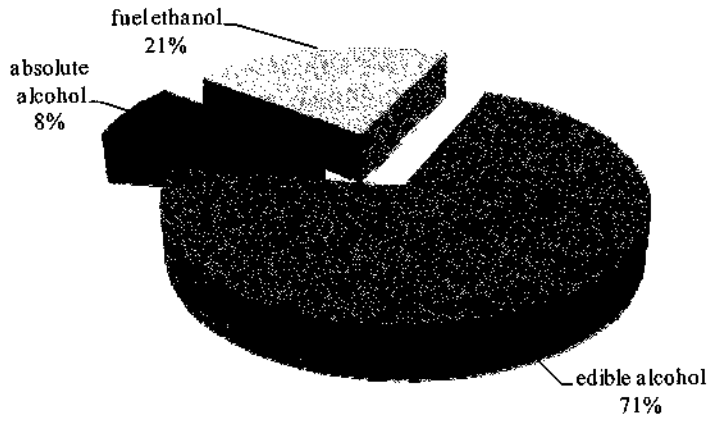

Figure 10. The use of fermentation ethanol products in China.

Although China started late in the bio-fuel ethanol industry, it has been developed rapidly, and fuel ethanol has a very bright future in China. Initially, fuel-ethanol production in China used stored grain for fermentation such as corn and wheat, especially corn, and fuel-ethanol production provided a huge market for agricultural products at that time. However, with the expansion of the production scale of fuel-ethanol and the rapid development of other grain-based products, the stored grain supply was rapidly depleted and there is now an increased demand for grains. The grain situation in China has changed from being fully self-sufficient into today's being in-short supply, and it is even related to the national food security problem. Therefore, this is a very good opportunity for the use of

cassava in ethanol production.

In October 2006, the first domestic cassava-based fuel ethanol project with annual output of 0.2 million tonnes, invested by COFCO, started construction in Guangxi. This had been approved by the National Development and Reform Committee and it was the first breakthrough of domestically producing clean energy using non-grain crops as the raw material. This project started operation in December 2007, which was followed by the use of 10% gasohol (E_{10}) within Guangxi province on April 1, 2008. Currently there are ten provinces in China using E10 gasoline.

2. Supply and demand situation of the cassava ethanol industry

As cassava fuel-ethanol has not been widely promoted in China, the cassava ethanol output is still rather low. In 2007, total ethanol production from cassava in China was about 0.45 million tonnes, which was mainly used in the medicine and alcoholic drinks making industry.

The output of the ethanol industry is growing continuously and rapidly. In recent years, the ethanol output in areas that have raw material advantages such as Jilin province, Heilongjiang province, and Inner Mongolia have been growing rapidly, and large-scale ethanol factories are emerging continuously. In 2007, there were 15 ethanol factories that have each an annual output capacity of over 0.1 million tonnes, while five of them have an output of over 0.3 million tonnes. Due to the national policy of canceling the export rebates, the volume of ethanol exports has dropped dramatically. In 2007, the total ethanol export was 130 million kiloliters, with an average monthly export around 10,000 kiloliters. The profit of enterprises in this industry is still low.

At present, potable ethanol still dominates the industry, but the market is tending to saturate and the output growth is slow (**Table 6**). The growth of fuel ethanol and dehydrated ethanol is very fast. The future market of fuel ethanol is especially bright, and its market position has been raised gradually. Therefore, there will be a huge market for cassava ethanol being used as fuel-ethanol.

Table 6. Ethanol output of various types in China in 2006 and 2007 (mil. tonnes).

	Fuel ethanol	Potable ethanol	Dehydrated ethanol	Total
Annual output in 2006	1.220	4.125	0.465	5.810
Annual output in 2007	1.335	4.516	0.509	6.36
Increment	0.115	0.391	0.044	

3. Cost analyses of cassava ethanol

Compared with corn ethanol, the cost of ethanol from cassava per tonne is about 1,600 RMB lower. Calculated with the selling price of 5,600 RMB/tonne for cassava ethanol, plus that of the by-products produced during the production process, the profit is about 1,000 RMB/tonne for cassava ethanol even without the subsidy (**Table 7**).

China has currently finished building four fuel-ethanol factories (by license), with a fuel-ethanol output in 2006 of about 1.2 million tonnes. According to the national medium- and long-term development plan for renewable energy, by 2010, the annual use volume of non-grain-based fuel ethanol in China will reach 2 million tonnes while the annual use volume of bio-diesel will reach 0.2 million tonnes; by 2020, the annual use volume of fuel ethanol will reach 10 million tonnes while the annual use volume of bio-diesel will reach 2 million tonnes.

Table 7. Comparison of the cost of producing fuel alcohol from cassava and other crops (RMB)[1] during the 2007/2008 harvest season.

	Fresh cassava	Dried cassava	Sugar cane	Molasses	Corn	Wheat	Potato	Sweet -potato
Raw material price (¥/t raw material)	450	1,250	380	900	1,530	1,640	800	480
Consumption (t raw material/t ethanol)	7	2.8	16	5	3.2	3.28	9	8.7
Raw material cost (¥/t ethanol)	3,150	3,500	6,080	4,500	4,896	5,379	7,200	4,176
Processing cost (¥/t ethanol)	800	600	700	500	800	800	800	800
Total Ethanol production cost (¥/t ethanol)	3,950	4,100	6,780	5,000	5,696	6,179	8,000	4,976
Sale price (¥/t ethanol)	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600
Profit (¥/t ethanol)	1,650	1,500	-1,020	600	-96	-579	-2,400	624

[1] 1 USA = 6.8 RMB

***Source**: Chen Mingyu. "Cassava is one of the important crops for ethanol production", presented in website of "Chinese Cassava Starch & Ethanol" in 2008.*

4. Effects of "Renewable Energy Law" on cassava further processing

This law spells out the definition of renewable energy, which includes wind energy, solar energy, hydraulic energy, biomass energy, geothermal energy, ocean energy etc; it also includes a series of supporting policies for the development and use of fuel-ethanol renewable energy. In 2007, the National Development and Reform Committee stated clearly that grain is no longer to be used as raw material for biomass energy, and industrial crops will be used instead. The "Temporary Managing Measures of Special Funds for Renewable Energy Development", published by the Ministry of Finance, stated clearly that,

"bio-ethanol fuel refers to the fuel ethanol produced from sugarcane, cassava, and sweet sorghum."

China's cassava is mainly planted in southern provinces such as Guangxi, Hainan, Yunnan, and Guangdong, among which Guangxi is the most important producer. In China, the role of cassava has had some major changes during its history, but it has never decreased or disappeared; on the contrary, it is becoming more popular. For over one hundred years, because of its easy-planting and good harvest, cassava has become very popular and has now become one of the most important traditional crops, especially for farmers who live in rural hilly areas, where they have to plant cassava, not only as an industrial crop but also as a feed crop, as well as a food crop once in a while. Thus, cassava is very necessary in many places. Because of its recent development as a renewable source of energy, cassava will become more and more adopted by the people in China. About 50% of cassava is currently intercropped with short-term crops like peanut, watermelon, soybean, maize, etc. since we have limited arable land resources.

V. The Current Situation and Future of Cassava as an Animal Feed

1. Current situation

Traditionally speaking, the ways of utilizing cassava as animal feed in China are as follows:

a) Leaves

Cassava leaves are one of the most favorite leaves that herbivorous fish like. As its protein content is much higher than that of good quality grass, cassava can be a good substitute of grasses used to feed fish, especially in the fall and winter (Oct to Jan) when the grass is dried up and it is difficult to find green feed. Cassava leaves can be used for feeding fish. In many places when the cassava is 3-6 months old, i.e. from Jul-Oct every year, farmers will pick 10-20 leaves at the bottom of the cassava stem to throw into the fish pond. The top of the cassava stem (around 30 cm) will be broken off after November. According to the farmers, the reason to remove it is that the cassava roots are already formed completely at that time, and there is no need to keep too many leaves. By breaking off the leaves at the top, it can prevent the wasting of nutrition while continuing the accumulation of starch in the roots. This is very common in many cassava planting areas.

Using cassava leaves to feed silk-worm also has a long history in China; it is an economic income source for farmers in some areas.

It is also very common to feed pigs with cassava leaf silage. Chop the cassava leaves into small pieces, add some rice bran, waste molasses and cassava meal (5% and 10%), pack it tight in a plastic bag or store it in the cellar to make the silage ferment and release

the hydrocyanic acid by evaporation. The cassava leaf silage with a protein content of 27-30% can be stored for more than five months. Mixed with other coarse fodder, it can be a good substitute for fishmeal or soybean meal with very good effect. Farmers don't use fresh cassava leaves to feed poultry, because the leaves contain hydrocyanic acid (HCN) which can be toxic if used directly as feeds. During fermentation into silage, the HCN of cassava leaves will be acidified, and the level of HCN is markedly reduced, while the nutrition of the leaves will still be in tact with some extra micro-protein. Cassava leaf silage is soft and tasty for poultry. Developing pig husbandry with cassava leaves can help to reduce the problem of a decline in soil fertility caused by the planting of cassava, as we can use the pig manure to fertilize the soil.

b) Roots

The most common ways of using roots as animal feed is to make dry slices. In the past, most cassava was of the sweet variety which is edible for both humans and animals, so cassava was usually minced and boiled directly to feed poultry; there was no need to detoxify the cassava. Now, most cassava is of the bitter variety (because the yield is normally higher than of the sweet type) and it is rare to boil these and eat it directly. The harvested cassava is normally made into dry slices and stored in a well-ventilated and dry place (close to the kitchen), where it is kept as feed. There are several ways to use it as feed. Either pound the dry slices and mix with other materials (corn, sweetpotato, taro and their stems etc), then boil the mixture. Pig feed is normally used this way.

The main form in which cassava is being fed to animals is dry slices. There are two ways of using as follows: one is for farmers who are far away from the market and from processing factories, so it is difficult from them to ship their cassava roots due to the high cost of transport and low profit. They normally make the fresh roots into dry slices to sell or for feeding. The other way is through the commercial feed processing factories, because cassava is the main raw material most of the time. In many hilly areas where farmers plant cassava, such as in Guangxi and Yunnan, 70-80% of cassava is used for animal feeding.

c) Cassava pulp from starch processing

This is a very important kind of animal feed in major cassava producing areas. China produces 0.9 million tonnes of cassava starch every year, as well as about 0.3 million tonnes of cassava pulp (semi-dry), 100% of which will be used as animal feed, mostly for pig feeding. Cassava pulp can be stored for a long time after being air-dried. It can also produce a tasty feed after fermentation, thus it is very popular with farmers, especially those who live in major cassava starch production areas, such as Wuming, Nanning, Longan, and Yongning counties in Guangxi, as well as Honghe in Yunnan, where cassava pulp is commonly used as feed. As cassava pulp itself contains very little protein and fat, it

is normally used as the base material. To improve the nutritional quality, such as protein and amino acids, farmers usually add their home-grown corn and soybeans into the feeds. In recent years, cassava pulp after fermentation is usually used to feed beef cattle, especially for fattening the cattle. It not only reduces the cost of raising cattle, but it also has a good effect on the cattle, because they like the taste, so the cattle will eat more and grow faster.

2. Developing trends in the future

Cassava pulp is the fibrous residue left after starch extraction and from cassava ethanol production. It has been one of the favorite cheap feeds for poultry raisers for a long time. Cassava solid residue has a relatively high nutritional value with nitrogen-free extract in the dry matter as high as 70.35%, while also being rich in vitamins and amino acids. However, because of the low crude protein content (around 1.8%), low crude fat content (around 0.28%), high content of coarse fiber (over 12%), low useful energy value (digestable energy and metabolizable energy), and some toxic substances such as hydrocyanic acid, as well as difficulties in storage, cassava residues will turn brown or black easily by aflatoxins. This is the reason for its low use in poultry raising (the use rate in pigs is less than 10%), while animal sickness and toxicity always happens.

In Guangxi, fermented cassava pulp is of good quality and has been promoted as feed for many years. Usually Shengjiaoji (a type of yeast starter) is used for fermenting the cassava pulp (it takes around 15 days), but now a coarse fodder enzyme is being used, so the fermentation time has been shortened greatly (it takes around one day). At present, the number of people using cassava pulp as a raw material to produce feeds by fermentation has greatly increased as compared to those who use other technologies. In the past, the number of farmers boiling the cassava pulp was less than 10%. Now with this fermentation technology, its use rate for sows can reach as high as 90% (90% for non-pregnant periods and pre-pregnant periods), as high as 50% for fattening pigs and around 40% for poultry. What's more, cassava pulp is not only used for feeding pigs but also for feeding poultry such as chicken, duck, and geese. In Guangxi, Guangdong and Hainan, nearly 80% of poultry raisers are using cassava fermented feeds.

The cassava fermented feeds produced by these micro-organic yeast starters can greatly improve the taste and sweetness, dramatically increase the content of crude protein, and effectively turn the inorganic nitrogen source into protein. With various complex enzymes to degrade the coarse fiber, systemic enzymes, mineral trace elements, and various vitamins, amino acids, calcium, hydrogen phosphate and calcium gluconate, the pH of the feeds is decreased during fermentation, and harmful bacteria and fungi cannot exist (these germs do not grow in an acidic environment). Also, the toxic substances in cassava pulp, such as hydrocyanic acid and linamarin, are degraded and eliminated during fermentation

by anaerobic microorganism, and the complex of enzymes starts to degrade the crude fiber in cassava pulp, resulting in a fragrant and tasty feed. Cassava pulp is no doubt the most popular feed in the future.

VI. Challenges in the Future

The development of the bio-energy industry has made cassava into a popular crop, and marks a new phase for the cassava industry. However, for cassava researchers, it is a big challenge that China's cassava output is far behind the rapidly increasing market demand. China is importing 10 million tonnes of cassava fresh root equivalent every year. According to the plan, because of the increasing demand for bio-fuel during the next five years, the new cassava market demand of China will increase by another 7.5 million tonnes; in total it will be 25 million tonnes. If China's own output can not be increased dramatically, how should we fill this huge gap? Should we continue to rely on importing cassava? What should we do to decrease this importation and save foreign reserves? How to improve the cassava output based on currently available land area, and at the same time to increase the profit of farmers planting cassava?

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CURRENT SITUATION AND FUTURE POTENTIAL OF CASSAVA IN CAMBODIA

Ung Sopheap[1]

ABSTRACT

In Cambodia cassava has rapidly changed its role from a food crop to an industrial crop, with a high rate of growth during the past two years. There are about 295 small-scale cassava starch factories and 27 small-scale sago processing operations in Kampong Cham province, and about seven medium-scale factories processing cassava roots into starch in Cambodia, each with a processing capacity of about 200 tonnes of fresh roots/day.

Cassava is commonly grown only for root production in Cambodia. It is a popular crop for farmers because it is easy to grow, resistant to drought and tolerant of low soil fertility. The crop also produces higher yields than most other upland crops. Several varieties have been used in different parts of the country. In general, cassava is still cultivated only for root production, either for industrial processing or for small-scale food production.

Cassava can be utilized not only for human consumption but also for animal feed. Cassava could be a high-demand crop for either domestic use or for export because it has a multiplicity of end-uses, including animal feed, starch, sweeteners and ethanol. Some farmers like to produce starch to be used for making bread or other food items in their small processing units, or they can make dry chips for sale. However, cassava yields in Cambodia have traditionally been low (at 9.61 t/ha in 2000) as the crop was basically used only for direct human consumption after boiling.

Farmer participatory approaches are now being used to evaluate new cassava varieties, fertilizers and agronomic practices as well as the use of cassava roots and leaves for animal feeding, in order to enhance the adoption of improved cassava varieties and agronomic practices, as well as its utilization, with the aim of increasing farmers' income.

Very recently cassava in Cambodia has changed from a traditional human food to an efficient crop for use in animal feed and for starch production; cassava has become an important source of cash income for poor farmers. Cassava production in the country has nearly quadrupled in the past three years, from 535,600 tonnes in 2005 to over 2 million tonnes in 2007. This was achieved by a marked increase of the planted area, from 30,000 ha in 2005 to over 100,000 ha in 2007, and by a significant increase in yields, from 17.9 t/ha to 20.5 t/ha.

It is hoped that cassava growing can become a good source of income for poor farmers and that cassava research can receive more support from the government, other organizations and from the private sector; these should work together to create good market conditions and to improve cassava research and extension in Cambodia.

Key words: Cassava, starch, improved varieties, agronomic practices, productivity, ethanol, research, extension

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) has its origin in Latin America where it has been grown by the indigenous Indian population for at least 4000 years. After the discovery of the Americas, European traders took the crop to Africa as a potentially useful food crop; later it was also taken to Asia to be grown as a food security crop in southern India, as well as on Java Island of Indonesia and in the southern Philippines, while in Malaysia and parts of Indonesia it was also used for extraction of starch After the Second World War it

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became an important industrial crop in Thailand, mainly to produce starch for local consumption, and dry chips and later pellets for the rapidly growing European animal feed market.

Cassava in Cambodia has rapidly changed it role from a food crop to an industrial crop in the beginning of the 21st Century. In 2006, the area planted to cassava was 96,324 hectares with a total production of 2.18 million tonnes of fresh roots and an average yield of 22.65 tonnes per hectare (FAOSTAT, 2009). Compared to 1997, the productivity increased threefold (average yield in 1997 was 7.68 t/ha).

Cassava has been known and planted by Cambodian farmers since the 19th Century. The planted area of this crop has slightly increased over the years. In general, cassava is cultivated for root production, either commercially or on a small scale for food consumption. This crop is popular with farmers in the northeast and eastern part of the country, especially for people that live in upland areas, but some farmers in the lowlands also planted cassava around their homes and used the crop for food consumption (MAFF, 2003).

Before the 1970s the crop was planted in small areas, especially on loamy type soils and along river banks, in upland environments and on red soil types in some parts of the country. Between 1975 and 1979 this crop was a very important food crop because during this time of civil war in the country, the people did not have enough rice to eat, so they always used cassava for food instead of rice.

Presently, this crop is being planted in many parts of the country, from sea level to upland areas. Statistics of the Ministry of Agriculture, Forestry and Fisheries (MAFF) indicate that cassava was grown in 24 provinces and cities in a total area of 29,975 hectares in 2005 with an average yield of 17.87 t/ha (MAFF, 2008) and the total production was 535,623 tonnes..

Farmers in Cambodia have always used their traditional practices for growing cassava and there was never any research conducted concerning planting method to produce higher yields of this crop.

This paper will describe the current situation of cassava in Cambodia and its future potential.

CURRENT SITUATION OF AGRICULTURE IN CAMBODIA

1. Agricultural Production

Rice is by far the dominant crop in Cambodia and about 85-90% of the cultivated area is planted to rice (**Table 1**). Cassava is the second most important crop, both in terms of area planted and total production.

2. Cassava Production in Cambodia and Other Asian Countries

Cassava production in Cambodia is characterized by a rather low production in a limited area, but with high yields as compared to other Asian countries (**Table 2**).

Table 1. Agricultural production in Cambodia in 2007.

Crop	Harvested area (ha)	Production (tonnes)	Yield (t/ha)
Rice	2,517,095	6,264,030	2.49
Cassava	**108,122**	**2,215,427**	**20.49**
Maize	105,297	376,938	3.58
Soybean	64,382	98,289	1.53
Mungbean	75,486	58,890	0.78
Sesame	46,612	24,789	0.53
Peanut	13,596	23,811	1.75
Sweetpotato	9,349	45,285	4.84
Sugarcane	8,296	141,704	17.08
Jute	449	575	1.28
Tabacco	8,768	14,220	1.62
Vegetables	43,986	222,893	5.07

***Source:** MAFF, 2008.*

Table 2. Cassava harvested area, production and yield in Cambodia and other countries in 2007.

Country	Harvested area ('000 ha)	Production ('000 tonnes)	Yield (t/ha)
World	**18,545**	**224,132**	**12.09**
Africa	11,905	114,021(51%)	9.58
Americas	2,804	36,945(16%)	13.17
Asia	3,816	72,922(33%)	19.11
Cambodia	***108***	***2,215***	***20.51***
China	*269*	*4,362*	*16.24*
India	*255*	*8,232*	*32.22*
Indonesia	*1,201*	*19,988*	*16.64*
Lao PDR	*11*	*233*	*21.19*
Malaysia	*41*	*430*	*10.49*
Myanmar	*17*	*211*	*12.79*
Philippines	*210*	*1,871*	*8.93*
Sri Lanka	*23*	*220*	*9.75*
Thailand	*1,174*	*26,916*	*22.92*
Timor-Leste	*12*	*49*	*4.14*
Vietnam	*495*	*8,193*	*16.53*

***Source:** FAOSTAT, 2010.*

3. Cassava Production in Cambodia

In Cambodia cassava production and yield have increased recently due mainly to the increasing number of factories established and improved market conditions. The production, harvested area and yield were 69,656 tonnes of cassava fresh roots, 13,000 ha, and 5.36 t/ha, respectively in 1996. But when both the domestic and export market demand increased and the price of cassava increased, production, harvested area and yield also markedly increased up to 2,215,427 tonnes of cassava fresh roots, 108,122 hectares and 20.49 t/ha in 2007 (**Table 3**).

Table 3. Cassava production, harvested area and yield in Cambodia from 1996 to 2007.

Year	Harvested area (ha)	Production (tonnes)	Yield (t/ha)
1996	13,000	69,656	5.36
1997	10,060	77,270	7.68
1998	8,208	66,534	8.11
1999	14,003	228,512	16.32
2000	15,380	147,763	9.61
2001	13,590	142,262	10.47
2002	19,284	122,014	6.33
2003	25,039	330,649	13.21
2004	22,507	362,050	16.09
2005	29,975	535,623	17.87
2006	96,324	2,182,043	22.65
2007	**108,122**	**2,215,427**	**20.49**

Source: *MAFF, 2008.*

In 2007/08, the price of cassava fresh roots in Cambodia increased to an extremely high level of up to US$ 70-75 per tonne, as compared to only US$ 30-35 per tonne in the previous year (**Figure 1**).

Table 4 shows the cassava harvested area, yield and production in the main cassava producing provinces of Cambodia in 2001 and 2007. In the six years between 2001 and 2007 the cassava harvested area increased almost eight times, yields nearly doubled from 10.5 to 20.5 t/ha, and production increased from 142,262 to 2,215,427 tonnes (**Figure 2**). Especially between 2004 and 2007 the cassava area and production increased rapidly in response to changing market conditions. Much of the cassava produced in Kampong Cham is exported to Vietnam, while increasing amounts of cassava produced in Battambang province and Pailin Town are exported to Thailand. In Kampong Cham there are now five medium, large and very large cassava starch factories, while there are 295 backyard operations producing cassava starch, and 27 small-scale operations producing noodles and sago pearls. There is also one cassava starch factory in Samlot district of Battambang province and another one in Kampong Speu (**Table 5**); the latter is currently not operating. This factory in Kampong Speu processed mainly cassava roots from its own

2,000 ha plantation, but finally closed in 2007, after incurring financial losses for four consecutive years due to lack of raw material.

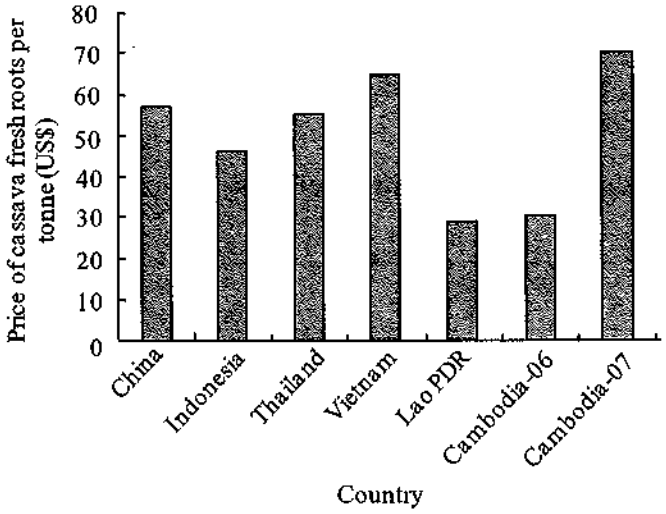

Figure 1. Price of fresh cassava roots in various countries in Asia in 2007 in comparison with the price in Cambodia in 2006 and 2007.
***Source:** Tin Maung Aye and P.Khanthavong ,2007.*

Table 4. Cassava harvested area, yield and production in the major cassava producing provinces and in all of Cambodia in 2001 and 2007.

	Harvest area (ha)		Production (tonnes)		Yield (t/ha)	
Province/City	2001	2007	2001	2007	2001	2007
Banteay Mean Chey	8	8,047	120	83,286	15.00	10.35
Battambang	146	10,747	903	441,900	6.18	41.12
Kampong Cham	4,740	53,798	67,051	1,082,660	14.15	20.12
Kampong Thom	1,880	1,743	19,660	13,206	10.46	7.58
Kratie	334	7,118	3,016	42,708	9.03	6.00
Mondulkiri	52	5,806	208	89,993	4.00	15.50
Preah Vihear	120	4,835	1,200	51,493	10.00	10.65
Siem Reap	865	1,254	10,243	16,026	11.84	12.78
Svay Rieng	568	3,296	4,444	24,616	7.82	7.47
Pailin	7	6,517	35	325,850	5.00	50.00
Total Cambodia	**13,590**	**108,122**	**142,262**	**2,215,427**	**10.47**	**20.49**

***Source:** MAFF, 2008.*

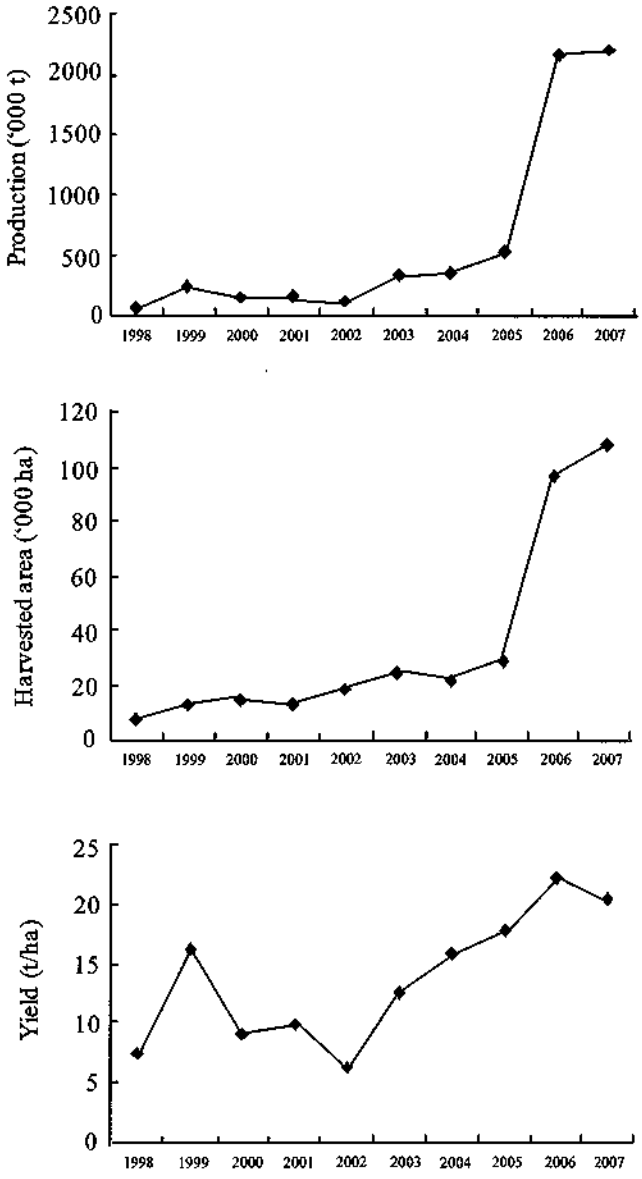

Figure 2. Cassava production (top), harvested area (middle) and yield (bottom) in Cambodia from 1998 to 2007.
***Source:** MAFF, 2008.*

Table 5. Cassava processing factories in Cambodia in 2007.

Type of factory	No. of factories	Name of factory	Location		Capacity	Buying price ($/ t fresh roots)
			District	Province		
Starch (large)	1	C.J Cambodia Co.	Phnom Srouch	Kampong Speu	200 t fresh roots/day	30-35 (2006)
Starch (large)	1	Private (unknown name)	Samlot	Battambang	100-200 t fresh roots/day	70 (2007)
Starch (small)	295	Farmer owned	Tbong Khmom	Kampong Cham	small	70 (2007)
Sago, noodles & flour (small)	27	Farmer owned	Tbong Khmom	Kampong Cham	small	-
Starch (medium)	1	Heng Sok San	Prey Chor	Kampong Cham	30 t fresh roots/day	72.5 (2007)
Starch (large)	1	Choun Ath	Ponea Kreak	Kampong Cham	100 t fresh roots/day	75 (2007)
Starch (large)	1	Seng Hong	Ponea Kreak	Kampong Cham	100-200 t fresh roots/day	70-75 (2007)
Starch (large)	1	Private (unknow name)	Ponea Kreak	Kampong Cham	100-200 t fresh roots/day	70-75 (2007)
Starch (very large)	1	TTY	Memout	Kampong Cham	800 t fresh roots/day	76 (2007)
Ethanol factory (very large)	1	MH Bio-energy Co	Ponear Leu	Kandal	870 t fresh roots/day →144,000 l ethanol/day	-

Source: *Statistic of DOA, Kampong Cham*

Figures 3 and 4 show the cassava growing areas of Cambodia in 2001 and in 2007, respectively. Recently, the cassava areas have expanded rapidly in Battambang, Kampong Cham and Pailin provinces with the building of cassava starch factories in Kampong Cham and Battambang, and a cassava-based ethanol factory in Kandal (**Table 5**).

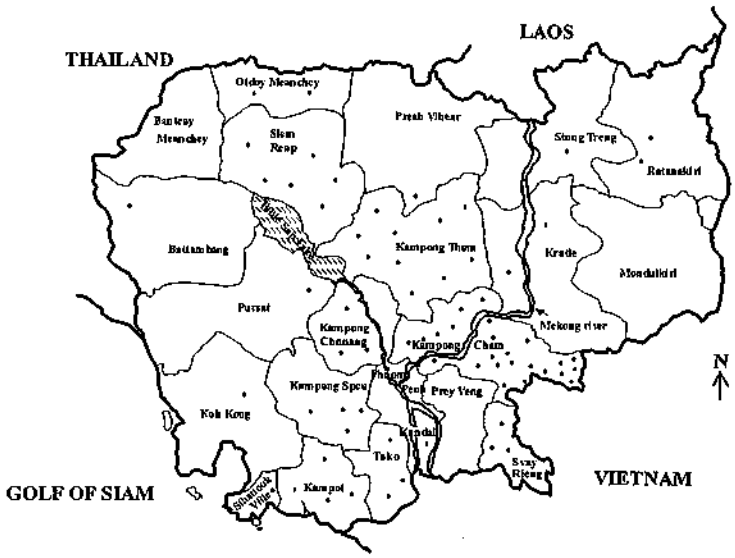

Figure 3. Distribution of cassava growing areas in Cambodia in 2001. Each dot represents 200 ha.

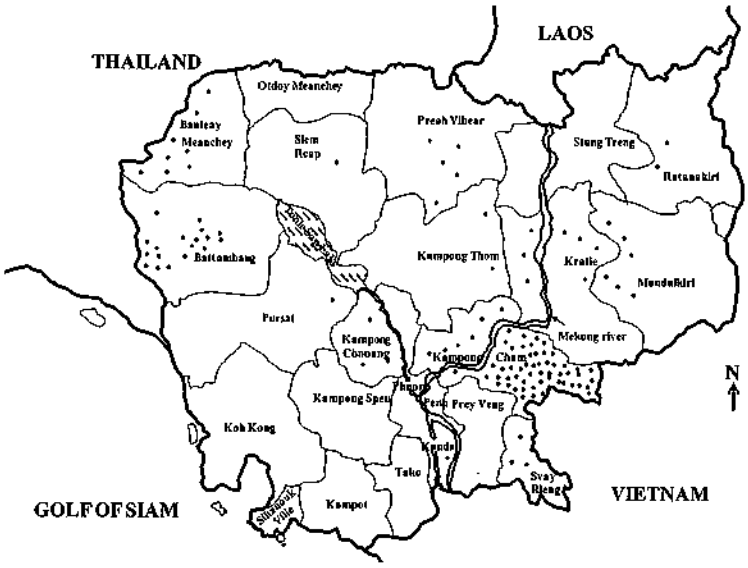

Figure 4. Distribution of cassava growing areas in Cambodia in 2007. Each dot represents 1,000 ha.

FUTURE POTENTIAL

In Cambodia, cassava has been used mainly for human consumption and for animal feeding. However, it is now becoming an important industrial crop, used mainly for production of cassava starch and animal feed, and recently also for production of fuel ethanol.

To maintain cassava competitiveness in the Cambodian market, much future research is required to increase yields, and reduce production costs. This can be achieved by the integration of production, processing and marketing through the active collaboration of various institutions involved, and through an effective partnership between the public and private sector.

In Cambodia, cassava has rapidly changed its role from a traditional human food crop to an industrial crop, and an efficient crop for animal feeding. Much of the cassava roots are now used for starch production and cassava has become an important source of income for many resource-poor farmers.

There are currently about 295 small-scale cassava starch factories and 27 sago and noodle processing operations in Kampong Cham province, and about seven large starch factories with a total processing capacity of about 1,500 tonnes of fresh roots/day. It is hoped that the number of starch factories will continue to increase in the near future so that cassava can become a valuable crop and an important source of income for Cambodian upland farmers.

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CASSAVA RESEARCH AND DEVELOPMENT IN THE PHILIPPINES

Algerico M. Mariscal[1]

ABSTRACT

Since the 7th Regional Cassava Workshop, held in Bangkok in 2002, the cassava industry in the Philippines has gained a quantum leap in terms of demand and utilization. Research and development has focused on varietal improvement that addresses the need for food, feed and raw materials for industrial use.

Thirteen new cassava varieties have been registered in the National Seed Industry Council (NSIC) and were released for utilization for food, feed and industry in the last six years. Major characteristics of these varieties are high yield, high dry matter and starch content, low to medium HCN, and field tolerance to pests and diseases. One very interesting variety is KU 50 from Thailand which passed the necessary requirements for registration and is now registered as NSIC Cv-22. This variety is now planted in more than 3,000 ha in Mindanao; this is expected to further increase in two years time to address the need for feed, and more recently, as a feedstock for bio-ethanol production. This variety can be considered an Asian variety considering its wide adaptation in practically all Asian countries.

The demand for cassava as a raw material source for the animal feed industry has also increased tremendously. San Miguel Corporation has a road map for 100,000 ha of cassava to be used for feed until 2010. Since the passage of the Biofuel Act in 2006, which mandates the use of a mixture of at least 10% ethanol in gasoline fuel in 2010, numerous investors have been coming to the country to engage in ethanol production using cassava as its feedstock. Investors from Korea, Japan and China are now looking at areas for cassava production in order to set up ethanol plants. Each ethanol plant needs 8,000 to 10,000 ha of cassava to produce about 100,000 liters of ethanol per day.

The government is supporting a national cassava planting material production and distribution system, to be located in strategic production areas, to enhance the fast introduction of newly developed varieties for both the feed and biofuel sectors. It is envisioned that it will take 4-5 years for a new variety to be distributed and widely used.

In order to balance food security with the need for fuel using bio-energy crops like cassava, the existing production areas devoted for animal feed should not be used for ethanol. Other areas that are not utilized will be put to use for this purpose

Our future research direction is also geared toward breeding cassava varieties that will address climate change, in addition to maximizing its use in multiple value-adding processes. Also, the long-term sustainability of cassava production will be addressed.

INTRODUCTION

The world-wide economic crisis experienced since the middle of 2007 has posed a tremendous pressure on developed and developing countries alike in searching for ways and means to address this crisis. The fossil fuel cost has risen to a level that has caused a concomitant increase in the price of almost all basic commodities necessary for human existence. It is a fact that the fossil fuel reserve will not last forever. Therefore, various alternative sources of fuel were identified and are being studied for possible use, including bio-energy crops that will help lessen the dependence on fossil fuels.

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In the Philippines, crops like cassava, sugarcane, sweet sorghum, maize and other starchy crops are identified to be possible sources of raw material for the production of ethanol that can be used in a blend with gasoline in the transportation sector. The passage of the Biofuel Act of 2006, allowing the voluntary blending of fuel-ethanol with gasoline at 10 to 20%, has resulted in the search for possible feedstock for the production of ethanol. The Biofuel Board during its meeting agreed that in the Philippines, cassava, sugarcane and sweet sorghum be the best sources for the production of ethanol. Maize was not selected for this use considering that it is better used in the food and feed industries.

Cassava is one of the important calorie-producing crops in the tropics, including in the Philippines. It is efficient in carbohydrate production, well adapted to a wide range of environments, and tolerant to drought and acidic soils (Jones, 1959; Rogers and Appan, 1970; Kawano *et al.*, 1978; Cock, 1982). Throughout the tropics, small farmers grow cassava in areas with poor soils using traditional methods of cultivation. The major portion of the economic product of cassava is the roots, which are consumed in varying forms for food, feed and for various industrial uses. To date, cassava is increasingly being used for animal feed, industrial starch and ethanol; as such, it is becoming an important source of cash income to a large number of small farmers (Mariscal *et al.*, 2007).

The PhilRootcrops cassava breeding program, through its strong collaboration with CIAT for more than two decades, has developed new varieties that are specific for the intended markets, i.e. food, feed and industry. This is the outcome of a systematic breeding program that includes enhanced germplasm collection and evaluation, generation of advanced breeding materials, and varietal selection and dissemination through the collaborative efforts of the National Cooperative Testing Program of Cassava in the country. The new cassava varieties are now widely grown in cassava areas in the country (Mariscal *et al.*, 2001). The main benefit resulting from the planting of new cultivars is their higher productivity, which in turn results in greater economic benefits for the target population of small, medium and large farms or plantations in the country.

CURRENT STATUS OF CASSAVA PRODUCTION AND UTILIZATION

Between 2003 and 2008 cassava fresh root production in the Philippines has increased from 1.6 to 1.9 million tonnes (**Figure 1**); the total area of production has slightly increased from about 204,000 to 212,000 ha in 2008. With increasing market demands for cassava it is expected that the area of production will continue to increase. In fact, San Miguel Corporation's feed requirement is 100,000 ha, but they were only able to plant 40,000 hectares.

The average yield of cassava, according to data of the Bureau of Agricultural Statistics, is only 9.8 t/ha which is very low compared to other Asian countries. This information, however, is the total of all cassava growers ranging from very marginal to commercial farms. Because of the non-observance of good production practices by many small farmers in marginal areas, their yields are very low bringing down the national average. However, in areas where cassava is more widely grown the production data is very different (**Table 1**).

By far the most important cassava producing region in the Philippines is the Autonomous Region of Muslim Mindanao (ARMM), which accounts for more than three fourth of the total area. The average yield in the region is 10.76 t/ha. The highest yields are found in Region 10, or Northern Mindanao, with an average of 22.07 t/ha. In a properly managed cassava farm in this area the reported yield was 30 t/ha. The arrival of foreign and local investors who want to use cassava as a feedstock for ethanol production has put pressure on the area of production of cassava.

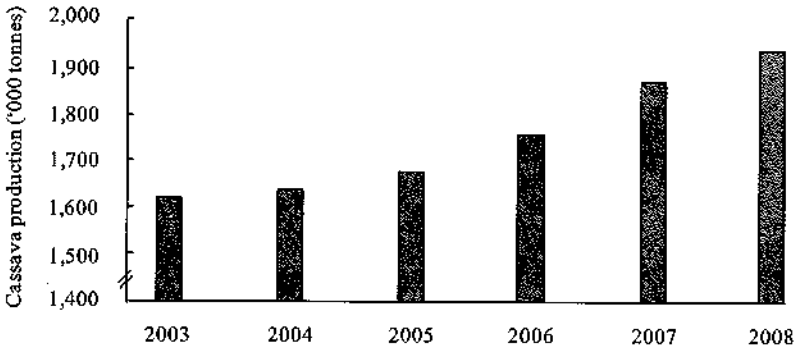

Figure 1. Cassava production in the Philippines from 2003 to 2008
***Source:** FAOSTAT, 2010.*

Table 1. Cassava area, production and yield of the top ten cassava producing regions in the Philippines in 2009.

Regions	Planted area (ha)	Production (tonnes)	Yield (t/ha)
ARMM[1)]	94,113	1,012,330	10.76
Region X (Northern Mindanao)	18,933	417,942	22.07
Region V (Bicol Region)	22,895	115,112	5.03
Region VII (Central Visayas)	13,701	106,078	7.74
Region VIII (Eastern Visayas)	22,165	73,194	3.30
Region VI (Western Visayas)	6,665	60,966	9.15
CALABARZON	8,150	54,786	6.72
CARAGA	7,631	47,885	6.27
Region II (Cagayan Valley)	3,090	38,545	12.47
SOCCKSARGEN	1,884	31,313	16.62

1) Autonomous Region of Muslim Mindanao
2) Data Source: BAS 2010

In the Philippines cassava is generally used for food, which accounts for 75% of total production (**Figure 2**). In fact, cassava is the staple food among muslims in Mindanao, especially in areas of Tawitawi, Basilan and Jolo islands. Only 20% is utilized for starch and 5% for feed, although recently this has increased as a result of a large demand in commercial cassava meal for feed formulations.

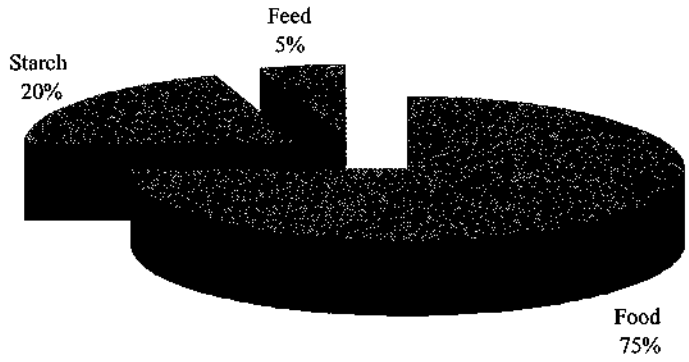

Figure 2. Cassava utilization in the Philippines.

Cassava used for food is basically in processed form. The muslim population in southern Mindanao prefer partially fermented cassava grates. Other areas in the country use cassava for bread, cakes, *cacharon*, *pitsi-pitsi* and in other forms. Marginal farmers in isolated areas eat cassava roots after cooking.

In the livestock sector, cassava meal is generally used as an energy source in feed formulations, replacing maize. The biggest user of cassava for feed is the San Miguel Corporation. The company needs 100,000 ha of cassava to satisfy the growing market of feed formulations for the livestock industry. Only 37,000 ha of cassava have materialized of the projected 100,000 ha. Aside from San Miguel there are other feed millers that now produce cassava-based feed formulations, thus making cassava roots a product in high demand. Feed millers normally buy cassava in the form of dry chips or granulated cassava meal.

The starch industry in the country is presently also in dire need for more cassava raw material. At present there are three very active starch companies in the country that utilize cassava for starch. PhilAgro Corporation in Baungon, Bukidnon has more than 2,000 ha of cassava that utilize NSIC Cv-22 (KU 50) for starch production. Still, the company operates at 50% capacity due to lack of raw materials. The Matling Agricultural Corporation at Malabang, Lanao del Sur has 3,000 hectares of corporate farms to support the mill. The company also uses the new cassava varieties developed by PhilRootcrops. The PhilStarch Corporation in Carmen, Bohol also has a massive campaign for planting cassava for starch. The company has a campaign for ten towns in Bohol to plant cassava. The starch millers normally buy fresh cassava roots directly from the farmers.

CASSAVA RESEARCH AND DEVELOPMENT

Varietal Improvement

The cassava breeding program of PhilRootcrops has for more than two decades developed new cassava varieties that are now registered in the National Seed Industry

Council (NSIC) for national release to the end-users. The progress in breeding was made possible through the strong collaboration with CIAT/Colombia and CIAT/Thailand in terms of genetic material introductions and institutional capacity building.

1. Objectives

The cassava breeding program aims to satisfy the needs of the farmers who grow cassava in diverse agro-climatic conditions, as well as the special requirements of processors who utilize the storage roots in various ways. The breeding objectives are as follows:

1. High yield
2. High dry matter and starch content
3. Low cyanide content for the fresh market
4. Resistance to pests and diseases
5. Good plant type

The level of hydrogen cyanide (HCN) in cassava, although not correlated with yield, is also considered during selection. Low-HCN varieties are identified and selected for farmers who use cassava as a staple food. High-HCN varieties, on the other hand, are used by starch processors because they tend to produce high yield and have high starch contents, while discouraging thefts. Those varieties having both low HCN and high dry matter and starch contents are considered dual-purpose varieties (for table use and processing) (Mariscal *et al.*, 2007).

2. Breeding and selection strategy

The breeding and selection scheme of the Center is patterned after the CIAT cassava germplasm improvement scheme (Mariscal, 1987).

Figure 3 shows the breeding and selection scheme used by the breeder, from germplasm collection, hybridization, F_1 seed observation, preliminary trial, single row trial, general yield trial, advanced yield trial, multi-location or regional yield trial, and multiplication and release. The regional trials are conducted in at least ten locations throughout the country for two cropping seasons prior to recommendation and release.

3. New cassava varieties developed and released.

From 2002 to 2007 the cassava breeding program of PhilRootcrops was able to evaluate 14 cassava varieties, and all of these were subsequently approved by the National Seed Industry Council (NSIC) for recommendation, and were released as new varieties for end-users to plant (**Table 2**).

This pool of new improved cassava varieties are now being multiplied and will be distributed to different cassava growing areas in the country. The latest cassava varieties, the NSIC Cv- 43, 44 and 45 were identified as good varieties for ethanol production. These three varieties with their detailed characteristics are presented in **Tables 3, 4** and **5.**

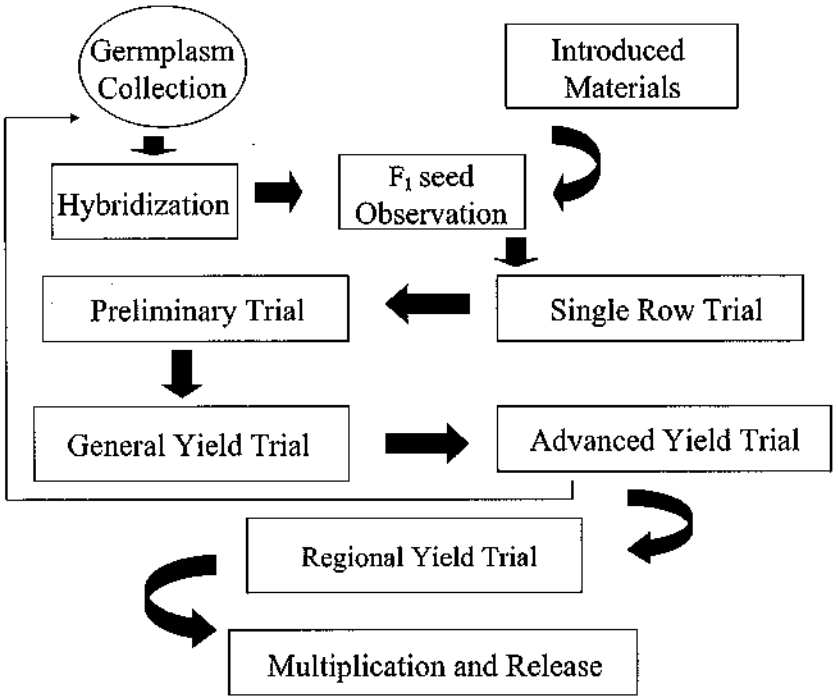

Figure 3. Cassava breeding and selection methodology.

Table 2. Cassava varieties from PhilRootcrops released for cultivation from 2002 to 2007.

Variety Name	Ave. yield (t/ha)	Root dry matter (%)	Root starch content (%)	HCN	Use[1)]
1.NSIC Cv-21 (SM 818-1)	28.2	38.2	27.6	Intermediate	S, Fe
2.NSIC Cv-22 (KU-50)	31.3	38.0	38.0	Intermediate	S, Fe, Fd
3.NSIC Cv-23 (OMR 33-12-3)	26.1	38.9	28.5	Intermediate	S, Fe
4.NSIC Cv-24 (OMR 33-12-7)	24.1	38.0	27.2	Intermediate	Fd, S
5.NSIC Cv-28 (OMR 36-05-09)	29.1	40.1	30.1	Low	Fd, Fe, S
6.NSIC Cv-30 (CMR25-105-112)(Rayong 5)	32.4	40.1	29.4	Low	Fd, Fe, S
7.NSIC Cv-32 (CM 9165-17)	31.4	38.0	29.1	Low	Fd, Fe, S
8.NSIC Cv-34 (CM 9175-25)	31.5	41.9	32.8	Intermediate	S, Fe, Fd
9.NSIC Cv-35 (CMR 37-24-1)	42.3	39.0	29.1	Intermediate	S, Fe, Fd
10.NSIC Cv-36 (OMR 36-62-03)	31.5	41.8	27.5	Intermediate	S, Fe
11.NSIC Cv-38 (SM 2065-2)	32.3	39.2	27.8	Intermediate	S, Fe, Fd
12.NSIC Cv-43 (OMR 40-40-03)	38.2	39.8	26.9	Intermediate	Fl, S, Fe
13.NSIC Cv-44 (CMR 39-50-18)	29.7	41.4	28.6	Intermediate	Fl, S, Fe
14.NSIC Cv-45 (OMR 39-48-2)	31.0	41.5	30.1	Intermediate	Fl, S, Fe

[1)] S = Starch, Fe = Feed, Fd = Food, Fl = Flour

Table 3. Varietal characteristics of variety NSIC Cv-43 (OMR 40-40-03), NSIC Cv-45 (OMR 39-48-02) and check variety NSIC Cv-22 (KU 50).

Varietal characteristics	Variety NSIC Cv-43 (OMR 40-40-03)	Variety NSIC Cv-45 (OMR 39-48-02)	NSIC Cv-22 (KU 50) Check variety
A. Root yield (t/ha)[1)]			
- Fresh	38.2	29.5	33.7
- Dry	16.2	12.9	13.7
B. Root dry matter content (%)			
- Oven-drying method	39.8	43.6	40.7
- Specific gravity method	38.7	41.6	39.4
C. Root starch content (%)	26.9	30.1	28.6
D. Root HCN content[2)]	4.9 moderate	4.6 moderate	6.8 moderate
E. Root peduncle length (cm)	1.8	1.7	1.8
F. Maturity period (month)	10-12	10-12	10-12
G. Reaction to pests and diseases[3)]			
- Scale insects	2.5 resistant	2.1 resistant	2.4 resistant
- Spider mites	3.0 resistant	2.5 resistant	2.5 resistant
- Brown leaf spot	2.0 resistant	1.7 resistant	2.0 resistant
- Cassava bacterial blight	1.8 resistant	1.8 resistant	1.5 resistant
H. Root skin color	light brown	light brown	cream
I. Root cortex color	cream	yellow	cream
J. Root flesh color	white	yellow	white
K. Stem color	silver green	silver green	silver green
L. Foliage color	green older leaves & green-purple young leaves	green older leaves & green-purple young leaves	green older leaves & purple young leaves
M. Growth habit	slightly branching	moderately branching	erect

[1)]Based on trials where the new varieties and the check variety were together
[2)]Using picrate test with rating scale; 1-4 low, 5-6 moderate, and 7-9 high HCN
[3)]Based on infestation rating scale; 1 = highly resistant to 9 = highly susceptible

BIO-ETHANOL FUEL PROGRAM

The rising cost of fossil fuel and the environmental concern among countries globally has triggered the national government to find ways and means to at least reduce our dependence on fossil fuel and minimize the environmental effects. The passage of the Biofuel Law in the Philippines in 2006 was a very significant step towards attainment of the long-term objectives of the bioethanol fuel program. The biofuel program in the Philippines aims to:

1. Reduce dependence on imported oil
2. Increase economic activity in the countryside
3. Boost employment
4. Be environmentally friendly
5. Improve combustion and reduce emissions.

If the ethanol blend with gasoline in the country is only 5% the ethanol requirement will be 266 million liters, and this will require nine ethanol plants and at least 63,610 ha of sugarcane or 47,936 ha of cassava. Increasing the blend to 10% will require 721 million

liters of ethanol, produced by 16 ethanol plants, with 171,091 ha of sugarcane or 131,091 ha of cassava. (**Table 5**).

Table 4. Varietal characteristics of variety NSIC Cv-44 (CMR 39-50-18) and check variety NSIC Cv-22 (KU 50)

Varietal characteristics	Variety NSIC Cv-44 (CMR 39-50-18)	NSIC Cv-22 (KU 50) Check variety
A. Root yield (t/ha)[1)]		
- Fresh	29.7	30.9
- Dry	12.3	12.6
B. Root dry matter content (%)		
- Oven-drying method	41.4	40.7
- Specific gravity method	38.7	39.4
C. Root starch content (%)	28.6	28.6
D. Root HCN content[2)]	4.3 moderate	6.8 moderate
E. Root peduncle length (cm)	1.7	1.8
F. Maturity period (month)	10-12	10-12
G. Reaction to pests and diseases[3)]		
- Scale insects	1.8 resistant	2.4 resistant
- Spider mites	2.2 resistant	2.5 resistant
- Brown leaf spot	1.7 resistant	2.0 resistant
- Cassava bacterial blight	1.6 resistant	1.5 resistant
H. Root skin color	light brown	cream
I. Root cortex color	yellow	cream
J. Root flesh color	cream	white
K. Stem color	light brown	silver green
L. Foliage color	green older leaves & light green young leaves	green older leaves & purple young leaves
M. Growth habit	slightly branching	erect

[1)]Based on trials where the nominated variety and check variety were together
[2)]Using picrate test with rating scale; 1-4 low, 5-6 moderate, and 7-9 high HCN
[3)]Based on infestation rating scale; 1 = highly resistant to 9 = highly susceptible

Table 5. Fuel ethanol demand and supply requirements.

Blend percentage	Ethanol requirements in million liters	Total no. of ethanol factories required	Planting area required (ha)	
			Sugarcane	Cassava
5%	266	9	63,610	47,936
10%	721	16	171,091	131,091

***Source:** DOE, 2006.*

In order to balance food security and utilization of cassava for biofuel, it is highly recommended that there should be varieties specific for food, feed and fuel. Low-HCN cassava varieties are intended for food and feed, while medium- to high-HCN varieties with high dry matter and starch contents can be used for starch and ethanol production. By so doing, all specific requirements of cassava utilization are addressed.

Cassava as Raw Material for Bio-ethanol

Since the passage of the Biofuel Law in 2006 several investors have shown interest to set up an ethanol factory in the country. The law provides for the voluntary use of a 10% blend of ethanol to gasoline between 2005 and 2007; a nationwide use of 5% blend by mid-2007 to 2009, and a nationwide use of 10% blend by 2010. The National Biofuel Board has agreed that in the Philippines only sugarcane, cassava and sweet sorghum will be used for ethanol production. Maize is not allowed to be used as raw materials for ethanol production considering that this crop is generally used for food as well as feed for livestock.

So far, PhilKor, a Philippine Korean Bioethanol project, has initiated setting up an ethanol plant in Cagayan Valley in northern Philippines with a capacity of 110,000 liters a day. Around 15,000 ha are identified for cassava production in the area. The initial plantation of cassava NSIC Cv-22 (KU 50) was established and will be scaled up in the years to come. Another company, the Alson Group is putting up an ethanol factory in Cagayan de Oro in Mindanao. The company is negotiating for a 10,000 ha cassava plantation to support the plant. And Basic Energy in Zamboanga is planning to set up an ethanol plant with a 10,000 ha cassava plantation to support the plant.

Many others are on the drawing board for possible investment. With strong government support it is expected to have enough ethanol production in the country. At the moment there is one big ethanol plant located in San Carlos City in Negros Occidental that produces ethanol using sugarcane as the raw material. The ethanol production is still insufficient to meet the expected blend provided by the Biofuel Law of 2006.

As far as cassava is concerned, PhilRootcrops has developed new varieties that can be used in the production of ethanol. These are presented in **Table 6**.

These new cassava varieties have yields ranging from 29 to 38 t/ha at ten months. Dry matter contents ranged from 39 to 43%. Looking at the ethanol conversion, NSIC Cv-43 has high ethanol production of 6,823 liters/ha, followed by NSIC Cv-44 with 6,039 liters/ha. The other two varieties also have quite high ethanol production potential. These varieties are the latest released by the National Seed Industry Council. The advanced populations from which these varieties were selected are from seed of the Thai/CIAT cassava program introduced in 1992.

Table 6. Comparative performance of NSIC CV-43, NSIC Cv-44, NSIC Cv-45 and check variety NSIC Cv-22 in 12 trials (2004-2007).

	Root yield (t/ha)		Dry matter content	Starch content	Estimated ethanol conversion/ production			Pests rating	
Variety	Fresh	Dry	(%)	(%)	(l/t)	(l/ha)	HCN	Insects	Mites
NSIC Cv-43	38.2	15.2	39.8	26.9	179	6823	4.9 M	2.5 R	3.0 R
NSIC Cv-44	31.7	13.1	41.4	28.6	190	6039	4.3 M	1.8 R	2.2 R
NSIC Cv-45	29.5	12.9	43.6	30.1	200	5896	4.6 M	2.1 R	2.5 R
NSIC Cv-22 (Check)	31.2	12.7	40.7	28.6	190	5925	6.8 H	2.4 R	2.5 R

M = Moderate H = High R = Resistant

NATIONAL CASSAVA SEED PIECES DISTRIBUTION SYSTEM

In order to address the growing demand for new cassava varieties for feed and industrial uses, the National Cassava Seed Pieces Distribution System was initiated with funding from the GMA Corn Program of the Department of Agriculture. The program aims to provide quality cassava planting materials to all regions of the Philippines. Cassava nurseries using new cassava varieties were set up in major cassava growing regions in the country (**Figure 4**). PhilRootcrops will provide primary planting material to the four major nurseries identified. These are located in Cagayan Valley Integrated Agricultural Research Center (CVIARC) in Isabela in Region 2; the Central Visayas Integrated Agricultural Research Center (CENVIARC) in Ubay, Bohol in Region 7; the Northern Mindanao Integrated Agricultural Research Center (NOMIARC) in Dalwangan, Malaybalay, Bukidnon in Region 10; and in the Central Mindanao Integrated Agricultural Research Center (CEMIARC) in Bololmata, Tupi, South Cotabato in Region 11. The project started in 2007 with a five hectare nursery per site using NSIC Cv-22 (KU 50) and NSIC Cv- 30 (Rayong 5) varieties. The 20 ha planted in 2007 became 200 ha in 2008. These nurseries will cater to the needs of planting material in cassava growing areas in each region. With collaboration of the Department of Agriculture, a nursery will be established in each region of the country using the materials from the four major nurseries previously established. It is planned to have a 4-5 year cycle for a variety to be widely grown nationwide.

To support the nursery sites, a series of trainings related to cassava rapid propagation, nursery management and cultural management of cassava were undertaken to ensure that the cassava planting material produced is healthy and of good quality, which will bring about increases in yield.

The cassava seed system is the avenue through which the distribution of high-quality planting materials is enhanced. Introduction of new cassava varieties will be through the cassava seed system established, which is self liquidating.

FUTURE RESEARCH DIRECTION

The cassava research and development in the Philippines will continue to do the following:

1. Continue to develop cassava varieties intended for specific uses, such as for food, feed, and fuel.
2. Breeding for important characters to address climate change.
3. Integrated soil management to address sustainable cassava production.
4. Integrated pest and disease management.
5. Multisectoral collaboration in providing raw material to various industries, such as bio-ethanol, starch and feed.
6. Joint government and private sector efforts in technology transfer.

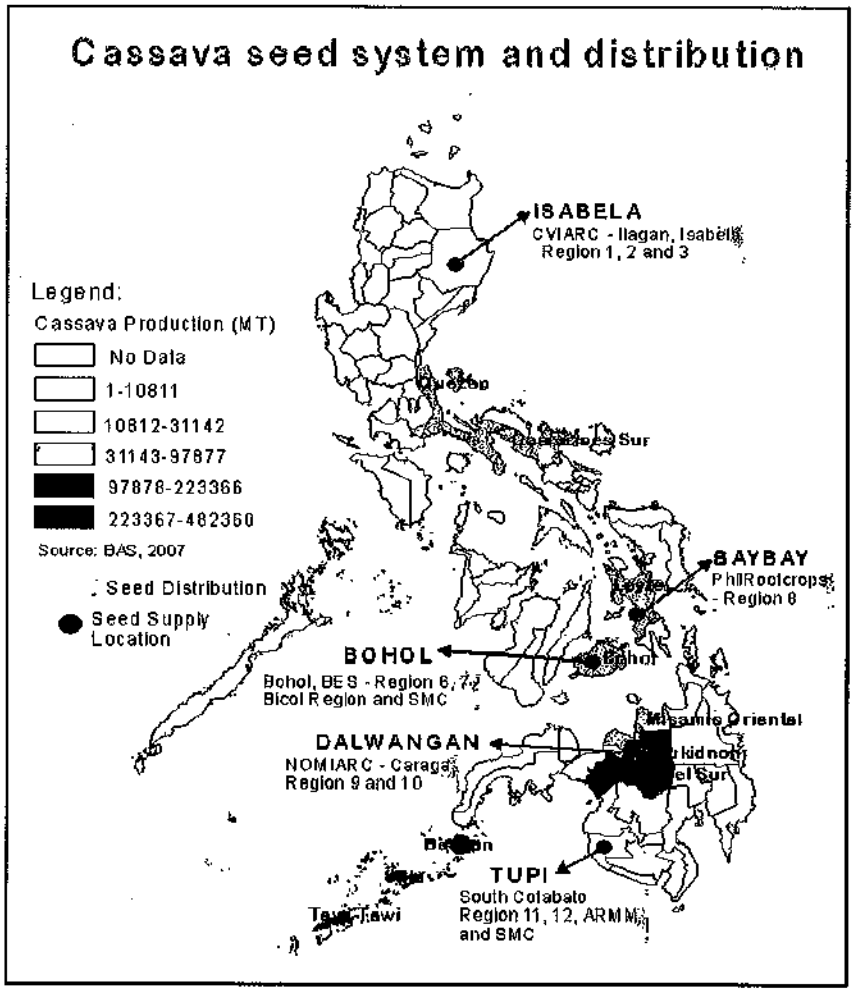

Figure 4. Cassava seed system and distribution.
***Source:** BAS, 2007.*

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CASSAVA: GETTING A NEW LEASE ON LIFE IN MALAYSIA?

Tan Swee Lian[1] *and Engku Ismail bin Engku Ahmad*[2]

ABSTRACT

The cassava industry in Malaysia has gone through several phases of change. From the time of its introduction into the country, cassava moved from being a small farmer cash crop to an industrial crop producing starch for local use and for export. This profitable starch industry of the 1960s and 1970s was severely curtailed with the enforcement of laws against "illegal" cultivation, and this was exacerbated by strong competition from Thailand in the 1980s. Small farmers switched to planting the higher-priced edible varieties for the snack and fresh food markets.

In recent years, due to changing global scenarios, there has been a revival of interest in planting cassava on a large scale. To counter the rising prices of fossil fuels, production of bio-ethanol and biodegradable plastics using cassava as the raw material has become a distinct possibility. The concurrent increase in the cost of importing maize has also led to the appeal of locally-grown cassava as an energy source in feed rations. At the same time, there is a developing trend in using cassava to produce snacks and frozen products on a commercial scale for the export market. MARDI's role in providing technologies to match the requirements of these new industries remains relevant, and has expanded to cover advisory/consultancy services in project planning and management.

INTRODUCTION

Cassava has had a long history of cultivation in Malaysia, having been introduced in 1836 from Batavia (old Dutch name for present-day Jakarta), Indonesia (Burkill, 1935). It has largely been a small farmer crop, but it drove two distinct markets – the industrial market for starch, and the smaller fresh market for food. The dominance of one market over the other has switched over the years.

Trends in Production and Utilization

1. Production

The production of cassava in Peninsular Malaysia peaked in 1976 at 20,913 ha, thereafter declining drastically to stabilize around 2,000 ha a year (**Figure 1**). It is interesting to note that the distribution of cassava cultivation has changed over the years (**Table 1**), with Perak state having the largest area in 1980, whereas by 2007 production had moved to Johor state.

This shift in planting reflects the change in dominance, from supplying the starch market to supplying the fresh food market. Growing cassava for the *kerepek* (oil-fried crisps) and other snacks dominates in Johor where a subsidiary of a biscuit manufacturer produces cassava-based snacks for the export market. Indeed, currently there is no planting of starch varieties (previously predominant in Perak). Farmers are no longer keen on growing the starch varieties because (1) they fetch a price which is about half that of the edible varieties; (2) they take longer (12 months *vs* 8-10 months) before they are harvested;

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and (3) available land is getting too scarce for the formerly profitable practice of "plant – leave – harvest" in the 1970s.

However, the shift does not imply that the starch demand has diminished. On the contrary, it has been steadily growing as the next section shows.

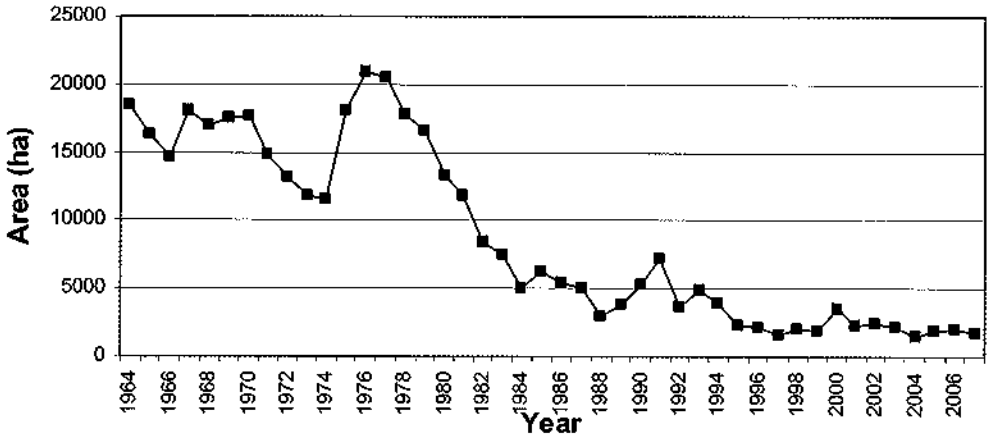

Figure 1. Area of cultivation of cassava in Peninsular Malaysia (1964-2007).

***Source**: Anon, 1966a-2008a.*

Table 1. Areas of cassava cultivation (ha) by state in Malaysia in 1980, 1997 and 2007.

State	1980	1997	2007
Perlis	9	0	0
Penang	35	63	36
Kedah	660	16	10
Perak	10,851	388	91
Selangor	157	124	192
Negeri Sembilan	56	23	5
Melaka	22	1	5
Johor	246	445	1,143
Pahang	76	7	15
Terengganu	186	10	10
Kelantan	214	191	55
Sabah	0	0	254
Total	**12,512**	**1,268**	**1,816**

***Source**: Anon, 1982a, 1999a, 2008a.*

2. Utilization (as reflected by imports and exports)

In the 1960s and 1970s the cassava industry in Malaysia was geared towards starch production, and the country was a major starch exporter to the United Kingdom, Japan, Canada, USA, other European countries such as Belgium, Luxembourg, Germany, Netherlands and Portugal and Singapore (Chan *et al.*, 1983). In the 1980s, Thailand became the world's largest exporter of cassava products, and it became cheaper for Malaysia to import starch from Thailand than to produce it locally. The import-export situation has changed drastically since 1994 when imports outstripped the annual exports of starch and starch products in the 1970s (**Figure 2**).

Starch is used in several industries, the more important of which are the manufacture of monosodium glutamate (until recently), glucose, cardboard cartons and paper products, and vermicelli (Anon, 2001c). Ajinomoto (Malaysia) Berhad, the main manufacturer of monosodium glutamate, used to require 18,000 tonnes of starch per year. Faced with problems such as difficulty in sourcing starch supplies locally, having to import starch, and the need for pollution and wastewater management, the company recently switched to using glutamic acid as the raw material for manufacturing the food enhancer.

Nevertheless (except for the extraordinary jump in 2000), there has been a steady increase in starch imports, indicating that demand is still strong.

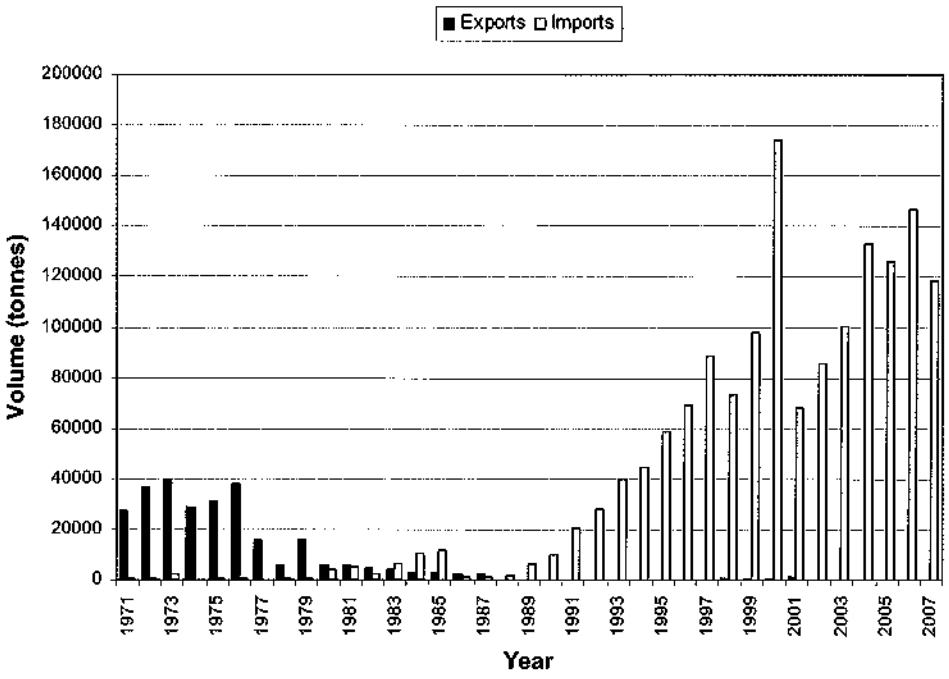

Figure 2. Imports and exports of starch and starch products, Malaysia (1971-2007). ***Source:*** *Anon, 1973b-2008b.*

It is interesting to note that of late there have been some imports and exports of non-starch cassava products (**Figure 3**). In the case of imports, these are very likely cassava-based feedstuffs. Although classified as "residues of starch manufacture and similar residues", it was noted that the price per tonne of this item was as high as RM 1,842 (USD 529) (Anon, 2008b), which qualifies it to be a feedstuff.

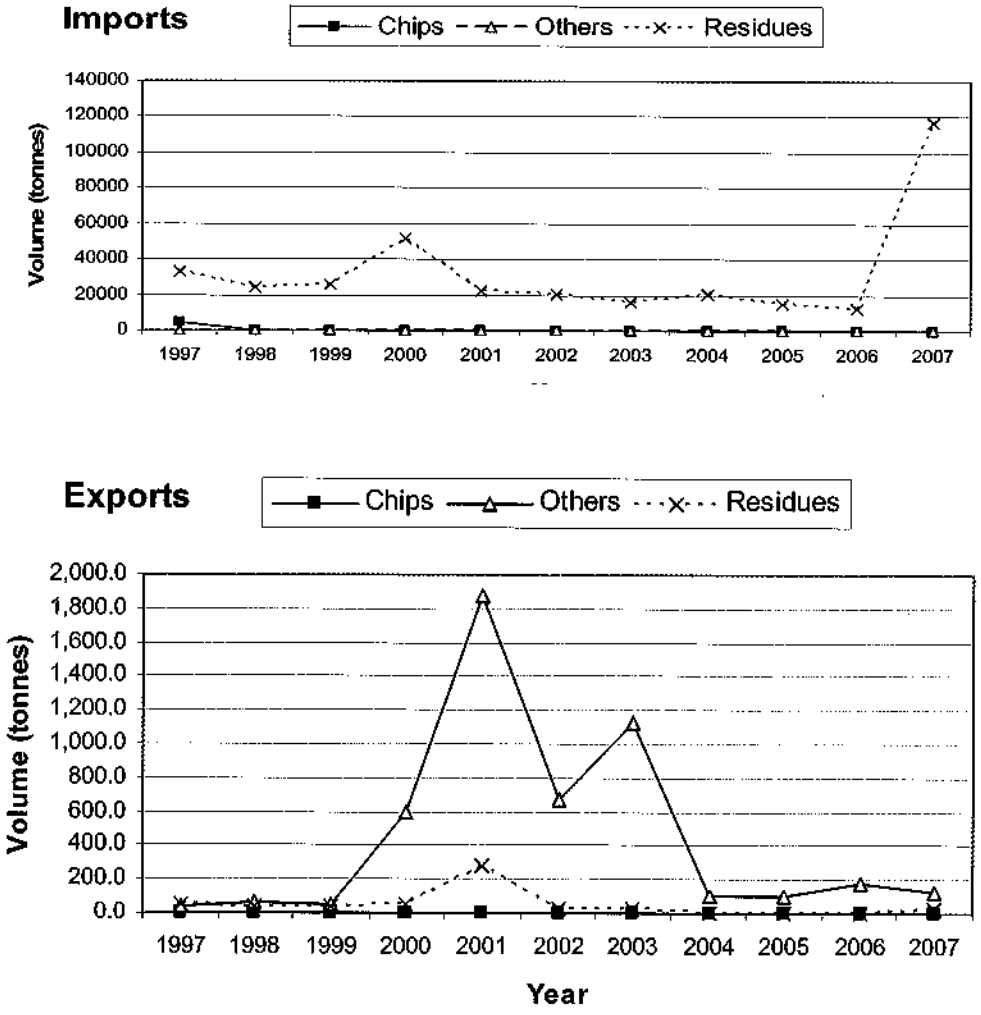

Figure 3. Imports and exports of non-starch cassava products, Malaysia (1997-2007).
Note: "Others" refers to cassava, other than dried or in the form of pellets;
"Residues" refers to residues of starch manufacture and similar residues
Source: *Anon. (1999b-2008b)*

In the case of exports, the outstanding item over the last ten years is classified as "cassava, other than dried or in the form of pellets". This is very likely a combination of frozen cassava food products (such as cassava *tikki*, balls, crinkle-cut fries and quick frozen cassava blocks) and variously flavored cassava chips currently being exported by a few local food processors. Apparently, there is a growing demand for cassava food products among the African and Asian migrant populations in Europe and USA. Also, the market for snackfoods has much room for exploitation. For example, the crisps market in the United Kingdom alone is estimated to grow at 2.5% per year (Eyre, 2007).

Recent Changes in the Malaysian Scenario

In recent years and months, Malaysia (as with the rest of the world) has faced escalating prices in fossil fuels. This has led to corresponding increases in the prices of grains due to higher fertilizer and freight costs. Of particular interest to Malaysia is grain corn which is a major component in the feeds for the local poultry and pig industries. Grain corn is totally imported (current figures put the volume at around 2.5 million tonnes per year) – from countries as near as Thailand, Indonesia and Vietnam, and as far away as China, the United States of America (USA) and Argentina. Prices have been rising steadily, and lately, the price of grain corn has reached as high as RM 1,420 (USD 408) per tonne. This is exacerbated by difficulties in even sourcing for supplies. One of the reasons for demand outstripping supply in the world market for corn is the increasing use of corn for conversion into biofuel in the US.

Facing a shortage of grain corn for use in feed formulations, Malaysian feed millers have turned to other alternatives, e.g. wheat (until the high prices also thwarted this move) and cassava (which hitherto had not been the preferred energy source among local feed millers).

Another pertinent development has been the growing public awareness of consequences to the environment from the use of fossil fuels. It is well-known that burning fossil fuels causes the emission of greenhouse gases (GHG), which have led to global warming and its effects in triggering extreme climate phenomena. By contrast, biofuels made from renewable crop resources is more environment-friendly, cutting back GHG by significant amounts (**Table 2**). In terms of net energy ratio (defined as the number of energy units produced for every unit of energy used in making the biofuel), it is evident that cassava is in fact more efficient than corn in producing bio-ethanol, but lags behind sugarcane (**Figure 4**).

Other than the problem of GHG emissions, plastics made from fossil fuels are non-biodegradable, staying undecomposed for anything from 100 to 1,000 years in landfills, clogging drains (and causing floods), and killing marine life by entanglement (causing turtles and sea mammals to drown), laceration, suffocation and ingestion (being mistaken for jellyfish). A move has been made by the Malaysian government to encourage the use of biodegradable plastic bags and food containers. Biodegradable plastics are of course made from starch produced by renewable crop resources – of which cassava is an option.

Revival of interest in cassava

The changes in the ways to utilize cassava have resulted in a revival of interest in growing this crop in Malaysia. This may be gauged from the many requests for technical advice, advisory services, feasibility studies and project development over the past two

years (**Table 3**). Topping the lists are enquiries on the use of cassava for starch production, biodegradable plastics and bio-ethanol. There was also interest in using cassava for snack food and livestock feed.

Table 2. Net energy ratios and greenhouse gas emission for biofuels produced from selected materials.

Material	Net energy ratio	Greenhouse gas emission	
		kg/L	Reduction
Sugarcane	8.3	1.08	56%
Sugarbeet	1.9	n/a	35-56%
Corn	1.35-1.5	1.94	22%
Cellulose from corn stover	4.39	n/a	n/a
Cellulose from switchgrass	8.3	n/a	n/a
Cellulosic ethanol	2-36	0.23	91%
Bio-diesel from canola	2.5	0.91	68%
Bio-diesel from soybean	2.5-3.0	n/a	41%
Bio-diesel from palm oil	6.0-9.5	n/a	>70%
Petrol	1.0	2.44	0%
Diesel	1.0	2.80	0%

Source: Adapted from Anon, 2006d; 2007d,e.

Moving from Research to Development/Commercialization

Despite the current mounting interest in growing cassava for bio-ethanol, biodegradable plastics and livestock feed, the varieties and technologies resultant from past research remain very much relevant.

In all three cases, high starch varieties are necessary to ensure good conversion rates. Thus, the varieties Sri Kanji 1 and Sri Kanji 2, released by MARDI in 2003, will fit the bill (Tan, 2001; Mohsin *et al.*, 2005). Again, for all three as well as for starch, in order to offset the lower root price (so much disfavored by small farmers), it would be necessary to consider growing cassava on a larger commercial scale with plantation management, integrated with downstream processing to the preferred final product. Thus, field mechanization packages, with machine selection tailored to the scale of operation and prevailing soil conditions, will be helpful in ensuring the success of the enterprise. MARDI has invested much time and effort in testing and modifying machines and packaging them into practical systems. These machines include implements for land preparation, planting and fertilizer application, chemical and mechanical weed management, shredding of above-ground plant parts prior to harvest, root harvest (digging and lifting) and in-field transportation of inputs and outputs (Sukra and Tan, 1994; Md Akhir and Sukra, 2007). Most of the agronomic practices developed for manual planting of cassava can be adopted for mechanized planting as well, e.g. fertilizer recommendations. One exception is plant

spacing; instead of the 1 m x 1 m square planting, spacing has to be adjusted to suit the width of the tractor wheels for planting and harvesting in particular.

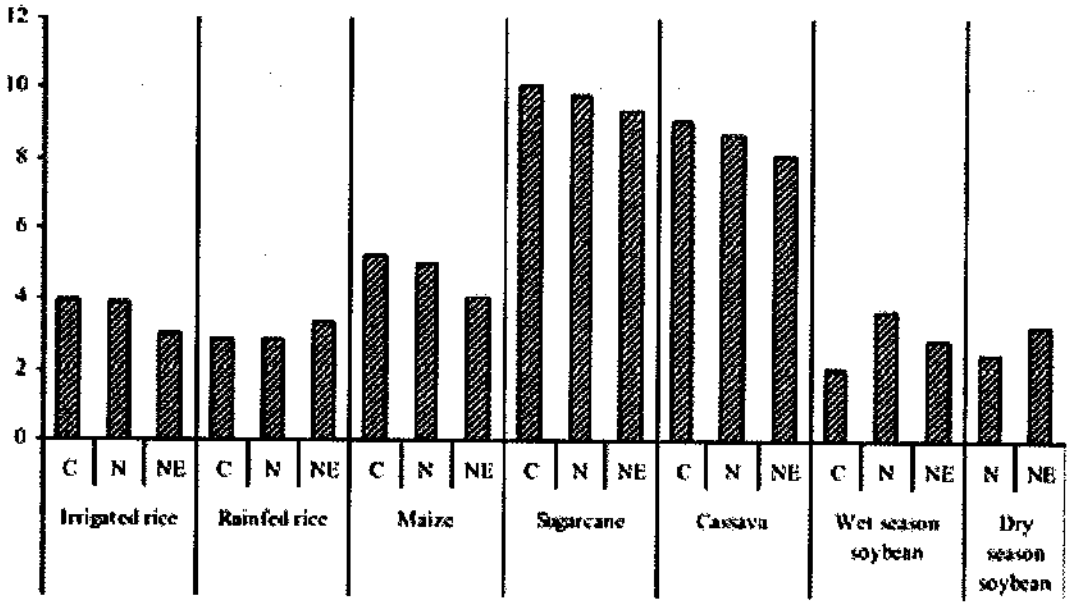

Figure 4. Energy ratios for different crops and regions in Thailand.
Note: C=Central plain, N=North and NE= Northeast
***Source**: Anuchit et al., 2006.*

For the making of snacks and frozen cassava food products for the local and export markets, MARDI has the variety Sri Pontian to offer. Sri Pontian outyields the current farmer varieties Ubi Kuning, Ubi Putih and Medan (Tan and Abd. Rahman, 2001).

Services required of MARDI these days are not only as a generator of technologies, but also in project planning and management, involving:

1. Assessment of soil/land suitability (in relation to crop and mechanization) in the proposed plantation area
2. Selection of variety to suit end-use, and multiplication of planting materials
3. Selection of field machines and formulation of machinery system
4. Crop scheduling and scheduling of field operations
5. Estimation of manpower requirements
6. Environmental impact assessment, and
7. Economic viability.

Table 3. Enquiries on cassava received by MARDI since 2006.

Year	Number of enquiries			Type of interest/enquiry
	Individuals	Companies/ Institutions	Total	
2006	3	5	8	Starch (including maltodextrin)
	3	4	7	Biodegradable plastics
	1	5	6	Bio-ethanol
	2	1	3	Livestock feed
		3	3	Snackfood
	5	4	9	Others (*Codex Alimentus* for "sweet" cassava, status, use of stems and leaves, integration with goats/with oil palm, leaves as an antihelminthic in sheep, production technology, fermentation products)
2007	3	2	5	Biodegradable plastics
	2	3	5	Bio-ethanol (including drinking alcohol)
	1	3	4	Snackfood
	1	2	3	Starch (including maltodextrin)
	2	1	3	Livestock feed (including fish)
	8	2	10	Others (production technology, table varieties, market potential)
2008	3	5	8	Starch
	1	6	7	Bio-ethanol (including drinking alcohol)
	1	3	4	Biodegradable plastics
		1	1	Livestock feed (including fish)
		2	2	Snackfood
	6	3	9	Others (varieties, cosmetics, production technology, peels, characterization, pests and diseases)

Depending on the end-product, there will be a need to estimate farm size in relation to factory capacity, to schedule cropping to keep the factory in constant supply with raw materials for processing, to select machines and design the factory, as well as items 5-7 in relation to the factory and processing.

Currently, MARDI is in the process of providing consultation to a feed milling company which has a strong interest in producing dried cassava chips as feedstuff for their own poultry business. The proposed scale of cassava production is about 4,000 ha.

CONCLUSION

Throughout the various phases of development of the cassava industry in Malaysia, MARDI has been the paramount generator of relevant technologies – particularly in field production – to meet the changing needs. As has been long advocated by MARDI, for the value-added processing component of the cassava industry to be viable (taking into consideration the dual price structure for the edible and starch varieties), field production of the crop must be on a large scale and integrated with processing. It is not realistic to depend on small farmers to grow and supply the roots to the factory when the price they get is about half the price for the edible varieties. Of late, this has become apparent to some

newcomers and potential investors, and MARDI has expanded its research role to include advisory/consultancy services in project planning and management.

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CASSAVA PRODUCTION AND UTILIZATION IN MYANMAR

Tin Maung Aye[1] and Thant Lwin Oo[2]

ABSTRACT

In Myanmar farming systems, the role of cassava is neglected compared to that of other economic crops. Generally, cassava is not consumed as a staple food but the crop is one of the main food and feed crops for smallholder farmers living in upland areas.

Cassava has a high yield potential and can be grown under a very wide range of upland conditions. The current cassava planted area of 16,500 ha and cassava yields of 12.79 t/ha are low in Myanmar. Lack of suitable cassava varieties and agronomic practices have hampered cassava productivity in the country. Cassava has been utilized not only for human consumption and for animal feed but also for small-scale production of starch, sweeteners and drinking alcohol.

The prospects for increasing cassava production in the immediate future are very bright. Recently the demand for cassava roots has been increasing very rapidly, both inside the country and in neighboring countries, and this is a great opportunity for smallholder farmers to produce cassava commercially.

In order to increase cassava yields, farmers should adopt the planting of new improved cassava varieties and use better agronomic practices. In addition, it may be necessary to establish contractual arrangements between farmers and processors to ensure an adequate cassava supply, and that farmers gain adequate benefits. It is expected that the use of farmer participatory research and extension approaches for specific agro-ecological areas will improve cassava yields as well as the long-term sustainability of cassava-based cropping systems in Myanmar.

Key words: Cassava, improved varieties, agronomic practices, productivity, utilization, Myanmar

INTRODUCTION

Myanmar is one of the least developed countries in Southeast Asia. The agricultural sector is a crucial economic activity which contributes 38.5% of GDP, 10.6% of total export earnings and employs 63% of the labor force (Soe Myint, 2006). The agricultural sector that includes the agriculture (crops), forestry, livestock and fisheries sub-sectors is considered as the most important sector in Myanmar's economy. Particularly, the agriculture (crop) sub-sector is the backbone of the economy. About 75% of the total population resides in rural areas and are principally engaged in the agriculture, livestock and fishery sectors for their livelihoods.

Cassava has a high yield potential and can be grown under a very wide range of upland conditions (Howeler, 1991). Cassava has been utilized not only for human consumption and for animal feed, especially by smallholder farmers living in upland areas, but also for starch, sweeteners and drinking alcohol. In Myanmar farming systems, however, the role of cassava is neglected compared to that of other economic crops. The current cassava production area (16,500 ha) and cassava yield (12.79 t/ha) are low (FAOSTAT, 2010). Lack of suitable cassava varieties and agronomic practices have

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hampered the cassava productivity in the country. This paper explores a research and development strategy for cassava-based crop and livestock systems in Myanmar.

OBJECTIVES

1) To review current farming systems and identify constraints to cassava production in cropping and livestock production systems.
2) To ascertain whether current agronomic practices address the constraints on cassava production and farmers' socio-economic conditions.
3) To plan a research and development program outline that aims to investigate management practices to improve the integrated cassava-based cropping and livestock systems in Myanmar.

BASIC INFORMATION OF MYANMAR

Geographical Location, Climate and Demographic Information

The whole country of Myanmar lies between 92° 10' and 101° 11' East longitude and 9° 58' and 28° 31' North latitude. Myanmar, with a total area of 67.7 million hectares, is the second largest country in Southeast Asia; it shares borders with Bangladesh, India, China, Laos and Thailand. The central part of the country is characterized by wide rivers and expansive plains of which the largest, the Ayeyarwady, is navigable for 1600 km of its length and its flood plains form the country's main agricultural area (Thein Han *et al.*, 2001).

Myanmar has a diverse topography, climate and natural vegetation. The country has two distinct climates, tropical and sub-tropical. The northern region, approximately one third of the country, has a sub-tropical climate while two thirds of the country is tropical. The monsoon winds bring a lot of rain, which is the most important factor in the seasonal cropping cycle of Myanmar. Generally, there are three seasons: the hot season from mid February to mid May, the rainy season from mid May to mid October, and the cold and dry season from mid October to mid February. The annual rainfall, number of rainy days, and the maximum and minimum temperatures vary greatly across the country. The annual precipitation may reach about 5,000 mm along the coastal regions, and varies between 500 mm to 1,200 mm in the rest of the country. In many parts of the country the temperature rises above 38°C during the hot season, and averages 21-26°C during the cold season. But in the northern region and high in the mountains, it can get much colder and the temperature can fall to the freezing point.

In regional terms, Myanmar has the fifth largest population (approximately 58.6 million in 2007), comprising about 9% of the regional total, a growth rate of 0.9% in 2006, and the sixth highest average population density (87 people per square km) in Southeast Asia. Myanmar is also ethnically diverse because the people of Myanmar come from several different ethnic groups which provide a rich and colorful cultural and traditional mosaic.

Current Farming Systems

Successful sustainable food production depends on the integration of soil/crop/animal systems and socio-economic considerations on the development of suitable strategies. Recently, the accelerated economic development in Myanmar has widened the gap between rich and poor, as well as the gap between urban and rural communities. Absolute land ownership is vested in the state in Myanmar. Farmers are granted the right to cultivate the land, and that right can be transferred to the next generation.

Farmers' attitudes and objectives, availability of resources, and crop and livestock management practices vary within the nation. Generally, the proportion of young farmers (below 35 years) is very low. A high proportion (more than 70%) of farmers are over 35 years of age. Many farmers have been taught only basic education by monks at Buddhist monasteries. Some farmers have had a formal primary and secondary school education. All families depend on farm income, but a few family members who work off-farm can make additional income.

Only 10 million ha of Myanmar's total land surface are used for agriculture, which is mainly cereal-based. The majority of the crops are produced by traditional methods and use local varieties. Most farmers practice permanent cereal-based cropping systems. The most common crop categories and crops include: grains – rice (*Oryza sativa*), maize (*Zea mays*), and wheat (*Triticum aestivum*); edible oil crops – groundnut (*Arachis hypogea*), soybean (*Glycine max*), cotton (*Gossypium spp.*), sugarcane (*Saccharum officinarum*) and food legumes. These crops are very important commodities of this production sector in which 64% of Myanmar's labor force is employed (Thu Kha, 1993).

The main areas of lowland rice occupy seasonally flooded lowlands, which are unsuitable for other crops in the rainy season. In upland areas, maize, wheat, groundnut, soybean and potato are by far the most important crops and are used either for home consumption or for sale as a cash crop. Farmers also grow upland rice for home consumption. Rice production is a major concern for the government because local rice production in the highland regions does not meet the local demand, and rice has to be imported regularly from lowland regions.

In heavily populated areas, some farmers irrigate vegetables by carrying water in buckets from nearby wells and streams during the dry season. Cereal-based cropping systems are important in Myanmar. Cereal-legume rotations are practiced by only a small number of farmers, while only a few farmers grow roots and tuber crops for animal feeding purposes. Rainfed agriculture is predominant. However, given the unpredictability of the rainfall, the crop yields are very low. While the potential yields of roots and tuber crops in this climate are very high, actual yields vary greatly, depending on varieties, seasonal rainfall, and on soil fertility and fertilizer inputs.

In addition, agricultural productivity has declined over the past decade, primarily due to insufficient integration in farming systems (crops and livestock) and a lack of agricultural inputs such as seeds, fertilizers, agrochemicals, etc.

Common Farming Systems of Smallholder Farmers in the Uplands

In the highland regions shifting cultivation forms the basis of agricultural production. In the cropping cycle, the long-fallow land has to be cleared from trees and bushes, and burnt before soil tillage operations. The predominant form of tillage is by bullocks, although a small proportion is cultivated by tractors. It is a sustainable form of production as long as fallow periods are sufficiently long for soil fertility to be restored. Fallow periods are becoming shorter as a result of increased population pressure (Aye, 2001). The government policy is to stabilize and reduce the area under shifting cultivation through a variety of measures and schemes, including resettlement of highland villages and the introduction of sustainable production systems such as integrated cassava-based crop-livestock farming systems.

Most farmers are resource-poor smallholders and their households rely on subsistence agriculture. The rural population depends primarily on rice cultivation coupled to a wide variety of other agricultural activities (including raising animals) for their food security. One of the important categories of land use is common grazing land for livestock. Many farmers, both women and men, are interested in livestock production activities such as pig and cattle production. There are good opportunities to further integrate root crop (cassava) production activities into existing agricultural livelihood systems, because both cassava roots and leaves can be used as human food and animal feed.

There is a high level of interest among women farmers in intensive crop production for their home consumption and for their animals. However, there are high entry costs for agricultural inputs such as planting material, hired labor, agro-chemicals and fertilizers, which only some farmers may be able to afford. Livestock production may also incur higher labor demand for the collecting of feeds and their preparation for the animals.

Women and men as well as children are involved in farming, although each may have different roles at different stages of the crop and animal production cycle. There are few cultural constraints to women's participation in most farming activities. While men often make the major decisions concerning the production system, women and children are also very much involved in crop cultivation and harvesting, and in the raising of animals. Generally, women control the cash income from the selling of products in the market or to middlemen, but consultation with their husbands on household expenditure is common. Income distribution within the household is relatively equitable, so income generated from crop and animal production is likely to benefit entire households.

In Myanmar, migration from rural to urban areas and to larger cities and towns has become a major issue. Men are more likely than women to migrate to the urban areas, perhaps leaving rural households short of needed male labor. At present, if people move to the cities it tends to be temporary and they often return to the villages at critical points in the year when their labor is required on-farm. There is a strong bond between children and their parents.

CASSAVA IN MYANMAR

Cassava (*Manihot esculenta* Crantz) is one of the popular root crops among resource-poor smallholders. The crop is locally known as "*Pilaw Penan*" or "*Kalaw*" and was introduced in the middle of the 19th Century by Portuguese traders. It was first grown in the coastal and delta regions of Myanmar as a food crop. Nowadays, cassava is grown in all parts of the country, but mainly in Ayeyarwady, Bago, Tanintharyi and Yangon divisions, and in Kachin state, mainly for industrial uses such as starch and drinking alcohol; it has thus become a cash crop. It is still grown by many resource-poor farmers as a "subsistence food crop" on small patches with so-called local varieties, while some farmers plant improved varieties.

Farmers generally plant cassava in dry areas on poor soils with no or little inputs, which result in low yields (3-5 t/ha/year) and a decline in soil fertility. Cassava production, planting area and yield in the various states and divisions of Myanmar are show in **Table 1.**

Table 1. Cassava production, planting area and yield in the States and Divisions of Myanmar in 2008.

State/Division	Production (t)	Area (ha)	Yield (t/ha)
Ayerawady	95,877	11,009	8.7
Bago	4,060	760	5.3
Chin	222	80	2.8
Kachin	6,572	744	8.8
Kayah	-	-	-
Kayin	1,222	264	4.6
Magway	-	-	-
Mandalay	68	26	2.6
Mon	2,794	311	9.0
Rakhine	787	208	3.8
Sagaing	3,956	461	8.6
Shan	1,602	1,172	1.4
Taninthayi	3,356	750	4.5
Yangon	8,521	1,906	4.5
Total	**129,224**	**16,037**	**8.5**

***Source**: Myanmar Agriculture Service, 2009*

Cassava roots and young shoots are used for home consumption and animal feeding, especially in rural areas. Traditionally, cassava roots are cooked for animal feedings but leaves are underutilized. Often, farmers eat boiled or steamed roots as snack food, and the leaves as a vegetable. During periods of rice shortage, however, this crop becomes the main diet for many farming communities in the uplands.

It is considered that there is a potential for increasing the scale and efficiency of cassava for food security and livestock production in Myanmar. However, in most rural areas in Myanmar, cassava for livestock production is underdeveloped mainly due to poor technical knowledge, infrastructure and market linkages.

Cassava Varieties

The most popular local varieties grown by farmers, and cassava varieties introduced from Thailand are presented in **Table 2.**

Table 2. Popular local and introduced cassava varieties in Myanmar in 2008.

Popular local varieties		Introduced varieties	
Variety name	Origin	Variety name	Origin
Bangkok	-	Rayong 1	Thailand
Hinthada	Local	Rayong 5	Thailand
Japan	-	Rayong 7	Thailand
Mon	Local	Rayong 60	Thailand
Malaysia	-	Rayong 72	Thailand
Shwepyitha	Local	Rayong 90	Thailand
Singapore	-	Huay Bong 60	Thailand
Chinese	China	Kasetsart 50	Thailand

Agronomic Practices

Time of planting

Farmers plant cassava in two different times according to the locality and rainfall conditions: at the beginning of the rainy season (i.e. May to June) and during the post-monsoon season (i.e. October to November). Under supplementary irrigation or when soil moisture is available, planting of cassava can be done throughout the year.

Land preparation and planting methods

Land preparation is usually done manually with a hoe, or by buffaloes and cattle. Few famers use small hand tractors. Pit followed by mound, flat method, mound method, and ridge and furrow method have been practiced. Different methods of planting stakes, such as horizontal, vertical and slanted planting, have been practiced. But horizontal planting with one stake (20-30 cm) per planting hole, either in the furrows or on mounds is the most common.

Fertilization and Weeding

Most farmers do not apply chemical fertilizers to cassava; however, farmers usually apply farmyard manure (5-10 t/ha) at the time of planting. Some farmers apply chemical fertilizers at the rate of 50 kg urea, 50 kg triple superphosphate, and 50 kg of potassium chloride per hectare. Fertilizers are applied at the times of first and second weeding and earthing up operations. Generally, the first weeding has be done at one month after planting and the second weeding has be done at two and a half months after planting.

Harvesting time and methods

Most farmers harvest cassava roots during the dry season, after 12-14 months; but some delay the harvest to about 16-18 months (i.e. Jan-April). Early varieties are harvested at 6 or 7 months after planting. Farmers use hoes or pull up the roots by hand. Fresh root yields depend on the climatic conditions and soil fertility, and range from 3 to 35 tonnes per ha per year.

Market Potential

The prospects for increased cassava production in the immediate future are very bright. Recently the demand for cassava roots has been increasing very rapidly, both inside the country and in neighboring countries; this is a great opportunity for smallholder farmers to produce cassava commercially. There is a lot of domestic demand for cassava roots, such as for local cassava starch processing, cassava starch for domestic consumption and by-products for animal feed. Cassava also has great potential in domestic and export markets in the form of dry chips and/or for processing into value-added products at factories in Myanmar and China.

Research and Development

Potential yields of existing local varieties are significantly lower than those of introduced cassava varieties from Thailand. Cassava root and starch yields of local and introduced varieties from Thailand, harvested at 9.5 months after planting in Kachin State, Myanmar, are shown in **Table 3.**

Table 3. Results of cassava root and starch yields of local and introduced varieties from Thailand in 2008.

Variety	Root yield (t/ha)	Starch content (%)	Starch yield (t/ha)
Local	13.5	16.8	2.27
Huay Bong 60	43.5	24.2	10.53
KU 50	29.0	22.6	6.55
Rayong 7	21.3	23.1	4.92
Rayong 90	16.0	20.7	3.31

Location: 26° 07' 22.7"N; 96° 43' 17.9"E, Elevation 224 masl

Much more research is needed to develop new cassava varieties such as high-yielding and high-starch varieties, drought-tolerant varieties, cold-tolerant varieties, disease- and pest-resistant varieties, as well as sustainable soil fertility and nutrient management practices (increasing yield through better nutrient use efficiency of both organic and inorganic fertilizers), and improved cassava-based cropping systems in upland and lowland environments. Research on improving marketing systems as well as linking farmers to markets remains to be done in the agricultural sector in Myanmar.

There is a great need to increase cassava yields in Myanmar as the national average yield is still far below its potential (**Figure 1**).

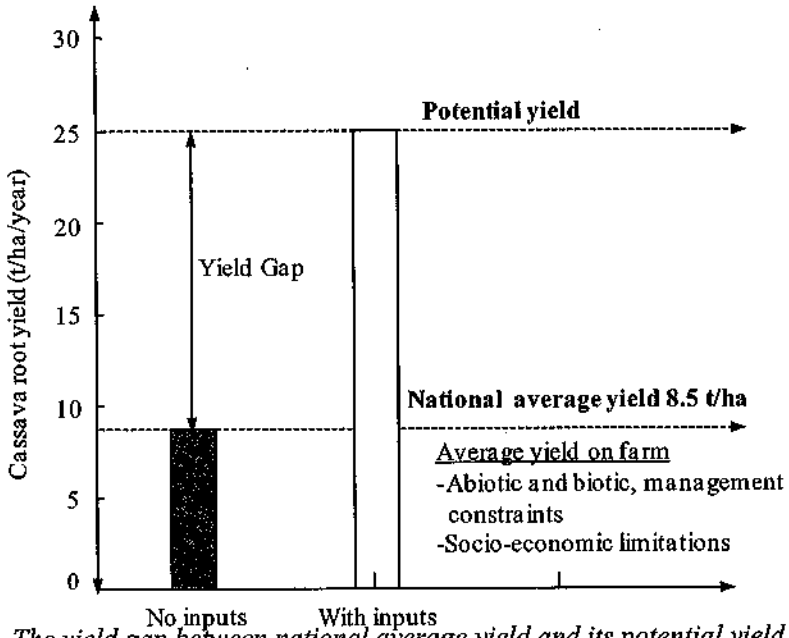

Figure 1. The yield gap between national average yield and its potential yield.

Unfortunately, farmers have not participated in the cassava research and development process. However, they would like to test new cassava varieties on their own land, and select the best varieties for their local conditions and their socio-economic situation.

Regional variations in food availability still remains a major issue in Myanmar. Agricultural research and extension systems require further institutional development. There is a need to continue to invest in capacity development for agricultural researchers and extension workers. Agricultural research and associated institutions are not routinely and sufficiently funded to meet the challenges facing them.

An important milestone has been achieved with the establishment of the Agriculture Research Department, but the research and extension system needs further capacity development, with more effective links among research, district-level organizations, and grassroots agents, for extension to be more effective in disseminating agricultural technologies.

Typical agricultural research and extension approaches often focus on improving farmer technologies, which often take 3-5 years to develop. Instead of working in individual villages, it is more efficient to use a territorial approach, working with clusters of villages. Set up a committee of village representatives. Researchers and extensionists should work with these committees to prioritize research topics based upon farmers' needs and determine possible actions in a participatory manner.

Farmers can reduce the cost of cassava production by using improved varieties and agronomic practices, and better farm management to achieve higher yields and better quality cassava. Farmers need to pay a role in the selection of better cassava varieties and more effective agronomic practices.

Also, the government may need to subsidize some agricultural inputs, such as chemical fertilizers and the distribution of planting materials of improved varieties, in order to reduce the cost of cassava production and increase the net income of smallholder farmers. Effective rural financing and sufficient commercial credit facilities in many rural areas should be promoted.

CONCLUSIONS

Cassava can be used as a multipurpose crop, both for food security and for income generation for smallholder farmers. There is a great opportunity to transform this subsistence crop into a major cash crop in upland areas. However, a good strategic plan will be required to increase the production of cassava, both by expanding the growing areas and by increasing yields.

In order to increase cassava productivity, farmers should be involved in the testing of new improved cassava varieties and better agronomic practices in order to enhance their adoption. In addition, contractual arrangements may need to be established between farmers and the private sector in order to ensure the adequate and timely supply of roots, and that farmers gain adequate benefits. It is expected that the use of farmer participatory research and extension approaches for specific agro-ecological areas will improve cassava productivity as well as the long-term sustainability of cassava-based cropping systems in Myanmar. Certainly, international and national collaboration and technical assistance are needed to address these important issues.

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CONSERVATION AND EVALUATION OF THE CIAT CASSAVA CORE COLLECTION IN THAILAND

Somlak Jutunka[1], Amporn Youngmod[1], Prapit Wongtiem[1], Jinajar Hansethasuk[1] and R.H. Howeler[2]

ABSTRACT

In 2001 the Department of Agriculture under the Ministry of Agriculture and Cooperatives in Thailand, offered to CIAT to maintain in Thailand a duplicate of the cassava core collection. It requested CIAT to send in tissue culture the complete cassava core collection containing 630 accessions, for preservation at Rayong Field Crops Research Center (FCRC) in Thailand. The purpose of the collaboration was to keep these genetic resources *in vitro* at another safe site away from CIAT; in case a disaster would happen, there would at least be a second place in the world where this collection was being preserved.

After the accessions arrived (in about 14 shipments over five years) the plants were sub-cultured and all accessions are now being preserved at Rayong FCRC. For the *in vitro* collection, ten plants of each clone are being maintained in tissue culture. After multiplication, the remaining plants were transferred to the greenhouse, and then after hardening, to the field. At present, about 90% of these accessions are growing and have survived in the field.

Nearly 30 genotypic characters have been evaluated and this information is now being saved in a database of cassava genetic resources, which will be very useful in our breeding efforts in the future. The creation of broad genetic variability in the cassava population through collection and introduction is essential for the successful recombination of certain desirable traits, in order to produce superior cassava cultivars for release to the farmers. The preservation and characterization of the core collection of 630 accessions from CIAT is one of the most important achievements of the Thai cassava breeding program during the past few years.

INTRODUCTION

In 1993, the Rayong Field Crops Research Center (FCRC) started a systematic collection of local cassava varieties and has maintained these in the field since then. In 2000, a cassava germplasm conservation program was established for the safe duplication of cassava genetic resources at Rayong FCRC.

In 2001, CIAT and the Department of Agriculture (DOA) in Thailand signed an agreement that CIAT will provide a duplicate of the cassava core collection to Thailand to conserve in the laboratory at Rayong FCRC. The core collection could then be evaluated across different ecosystems in Thailand in order to determine the genotype by environmental interaction on important traits. This could be an opportunity for Asian cassava breeders to use a wider genetic diversity in their breeding programs. The duplicate core collection was sent in the form of *in-vitro* plants, two test tubes for each clone. The 628 accessions were sent in 14 batches between 2002 and 2007.

The original Thai collection of 266 varieties is composed of local and imported varieties, which were collected from many countries in Latin America and Asia, such as 17 varieties from the Virgin Islands, five from Indonesia, 48 from CIAT-Colombia, while 185 were breeding lines from Thailand.

The 628 accessions in the core collection from CIAT were collected from many

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countries in Latin America such as from Argentina, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatamala, Mexico, Panama, Paraguay, Peru, Puerto Rico, United States and Venezuela; and from Asia, such as from China, Fuji, Indonesia, Malaysia, Philippines and Thailand.

Reception and Multiplication of the Tissue Culture Plants

As soon as possible after the release from Quarantine, the boxes with tissue culture plants were opened to expose the plants to light. After recovering for 2-3 weeks, the plants were subcultured to increase the number of plants using Murashige and Skoog medium (BAP 0.05 ml/l, NAA 0.02 ml/l, and GA 30.05 ml/l).

After the plants were about three months old, they were transferred to the closed-nursery. The plants were carefully removed from the tubes and planted in plastic bags containing a mixture of coconut fiber, compost, soil and ash. Plants were kept in closed misting chambers for 5-7 days, after which the bottom of the plastic cover of the chambers were opened to allow air ventilation for 25-30 days. After that, plants were transferred to bigger plastic bags and kept for another 25-30 days. Finally, plants were transferred to a shaded spot outside for aclimatization to the outside environment. Some varieties died during shipment from Colombia to Thailand or during transportation from the airport to Rayong FCRC. Some others did not survive during multiplication, hardening or transfer to the fields. These accessions were requested and shipped again from CIAT-Colombia.

In-Vitro Conservation of the Germplasm

Ten tubes of tissue culture plants of each variety are being kept for long-term conservation in the tissue culture laboratory of Rayong FCRC under the following conditions: 20±1°C, 70-90% relative humidity, 1000-3000 lux lighting 16 hours a day.

Germplasm Characterization

Once plants were growing in the field, each variety was characterized using IPGRI descriptors, such as apical leaf color, leaf shape, leaf length, petiole color, and stem color. Also, leaf area coefficients were determined for some leaf shapes. The leaf area coefficient of lanceolate and pandurate leaf shapes varied from 0.58 to 0.62 and from 0.60 to 0.66, respectively, depending on the variety.

At harvest time (12 months), both morphological and agronomic traits, such as plant type, number of stems per plant, plant height, root cortex color, root number per plant, and yield, were determined.

The Cassava Germplasm Conservation Program

Many cassava germplasm research projects are being conducted at Rayong Field Crops Research Center, as shown in **Figure 1.**

Germplasm Evaluation

Table 1 shows that two varieties from the original Thai collection produced higher yields than Rayong 9, and four varieties produced more than Rayong 7. The CIAT core collection produced similar results, as shown in **Table 2**, with two varieties producing higher yields than Rayong 9 and four higher yields than Rayong 7. Currently, about 90% of the various germplasm evaluations of the 628 accessions have been completed and entered into the cassava core collection database.

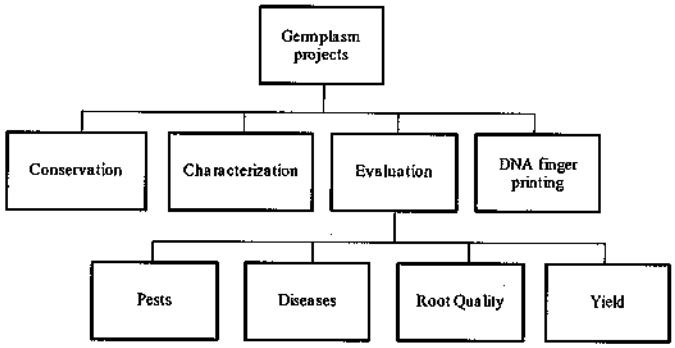

Figure 1. Germplasm projects at Rayong Field Crops Research Center.

Table 1. Fresh root yield, starch content, and root number per plant of some varieties in the original Thai collection harvested in 2007.

Variety	Root yield (t/ha)	Root starch content (%)	No. roots/plant
CMR 33-18-101	53.31	30.2	17
CM 3306-3	47.31	27.0	10
CM 125-22	46.00	25.5	11
CMR 25-38-157Q	40.00	26.2	9
CMR 35-22-196	33.31	30.0	11
CMR 35-91-63	33.31	26.0	13
CMR 31-37-105	33.31	25.6	10
Rayong 7	36.63	28.0	15
Rayong 9	46.63	27.0	14

Table 2. Fresh root yield, starch content, and root number per plant of some varieties from the CIAT core collection harvested at 12 MAP in 2007.

Variety	Root yield (t/ha)	Root starch content (%)	No. roots/plant
CM 3306-4	39.37	31	6
MCol 1516	38.43	28	11
MMex 8	32.68	29	8
MCol 2215	30.68	30	10
MCol 2638	26.62	29	8
MCol 1805	25.87	29	7
MVen 90	25.81	31	10
CM 3306-9	25.68	31	10
Rayong 7	26.87	32	13
Rayong 9	37.50	32	13

Table 3 shows a range of plant canopy characteristics of some varieties in the CIAT core collection, while **Table 4** indicates that some varieties had greater tolerance to CBB and Brown Leaf Spot disease than the three most commonly grown Thai varieties, i.e. KU 50, Rayong 5 and Rayong 90.

Research on root quality characteristics was conducted in the quality laboratory at Rayong FCRC. **Table 5** shows the range in root component characteristics and starch properties of 157 varieties in the CIAT core collection, indicating a very wide range in both root and root starch characteristics.

The frequency distribution for the root starch content of 157 accessions is shown in **Figure 2a.** It indicates that 60 accessions had 15.1-20% starch, while only very few had starch contents in the range of 25.1-30%. **Figure 2b** shows that most varieties had total cyanogens contents of less than 200 mg/kg, while few accessions had very high cyanogens contents. The nutritional composition of the same 157 accessions is shown in **Table 6.**

Table 3. Canopy traits of some varieties from the CIAT core collection.

Variety	Canopy	No. of forking	Plant height (cm)	Height at 1st forking (cm)
CM 3306-4	very spread	2-3	160	65
MCol 1516	spread	1-3	210	110
MMex 8	very spread	3-4	190	100
MCol 2215	erect	0-2	145	65

Table 4. Score of Cassava Bacterial Blight (CBB) and percentage of Brown Leaf Spot of some varieties from the CIAT core collection.

Variety	CBB score[1)]	Brown leaf spot (%)[2)]
MArg 2	2.0	36.3
MPar 101	2.1	23.0
MPar 221	2.2	24.6
MGua 32	2.3	31.4
MMex 17	2.4	34.8
MMex 83	2.8	32.4
MMex 8	3.2	32.4
MCol 2215	3.5	28.9
CM 3306-4	3.8	39.5
MCol 1516	3.9	24.5
Rayong 5	3.6	-
Rayong 90	3.7	-
Kasetsart 50	3.6	-

[1)] Evaluation in the plant nursery at 1-3 MAP after inoculation using the clipping method; 1 = low; 5 = high incidence

[2)] Evaluation in the field at 5-12 MAP

Table 5. Proximal analysis of cassava root components and physio-chemical properties of the starch of 157 accessions from the CIAT core collection.

Root components/starch properties	Minimum	Maximum
A. Root characteristics (on fresh wt. basis)		
Moisture content (%)	55	81
Peel (% weight of whole root)	13.3	31.0
Starch content (%)	0.8	27.3
Total cyanogens content (mg/kg)	28	1,685
B. Starch properties (on dry wt. basis)		
Amylose content (%)	19.2	31.1
Pasting temperature (°C)	66.6	72.8
Peak viscosity (BU)	446	1,029
Trough viscosity (BU)	13	412
Breakdown (BU)	301	704
Final viscosity (BU)	30	754
Setback (BU)	17	347

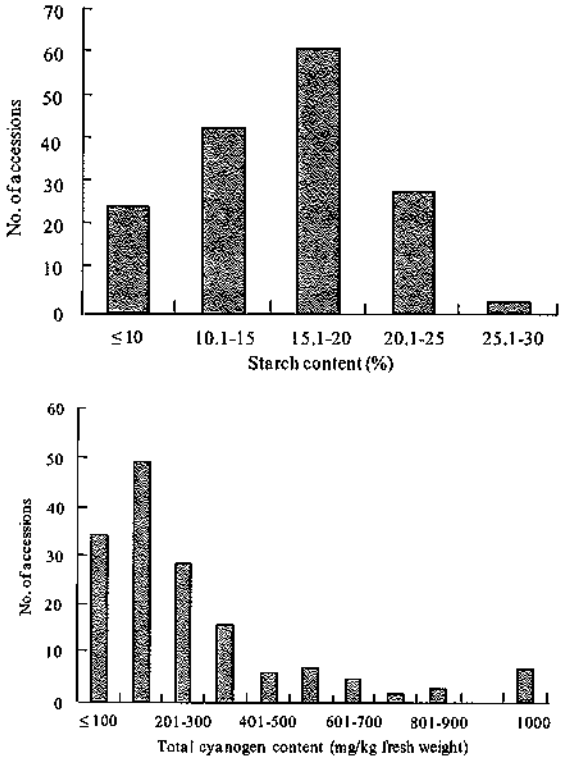

Figure 2. Frequency distribution of 157 accessions from the CIAT core collection for starch content (above) and total cyanogens content (below) of fresh roots.

Table 6. Range in the nutritional composition of cassava roots of 157 accessions (on dry weight basis) from the CIAT core collection.

Nutritional composition	Minimum	Maximum
Protein (%)	0.72	3.20
Phosphorus (%)	0.073	0.271
Potassium (%)	0.308	2.819
Calcium (%)	0.006	0.301
Magnesium (%)	0.045	0.352
Iron (ppm)	0	21.462
Manganese (ppm)	1.163	23.469
Copper (ppm)	0	8.815
Zinc (ppm)	2.238	88.710

Research on the characteristics of the accessions from the CIAT core collection and the original Thai collection conserved at Rayong FCRC is being conducted progressively each year. It is hoped that some accessions can be identified with very useful characteristics, which can be incorporated to produce new, even better, varieties in the near future.

MOLECULAR CHARACTERIZATION OF THE CIAT CASSAVA CORE COLLECTION AND THE THAI AND LAO GERMPLASM COLLECTIONS USING ISSR-TOUCHDOWN PCR

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ABSTRACT

The assessment of genetic diversity of three cassava collections was done using ISSR-touchdown PCR techniques. A total of 532 accessions, of which 276 accessions were from the local collection of Thai varieties and hybrids, and 256 accessions from the CIAT core collection in Thailand, were used for assessment. Twenty-five ISSR primers were selected and used for PCR amplification. A total of 425 loci were generated altogether with 418 polymorphic loci and an average of 17 bands per 1 primer. The size of the fragments varied from 200 to 2500 bp. Genotypic data was analyzed using NTSYS pc V2.1 and Jaccard Similarity Coefficients to perform cluster analysis (UPGMA). The similarity coefficients ranged from 0.70-1.0. The dendrogram topology shows two major clusters: (1) local Thai varieties, and (2) the core collection at 70% relation. The relationship of local varieties was approximately 77% whereas that of the core collection was approximately 73%.

In addition, 40 cultivars of the Lao PDR cassava germplasm collection using the same technique exhibited 87% relation and was divided into three major groupings. It was found that C1 and Hanatee show a very a close relationship (99%) while KM 98-1 and Rayong 72 showed a 93% relationship.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an important crop in Thailand. It is not a staple food for Thai people but it is a cash crop produced by a large number of small-scale farmers. Nearly all the harvested roots are processed into dry chips and pellets for animal feed, and into starch. About 80% of the production is exported. Cassava is not a native crop in Thailand; therefore, the creation of a broader genetic background through germplasm collection and introduction of new varieties was essentially needed for successful recombination of certain desirable traits. The breeding program of Thai cassava was initiated in 1937 by the Department of Agriculture, and is continuing until the present.

Before 1960, twenty cultivars were introduced, mainly from Malaysia, Indonesia and Mauritius. During the 1960s more clones were introduced, from Indonesia in 1963, and from the Virgin Islands in 1965. The first introduction from CIAT (Centro Internacional de Agricultura Tropical) in Colombia was in 1975. The collection has been maintained at Rayong Field Crops Research Center by annual planting in the field, while some accessions are duplicated in the field at Khon Kaen Field Crops Research Center for a breeding program.

More cassava clones have been introduced since 2001 through CIAT-DOA collaboration to send a duplicate of the CIAT cassava core collection for preservation to Thailand in the form of tissue culture. The total collection now includes the original collection of over 273 accessions of local cultivars, those from Indonesia, the Virgin

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Islands and China, open-pollinations and hybrids from CIAT/Colombia, as well as another 628 accessions from the CIAT core collection. These germplasm accessions are being observed and evaluated for morphological characteristics, agricultural traits and nutritional characters, e.g. HCN, protein and starch content. Along with this agricultural and morphological study, molecular markers have been introduced to investigate genetic variability to assist the breeding program and conservation scheme. This work was started in 2004 at Khon Kaen Field Crop Research Center and finished in 2008. This paper reports the work done using the ISSR-touchdown PCR technique to study genetic diversity in the germplasm collection of the CIAT core collection, and of local Thai varieties collected and maintained at Rayong Field Crop Research Center, as well as the Lao germplasm collection.

MATERIALS AND METHODS

Plant Materials

A total of 532 accessions of cassava maintained at the Rayong Field Crops Research Center in Thailand were used in this study. The collection comprised local Thai varieties, the hybrids from the Thai breeding program, and the collection of cassava from CIAT.

In addition, fresh leaf samples of 40 accessions in the germplasm collection in Lao PDR were sent by CIAT representatives for analysis in this molecular study. The collection of cassava in Lao PDR included South China (SC) (5, 8, 9, 124, 201, and 205), GR891, Yolk, Nanzi 199, OMR 36-31-1, OHR , Chinese red, Chinese green, NARC (48, 50, 61, 96, 101, 114 and 115), C(1,2,3), local Oudomxay, Nep, Vinh Phu, Ba Trang, HL 23, KM 98-1, KM140, Mantega and some of the Thai cultivars, i.e. Rayong (1, 2, 5, 60, 72 and 90), KU 50 and Hanatee.

ISSR analysis

Young fresh leaves were used for DNA isolation. DNA extraction was done according to Li and Midmore (1999). Genomic DNA was used as a template for PCR amplification (Sakuanrungsirikul *et al.*, 2005). The reactions were carried out in 15 µl final volume containing 20 ng genomic DNA, 0.1 µM of ISSR primers (**Table 1**), 10 mM of Tris-HCL (pH 7.2), 50 mM $(NH_4)_2SO_4$, 1.5 mM $MgCl_2$, 2 mM of each dNTP and 1 U Taq DNA polymerase (Fermentas). The temperature cycling profiles were: 94°C 5 min, 5 cycles of 94°C 30 sec, 52°C (decreased 1°C every cycle), 72°C 1 min, 30 cycles of 94°C 30 sec, 48 °C), 72°C 1 min, followed by 72°C 5 min and keep at 4°C. PCR products were separated on 1% agarose gel electrophoresis for 1 hour at 100V. DNA was visualized by ethidium bromide staining and photographed during UV light exposure.

Data analysis

Unequivocally scorable and consistently reproducible amplified DNA fragments were transformed into binary character matrix (1 = presence, 0 = absence). Genotypic data was analyzed using NTSYS pc v. 2.1 (Rohlf, 2002). Jaccard similarity coefficients were obtained to perform a cluster analysis (UPGMA). Consensus analysis was done by Bootstraps using the Winboot program (Yap and Nelson, 1996) with 500 repeated samplings (limited at 300 accessions per one analysis).

RESULTS AND DISCUSSION

The Thai and CIAT Core Collections

A total of 532 accessions were used for this analysis. Of these, 276 accessions were Thai varieties and hybrids, and 256 accessions were from CIAT. A total of 100 ISSR primers were used for screening using Touchdown PCR profile. Twenty-five primers tested were selected for their quality, quantity and reproducibility capacity of fragments amplified. A total of 425 loci were generated across all accessions with the average of 17 loci per primer (ranging from 8 to 23). Size of amplification fragments varied from 200 to 2500 bp. Of these, 418 loci (98.4% of total loci) were polymorphic, which concentrated mostly at 5'-anchored GA and GAA repeats (**Table 1**). Only 7 loci (1.6% of total loci) was monomorphic. These results indicate the potential of using molecular markers for this analysis and the average range of genetic diversity of this germplasm collection.

Table1. Primer sequences used for ISSR analysis and number of amplified products.

Primer	Sequences	Number of loci	Monomorphic loci	Polymorphic loci
ISSR7	$(AG)_8T$	16	0	16
ISSR8	$(AG)_8C$	21	0	21
ISSR10	$(GA)_8T$	22	0	22
ISSR13	$(CT)_8T$	20	0	20
ISSR14	$(CT)_8A$	18	0	18
ISSR15	$(CT)_8G$	14	0	14
ISSR16	$(CA)_8T$	14	0	14
ISSR17	$(CA)_8A$	14	0	14
ISSR18	$(CA)_8G$	16	0	16
ISSR22	$(TC)_8A$	11	0	11
ISSR23	$(TC)_8C$	18	0	18
ISSR24	$(TC)_8G$	14	0	14
ISSR26	$(AC)_8C$	16	0	16
ISSR56	$(AC)_8YA$	21	0	21
ISSR67	$(GGC)_6$	11	0	11
ISSR68	$(GAA)_6$	22	0	22
ISSR73	$(GACA)_4$	9	2	7
ISSR74	$(CCCT)_4$	20	0	20
ISSR78	$(GGAT)_4$	19	0	19
ISSR80	$(GGAGA)_3$	20	0	20
ISSR81	$GGG(GGGGT)_2G$	19	0	19
ISSR89	$DBD(AC)_7$	23	0	23
ISSR90	$VHV(GT)_7$	20	2	18
ISSR91	$HVH(TG)_7$	19	2	17
ISSR97	CCG ACT CGA GNN NNN NAT GTG G	8	1	7
Total		**425**	**7**	**418**

Note: Y = (C,T), D =(A,G,T) (i.e.not C), B = (C,G,T) (i.e.not A), V = (A,C,G) (i.e.not T), H = (A,C,T) (i.e.not G), N = (A,G,C,T)

The similarity coefficients from the cluster analysis, performed by UPGMA, varied from 0.7-0.1 (70-100%) with two accessions (V30 and V40) showing similar DNA profiles (T401 in **Figure 1**). The gross topology of the dendrogram shows two major groupings at the similarity coefficient of 0.7 (70%) (**Figure 1**). These results are similar to those of Columbo *et al.* (2000b) using RAPD markers to assess the genetic diversity of cassava in the Americas, which included two varieties from Thailand, i.e. Rayong 1 and an unidentified variety. These two Thai varieties were classified into the same cluster with those of Malaysia and showed a 70% relation to other cultivars from other parts of the world, such as those from Colombia and Brazil.

Most accessions in our study were clustered, corresponding to their origin of distribution and breeding pedigrees. This could be the result of a high number of marker loci used that allow a better resolution for classification. For instance (Ratanawaraha *et al.*, 2000):

- Rayong 1 (R1), an introduced variety from Malaysia, was classified into the same group with Java 5.

- Sriracha 1, a hybrid of MKU2-162 (KU F1 hybrid) and R1, was classified into the same group with R1 and KU 50, showing 95-96% relation.

- Rayong 2 (R2) formerly called CM305-2 or Huaypong 6 (HP 6), is a hybrid of MCol 113 and MCol 22. R2 appeared to have a higher carotene content than the other varieties and was classified into the same group with other yellow root varieties.

- Kasetsart 50 (KU 50), a hybrid of R1 and R 90, was classified into the same group with R 90, KU, yellow root and R1. It showed a similarity coefficient to R1 and R 90 at 94-95%.

- Hanatee is a Thai local variety that is assumed to have been introduced form Malaysia. It was classified into the same group with KK1, Kraburi, Java 2, Indonesia and SUAN which originally came from the southern part of Thailand.

- Rayong 3 (R3), formerly called CM407-7 or Huaypong 4, is a hybrid of MMex 55 and MVen 307, which has a high starch content. It was classified into the same cluster with HP 8, Varigated (green), HP 7 and Adira.

- Rayong 5 (R5), a hybrid of 22-77-10 and Rayong 3 (R3) was classified into the same cluster as R3.

The majority of the members in cluster I were those that had been in the collection at Rayong Field Crop Research Center, which included all the local Thai varieties, as well as most of the hybrids and parents used in the Thai breeding programs. The similarity coefficients among these accessions ranged between 0.77 and 1.0 (77-100%). Cluster II consisted mainly of the CIAT core collection, which had not been exploited yet in the Thai breeding program, and which are in the field evaluation stages. The similarity coefficients among cassava in this group ranged between 0.72 to 0.99 (72-99%). Each cluster is further divided into many groups and subgroups. For example, the members in the groupings 1 and 2 are mainly local Thai varieties and hybrids that were released during 1970-1994, such as Sriracha, Kraburee, Hanatee, R1, R2, R3, R60, R90, R5 and KU50.

The wild variety (*M. glaziovii*), the varieties from the Virgin Islands and Rayong 60 are classified in the same grouping (group 3) (**Figure 1**). In our study, the accessions "wild 1" and "wild 2" showed 88% and 97% relation to those of the Virgin Islands and 77% relation to other *M. esculenta* varieties. This is not surprising since many wild species were exploited in many cassava breeding programs. This was also supported by the study

using RAPD and AFLP markers which revealed that *M. glaviozii* and *M. raptans* were closely related to *M. esculenta* (Columbo *et al.*, 2000a). In addition, there was a report indicating that the natural hybrid of *M. esculenta* and *M glaviozii* existed in Africa and in other areas (Nichols, 1947; Columbo, 2000a).

The core collection (Cluster II) was separated as a large group but was related with another cluster at 70% with the range being between 72-99% among the members in this cluster. Despite the exploitation of some accessions in the breeding programs, the diversity among the members in this cluster could be higher as only 266 accessions of the core collection, out of over 600 accessions, were used in this study. Most of the plant samples were from Colombia (56 accs.), Peru (36 accs.) and Brazil (24 accs.), while the rest were accessions from 25 countries. Some of these accessions may have been used in cassava breeding programs in many other countries. Columbo *et al.* (2000b) reported that the cultivars from Sao Paulo, Brazil, and from the CIAT core collection were distributed on nearly all branches of the dendrogram.

Cluster II was divided into two groupings with a similarity coefficient of 0.735. Most, though not all, of the members in each group were segregated according to their origin of distribution, as found in Cluster I. Most of these accessions are still at the field evaluation stage and have not yet been used in our cassava breeding program.

According to the Bootstrap analysis based on 500 resamplings of the data set, it was found that within the local Thai cassava collection the confidence level of clustering ranged from 7.5-100%, and from 1.3-100% for the CIAT core collection. The regrouping maintained the same dendrogram structure to that previously created by UPGMA with a minor replacement. High confidence values were formed within the subgroupings, while lower values were found in the higher branches. Though it was shown in this study that molecular markers are a useful tool for structuring the genetic diversity, the genetic classification of this cassava collection could be more reliable if it is done in combination with their morphological and agricultural characteristics, as the molecular markers alone may not cover all important genetic variations across the whole genome.

The Lao PDR Cassava Germplasm

Forty samples were included in the study of genetic diversity among this germplasm collection. Twenty-five ISSR primers were used for this analysis, as was done with the above study.

From the first sample set collected for analysis, we found that Rayong 90 and Rayong 72 from the Thai and Lao collections showed different DNA banding patterns (**Figure 2**). However, the analysis of the second sample set revealed that the mistake arose from the wrong labeling of the samples that were used for analysis (**Figure 3**). This result thus illustrates that ISSR marker and the method used in this study is not only valid for the establishment of genetic distances between genotypes but is also useful for characterization of cassava cultivars and for the identification of duplicates in the collection.

The diversity in the Lao PDR collection within those 40 accessions, which included some varieties cultivated in Thailand, showed genetic similarity coefficients in the range of 0.87-1.00, with two major groupings at 0.87 and several subgroupings (**Figure 2**). It was revealed by this method that R72 and KM98-1 were 93% related, while C1 and Hanatee showed a very close relationship (0.99). It was also found that all Thai varieties were

distributed throughout the subgroupings of this collection, which supported the findings of the above study of the Thai and CIAT core collections.

CONCLUSIONS

ISSR-TouchDown PCR has proven to be an effective tool to assess the genetic diversity and to identify duplicates in cassava collections. The consensus analysis of this method using bootstraps showed a high confidence in the groupings that fall in the range of 1.3-100%. This study revealed that the local Thai cultivars fall into different groupings from those of Latin America and the germplasm collected from other parts of the world, but were closely related to cultivars from other Asian countries. The majority of the groupings corresponded with their origins of distribution and their genetic background, with some accessions that appeared to be very closely related or identical. However, additional information on morphological and agricultural characteristics and molecular analysis could provide an even better characterization of these germplasm collections.

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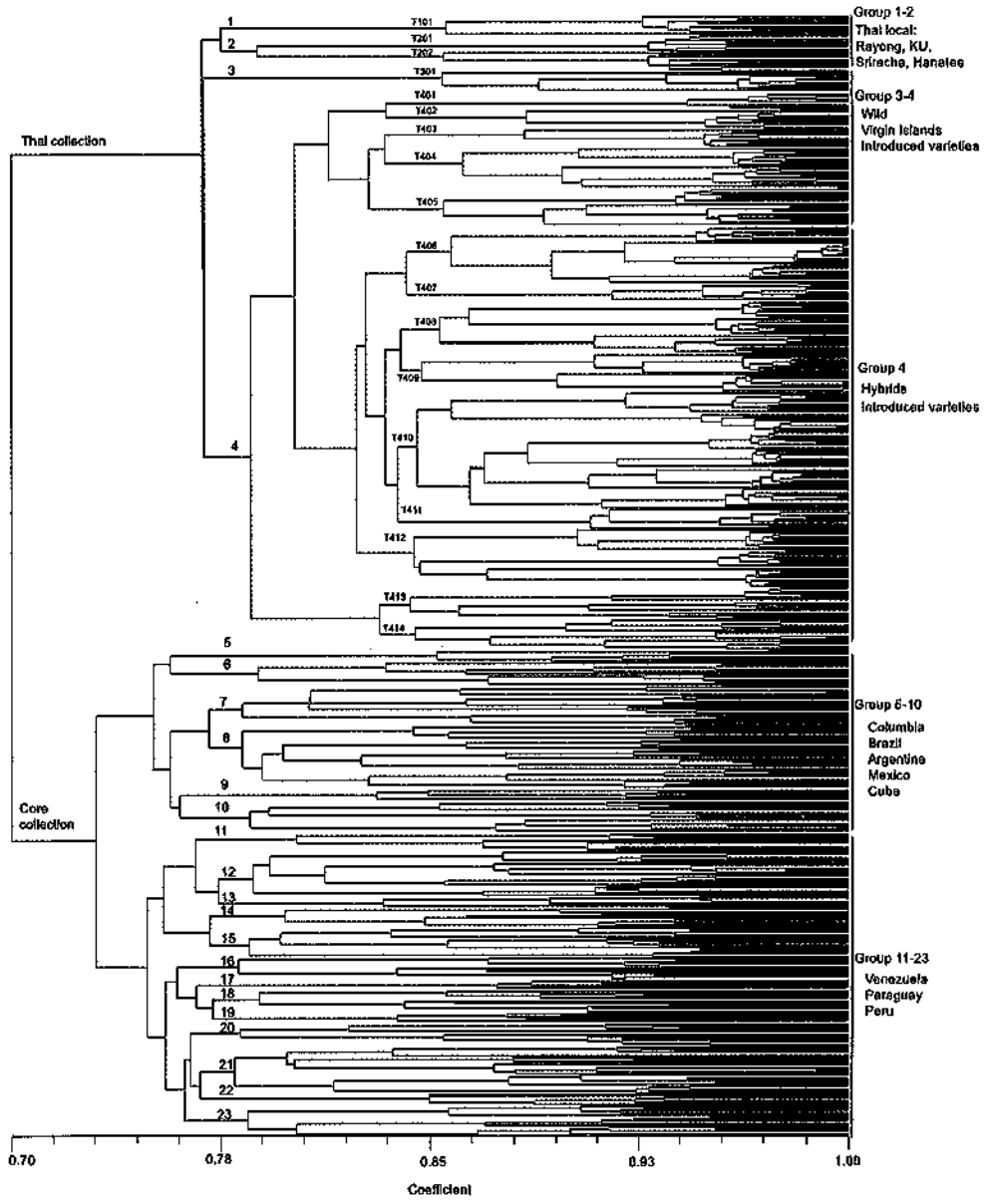

Figure 1. UPGMA dendrogram showing genetic relationship among 532 accessions of cassava including 276 accessions of the Thai collection and 266 accessions of the CIAT core collection based on ISSR markers and and Jaccard similarity coefficient.

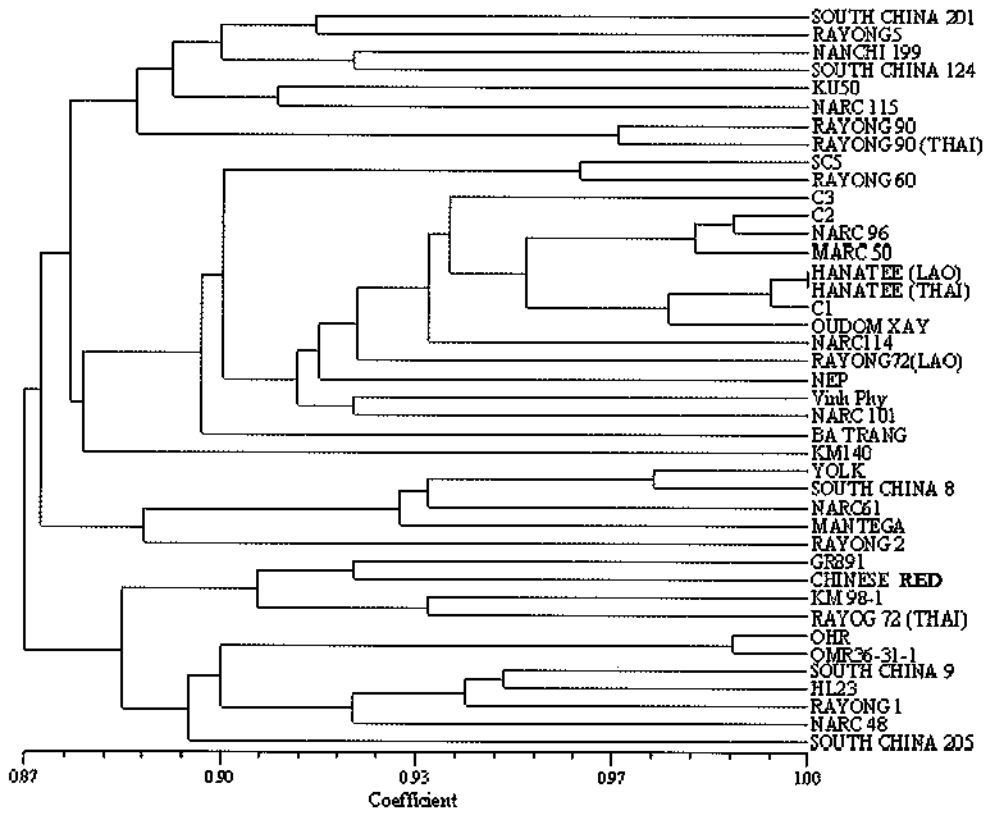

Figure 2. UPGMA dendrogram showing genetic relationship among 41 accessions of cassava including 7 Thai cultivars and 35 accessions of the cassava collection in Lao PDR, based on ISSR markers and Jaccard similarity coefficient. Repeated cultivars (Thai-Lao) were used for checking accession identity.

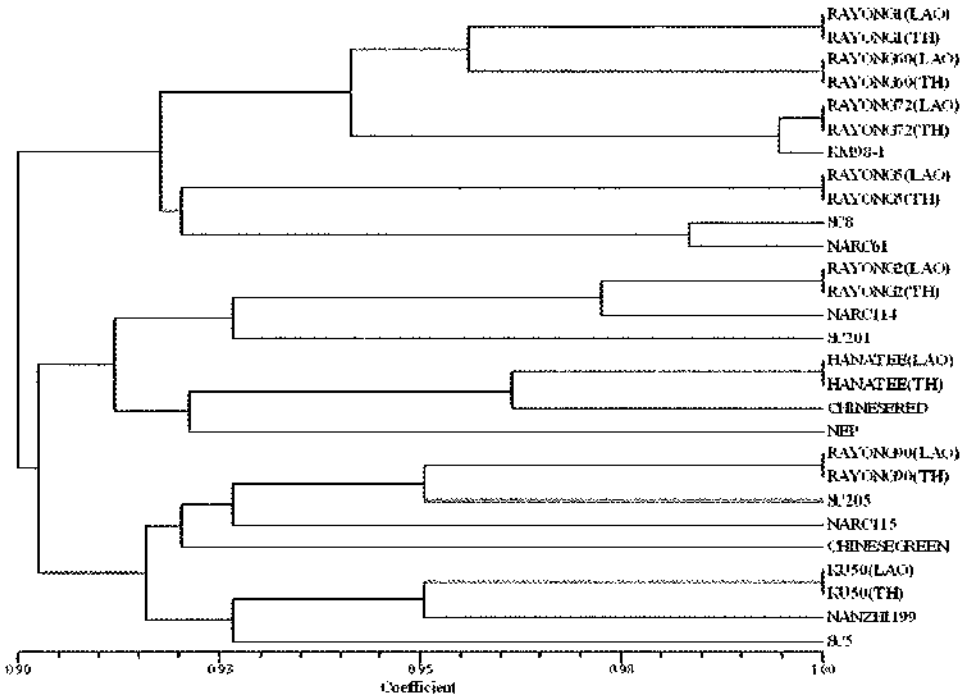

Figure 3. UPGMA dendrogram showing genetic relationship among 28 accessions of cassava including 8 Thai cultivars and 20 accessions of the cassava collection in Lao PDR based on ISSR markers and Jaccard similarity coefficient. Identical cultivars (Thai-Lao) were used for checking accession identity.

THE DIFFERENTIATION OF CYANIDE CONTENT IN YOUNG CASSAVA USING GENE EXPRESSION

Suchirat Sakuanrungsirikul[1], *Theerawut Wongwarat*[1,2], *Peaingpen Sarawat*[1] *and Piyada Theerakulpisut*[2]

ABSTRACT

In this research the expression of genes involved in cyanogenesis in cassava (*Manihot esculenta* Crantz) was observed in order to develop tools to facilitate the work of the cassava breeding program. The Reverse Transcriptase-PCR (RT-PCR) study of the genes CYP79D1, CYP79D2 and linamarase, in young leaf tissues displayed different expression patterns in the seven cassava cultivars used: Rayong 60, Rayong 3, Rayong 72, Rayong 9, Rayong 7, Hanatee and Rayong 2, which contain different levels of cyanide in the roots. Analyses of these gene expressions in young leaves of 1-month old plants showed a high correlation with the cyanide content of the roots of 12-month old plants (R^2 = 0.85-0.90), and a moderate correlation with the cyanide content of leaves of the 1-month old plants themselves (R^2 = 0.73-0.80). However, no correlation was found in the RT-PCR study of the leaf tissues of 12-month old plants; this may be caused by physiological changes in the plant tissue due to flowering. These results show that the differentiation of root cyanide levels can be identified by the RT-PCR study of these three genes in young cassava leaf tissue.

Key words: cyanide content, gene expression, reverse transcriptase-PCR.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an important tropical crop. It can withstand drought, and is sometimes a nutritionally strategic famine reserve crop in areas of unreliable rainfall. Cassava roots are quantitatively the third most important food in the tropics, after rice and corn. It is an important source of calories because it covers 60% of the daily calorific needs of various populations. Leaves of cassava are rich in protein (17-34% on dry weight basis), minerals and vitamins (Kobawila *et al.*, 2005). However, the roots and leaves of this plant contain the cyanogenic glucosides, linamarin and lotaustralin (Montgomery, 1980; Dunstan *et al.*, 1996) in a ratio of 93:7 (Butier and Kennedy, 1965). Linamarin, a major component, is derived from valine by the activity of two cytochromes P450 genes, *CYP79D1* and *CYP79D2* (Anderson *et al.*, 2000). Linamarin is stored in the vacuoles of cassava cells and is hydrolyzed by linamarase to cyanohydrin and glucose. Cyanohydrin dissociates spontaneously at pH $\geq$ 5.0 or is enzymatically digested by hydroxynitrile lyase to produce cyanide and acetone (McMahon *et al.*, 1995); cyanide is highly poisonous.

The cyanogenic potential of cassava roots and leaves ranges from 2 to >1000 mg HCN equivalents/kg fresh weight (Bradbury *et al.*, 1991; Bokanga, 1994). In general, cassava is being grouped into "bitter" and "sweet" cultivars. The sweet cultivars are supposed to have much lower hydrogen cyanide contents than the bitter cultivars. Cassava roots and leaves should be processed to reduce the cyanogenic potential, before their use for animal or human consumption.

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The lethal level of cyanide is approximately 0.5-3.5 mg HCN/kg body weight (Montgomery, 1980). Health problems, which have been attributed to high dietary cyanide intake, include acute poisoning, the paralytic disease konzo, tropica ataxic neuropathy (TAN) and aggravation of iodine deficiency disorders (Tylleskar *et al.*, 1992; Delange *et al.*, 1994). Several strategies have been used to promote safety in cassava consumption. These include breeding cassava for low cyanide content, encouraging the use of appropriate cassava varieties, improving cassava processing methods, and developing reliable and simple procedures for monitoring the cyanide content in roots and leaves.

The aims of our study, firstly, was to determine the free cyanide content in different varieties of cassava, both in leaves and roots, using the enzymatic method; and secondly, to determine the relationship among the expressions of the genes associated with cyanogenesis, i.e. *CYP79D1, CYP79D2* and *linamarase* in young cassava leaves of 1-month old plants and the cyanide content of roots at time of harvest, in order to develop tools to facilitate the selection of cassava lines with low cyanide content during the early stage of plant development.

MATERIALS AND METHODS

Plant Material

Fresh young leaves and fresh roots of seven cultivars grown in the same field condition at Khon Kaen Field Crops Research Center, including Rayong 60, Rayong 72, Rayong 9, Rayong 7, Rayong 3, Rayong 2 and Hanatee, were used for the analysis of free cyanide contents and gene expressions. Three plants were used as triplicate samples for each cultivar.

Determination of Free Cyanide

Fresh roots of 12-month old plants, and young leaves of 1 and 12-month old plants were sampled for analysis of free cyanide following Sakuanrunsirikul *et al.* (2007). Protocols are as follow:

Sample preparation: The tuberous roots and leaves were harvested and thoroughly washed; the roots were separated into root pulp (parenchyma) and peel. The leaves (0.1 g) and root pulp (0.3 g) were cut into small pieces and added to 1 ml extraction medium (0.1 M phosphoric acid, 95% ethanol, pH 5.0) in microcentrifuge tubes, incubated at 50°C for 60 minutes. The tubes were centrifuged at 12,000 rpm for 10 minutes. Supernatant was collected for a free-cyanide assay.

Assay procedure: The extract (0.1 ml) was diluted with 3.9 ml of phosphoric acid buffer, pH 4.0 in a stoppered test tube, mixed well and placed on ice for 5 minutes; then 0.8 ml of pyridine/pyrazolone reagent was added. The mixture was taken to determine the absorbance value at 620 nm after 90 min of incubation. Duplicate analyses were performed and blanks containing the extraction medium were run for each analysis.

Calibration standards and test: A stock solution of KCN (250 mg/l in 0.2 M NaOH) was serially diluted in the range of 0.25 µg and 2.5 µg KCN (equivalent to 0.1-1.0 µg HCN) with phosphoric acid buffer pH 6.0, and subjected to the same assay procedure.

RNA isolation

Total RNA was isolated from young cassava leaves of the 1- and 12-month old plants using a SV Total RNA Isolation System (Promega, USA) and verified by 1.2% agarose gel electrophoresis, which was visualized by SYBR Gold staining and UV exposure. RNA quantity and quality were determined by the absorbance spectrum at 260 nm and 280 nm.

Reverse Transcription-Polymerase Chain Reaction (RT-PCR) Analysis

RT-PCR reaction was performed using the Two-step RT-PCR kit (USB, US). First strand cDNA synthesis were performed in a final volume of 25 µl containing 100 ng/µl of total RNA, 1x RT buffer, 0.5 mM dNTP, 10 µM reverse primer, 0.16 unit/µl RNA inhibitor and 1 x M-MLV RT. The cDNA amplification were done in a final volume of 25 µl containing 1 x RT buffer, 25 mM $MgCl_2$, 0.2 mM dNTP, 0.4 µM reverse and forward primer (**Table 1**), 1 µl of RT-PCR product and 0.1 unit/µl Taq DNA polymerase ((USB, US).

Table 1. Forward and reverse primer sequences of the genes *CYPD1, CYPD2, linamarase* and *GADPH* used in this study.

Primer	Strand[1)]	Sequence (5'-3')	Reference
CYP79D1	F	AATTTGTGCATGCAAATAAGA	Wongwarat (2008)
CYP79D1	R	CTTCTTCAGGATTTCTGGTGGATT	Wongwarat (2008)
CYP79D2	F	ACAGAGTGGTCGGCAAAGAC	Wongwarat (2008)
CYP79D2	R	TGAAGCACTGAAGCATCCTG	Wongwarat (2008)
linamarase	F	CAGAAGACTGTTGACGGCCC	Santana *et al.* (2002)
linamarase	R	CAATTCCAGCCTTGGCGTC	Santana *et al.* (2002)
GADPH	F	GCAATGGAGACGTTGCAGTTG	Santana *et al.* (2002)
GADPH	R	GTCGCATTAACACCACTATCA	Santana *et al.* (2002)

[1)] F = forward; R = reverse

Amplification of cDNA for the genes *CYPD1, CYPD2* and *GADPH* were amplified in a thermocycler (Creacon T-Cy, the Netherlands) programmed as follows: 30 cycles of 94°C for 30 sec, followed by 52°C for 30 sec and 72°C for 1 min, with a final stage of 72°C for 7 min extension step. The amplification of *linamarase* was done under the same conditions but with 26 amplification cycles. Amplification products were submitted to 1.2% agarose gel electrophoresis in 0.5XTBE, stained with SYBR Green and visualized under UV exposure. Images were recorded by the E-Box system (Vilber Lourmat, France).

RESULTS AND DISCUSSION

Distribution of Cyanide Content in Tissues

Cassava synthesizes and accumulates cyanogenic glucosides in all tissue types (YeOh and Oh, 1987). These cyanogenic glucosides are distributed throughout the plant

system, i.e. in the leaves, petioles, stems and tuberous roots. The hydrolysis of cyanogenic glucoside by endogenous enzymes results in the release of free cyanide, which can directly be detected (Ikediobi *et al.*, 1980). The cyanide content of roots does not only vary among varieties but also among plants of the same variety and within the roots of the same plant (Bradbury *et al.*, 1991; Bokanga and Otoo, 1994). The cyanide content in the pulp was much lower than that observed in the leaf or peel (YeOh and Oh, 1987).

This study presents cyanide contents in leaves and roots of cassava at different developmental stages (1- and 12-month old plants) (**Figure 1**). The determination of free cyanide content in this paper employed an enzymatic method which provided a more accurate and precise contents of cyanide than the conventional method of pricrate paper (Sakuanrunsirikul, *et al.* 2007, Bradbury, *et. al.*, 1999). By this approach, it was found that the cyanide contents varied widely in different types of tissues and different cultivars. The result showed that the cyanide contents of young leaves of 1-month old plants ranged from 4,000 to 6,000 μg/g fresh weight (**Figure 1A**), and from 100 to 1,000 μg/g fresh weight in young leaves of 12-month old plants (**Figure 1B**), while the cyanide contents in the roots of 12-monthold plants ranged from 10 to 250 μg/g fresh weight (**Figure 1C**). It was thus revealed that the cyanide contents in young leaves of 1-month old plants were much higher than those of the leaves and roots of 12-month old plants. The mean values of cyanide contents in leaves of 1-month old plants were significantly different among these varieties and were correlated with the cyanide contents of the roots of 12-month old plants. However, no correlation was found between the cyanide contents in leaves of 12-month old plants and in the roots of 12-month old plants, which could be due to the physiological changes during the flowering stage of the plants. In this study, we used the cyanide contents in roots of 12-month old plants as reference to study gene expression.

Several safety level values of cyanide have been introduced. The Indonesian Ministry of Industry and Trade identified the food safety level for cyanide content at 40 mg HCN/kg fresh weight (Widowati *et al.*, 1992); however, according to WHO (FAO/WHO, 1991), the level is 10 mg CN^-/kg fresh weight. Cassava is commonly divided into three groups on the basis of its cyanide content. The sweet or non-toxic level, considered "innocuous", contains less than 50 mg/kg fresh weight, the intermediate level, "moderately poisonous to poisonous", contains 50-100 mg/kg fresh weight, and bitter or "very poisonous" contains above 100 mg/kg fresh weight (Bolhuis, 1954).

However, according to Dufour (1993), cultivars with a cyanide content of less than 100 mg/kg fresh weight in roots are considered to be "sweet" cultivars while those with the content higher than 100 mg/kg fresh weight in roots are "bitter" cultivars. By the latter criteria, Rayong 60, Rayong 72, Rayong 9, and Rayong 3 were considered to be the bitter cultivars while Rayong 7, Hanatee and Rayong 2 were the sweet cultivars.

Expression of Genes Associated with Cyanide Synthesis

The *CYP79D1* and *CYP79D2* genes that encode a small sub-family of cytochrome P450s, catalyze the first-dedicated step in cyanogenic glucoside synthesis using linamarin as a major component (Andersen *et al.*, 2000). The hydrolysis is catalyzed by linamarase to form acetone cyanohydrin and glucose. This cyanohydrin may spontaneously, or enzymatically, decompose to cyanide and acetone. Hence, linamarase activity is considered to be the rate-limiting step in cyanogenesis (McMahon *et al.*, 1995; Fokunang *et al.*, 2001).

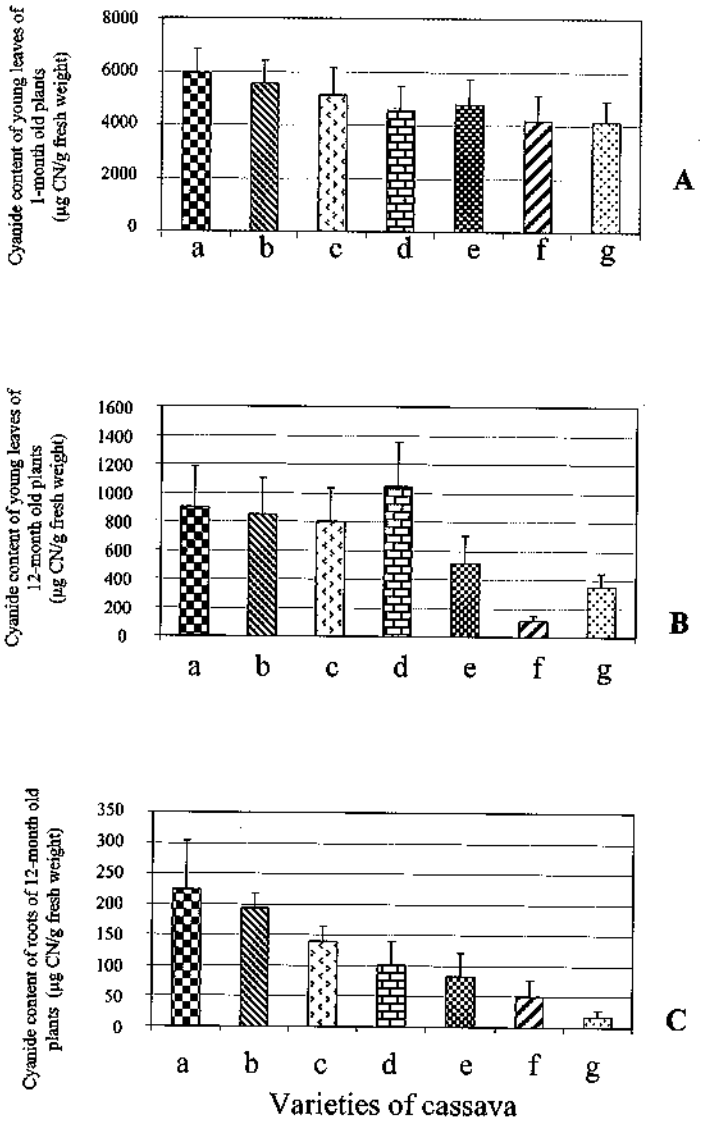

Figure 1. Cyanide content (µg CN/g fresh weight), analyzed by the enzymatic method, of young leaves of 1-month old plants (A), young leaves of 12-month old plants (B) and roots of 12-month old plants (C). Columns represent Rayong 60 (a), Rayong 3 (b), Rayong 72 (c), Rayong 9 (d), Rayong 7 (e), Hanatee (f), and Rayong 2 (g).

In this report, the RT-PCR products of *CYP79D1, CYP79D2* and *linamarase* genes were detected as bands at the size of 267, 391 and 871 bp, respectively (**Figure 2**). The expression level of the gene was recorded as the intensity of the banding of the RT-PCR products. The results show that the expression level of the three genes in young leaves of 1-month old plants varied in accordance to the different levels of cyanide in the roots of 12-months old plants. The cultivars with higher cyanide contents in the roots showed higher levels of gene expressions than those cultivars with the lower cyanide (**Figure 2A, C** and **E**). The expressions of *CYP79D1, CYP79D2* and *linamarase* in young leaves of 1-month old plants of all cultivars showed a high correlation in the range of 0.85-0.90 with the cyanide content of roots of 12-month old plants; CYP79D1 showed the highest correlation coefficient (**Table 2**). However, low correlations were found among the expressions in young leaves of the 12-month-old plants and the cyanide contents of roots, whereas the expression of the *GADPH* gene that was used as the internal control of the RT-PCR amplification reaction showed normal expression levels in all cultivars tested (**Figure 2G** and **H**). Santana *et al.*, (2002) found that the low-cyanide type cassava displayed very high linamarase activity in young leaves and root peels of 3-month old plants and progressively increased and reached a peak at 11-months after planting, but activity of this enzyme decreased during the growth cycle in high-cyanide types. It could thus be hypothesized that the expressions of *CYP79D1, CYP79D2* and *linamarase* genes in the low-cyanide types increase during plant development until the flowering stages, whereas the expressions of these genes are reduced in the high-cyanide types.

CONCLUSIONS

In this present study we found that the expression of the three genes, *CYP79D1, CYP79D2* and *linamarase* in young leaves of 1-month old plants displayed a high correlation with the cyanide content in young leaves of 1-month old plants and in roots of 12 month old plants. These results indicate that the RT-PCR study of these three genes in young leaves of 1-month old plants can be used as a tool to identify cassava with high- and low-cyanide contents at the very early stage of development, as young as one month after planting, thus providing benefits for breeders in reducing time, budget, labor and cultivation areas in the breeding program.

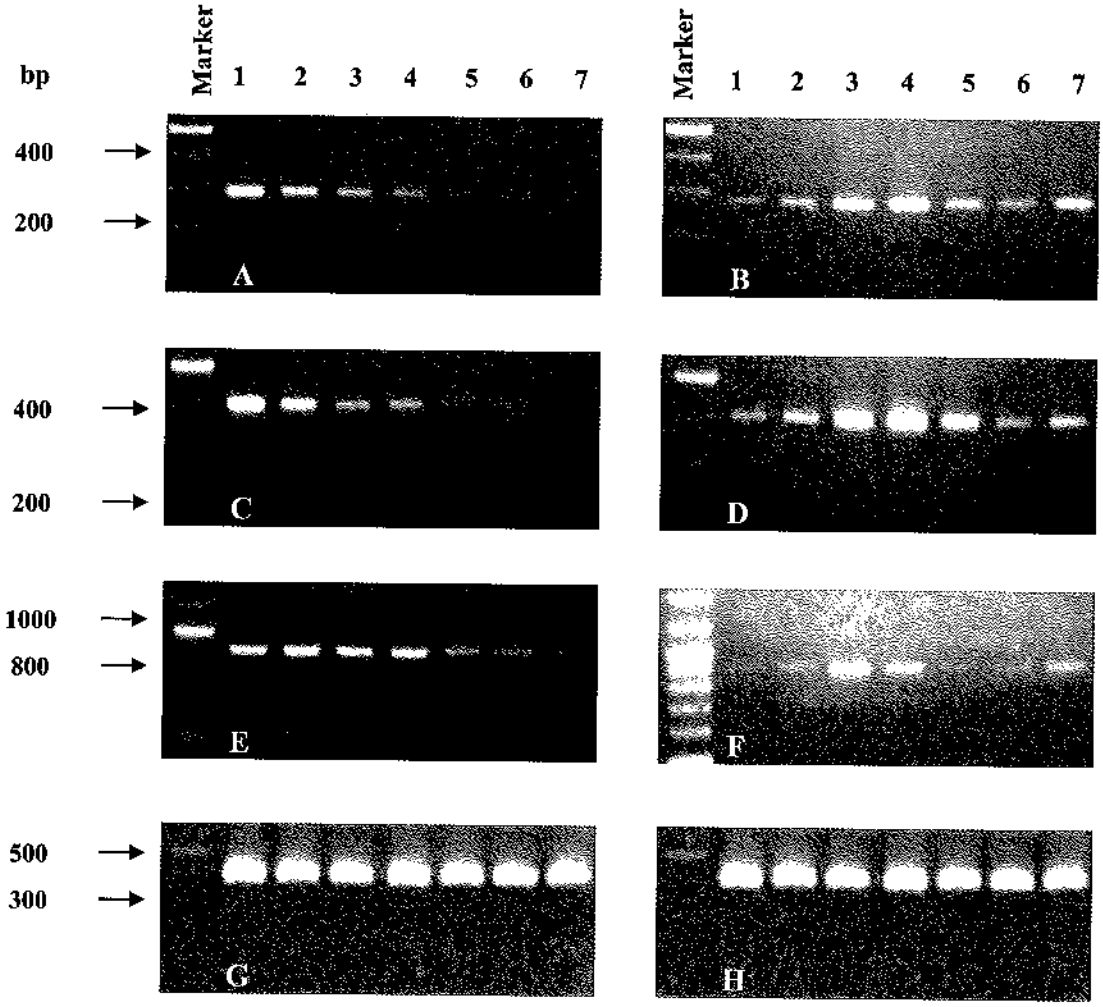

Figure 2. Reverse transcription-PCR (RT-PCR) analysis of the expressions of CYP79D1 (A,B), CYP79D2 (C,D), Linamarase (E,F) and GADPH (G,H) in young leaves of 1-month old plants (A, C, E, G) and 12-month old plants (B, D, F, H). Lanes 1, 2, 3, 4, 5, 6 and 7 are RT-PCR products of Rayong 60, Rayong 3, Rayong 72, Rayong 9, Rayong 7, Hanatee and Rayong 2, respectively.

Table 2. Correlation coefficients of the regression lines (R^2) of gene expressions in young leaves of 1- and 12-month old plants, and the cyanide content of young leaves of 1-month old plants and of young leaves and roots of 12-month old plants of seven cassava cultivars.

Gene	Expression in young leaves (plant age)	Correlation coefficients (R^2)		
		1-month old plants	12-month old plants	12-month old plants
		Young leaves	Young leaves	Roots
CYP79D1	1-month	0.8068	0.0845	0.9066
	12-month	-	-	0.1642
CYP79D2	1-month	0.7421	0.1947	0.8576
	12-month	-	-	0.0047
Linamarase	1-month	0.7301	0.1747	0.8577
	12-month	-	-	0.0142

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RECENT PROGRESS IN CASSAVA BREEDING AND VARIETAL ADOPTION IN THAILAND

Chareinsak Rojanaridpiched[1], Vicharn Vichukit[1], Somsak Thongsri[2], Opas Boonseng[2], Atchara Limsila[2] and Danai Suparhan[2]

ABSTRACT

The success of the Thai cassava breeding program has been due to the release of three outstanding varieties in the 1990s, namely, Rayong 90, Rayong 5 and Kasetsart 50. Other new varieties, Rayong 72, Rayong 7, Rayong 9, Huay Bong 60 and Huay Bong 80, have been released more recently. All varieties have high root yields and high root starch contents. Massive amounts of planting material of these new varieties have been produced and more than 20 million stakes have been distributed freely to farmers. Kasetsart 50, Rayong 5 and Rayong 90 now occupy more than 90% of the cassava planting area. The national average yield has increased more than 50% due to genetic improvement and increased fertilizer application. Further breeding objectives are to increase productivity as well as root quality characteristics for specific industries. In order to achieve the future goal, new germplasm from CIAT with high root yield and high root starch content are necessary to be crossed with elite Thai varieties. Finally, greater tolerance to diseases and insect pests should be incorporated into the next generation of improved varieties as a preventive measure in case these problems are accidentally introduced into the country.

INTRODUCTION

Thailand is the world's leading cassava exporter because of its suitable environment for production and its experienced farmers. Furthermore, Thailand has developed modern production technologies, especially in the areas of cassava breeding, soil management and agronomic practices.

Cassava breeding in Thailand started around 1937 with the introduction of several cassava clones from neighboring countries (Srinives and Rojanaridpiched, 1986). During the 1960s to 1980s, only one local cassava variety was planted for industrial purposes. Later, in 1975, the official name of Rayong 1 was given to that local cultivar. The excellent adaptation of Rayong 1 to the soil and climatic environment in Thailand supported the highly successful cassava industry. Kawano (1992) estimated that Rayong 1 was the most successful industrial cassava cultivar in the world at that time. A comprehensive breeding program was initiated in collaboration with CIAT in 1983. During the 1980s and 90s the aim was to develop new clones that were superior to Rayong 1. Even though several new cultivars were released during the 1980s and 90s, three cultivars have been most successful due to having higher fresh root yields and fresh root starch contents than Rayong 1. During 1994 to 1998 these new cultivars, i.e. Rayong 90, Rayong 5 and Kasetsart 50, were massively multiplied and distributed to farmers, which in turn resulted in a decrease in the area planted to Rayong 1, from nearly 100% of total cassava acreage before the 1990s to only 0.06 % in 2008. The national average yield had increased from 14-15 t/ha during 1967–1996 to more than 17 t/ha during 2002, as shown by Sarakarn *et al.* (2001) and Rojanaridpiched *et al.*(2007).

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Recent Progress in Cassava Breeding

During the first decade of the 21st century, Rayong 1 was no longer used as the check variety in the breeding trials due to its very limited planted area. Our new goal is to compare newly developed lines with Kasetsart 50, Rayong 5 and Rayong 90 which are now used as the check cultivars.

The cassava breeding program of Kasetsart University released a new variety called Huay Bong 60 in 2003. Huay Bong 60 was a progeny of the cross between Rayong 5 and Kasetsart 50 **(Figure 1).** This cultivar has a higher fresh root yield than Kasetsart 50, but has a similar fresh root starch content **(Table 1).** Another cultivar, called Huay Bong 80, a progeny from the same cross between Rayong 5 and Kasetsart 50 **(Figure 1)** has been submitted (May 2008) for plant variety protection under the Thai Plant Varieties Protection Law of 2542 BE (AD 1999). Huay Bang 80 has an outstanding root starch content, which is higher than those of Kasetsart 50 and Huay Bong 60, while it has a similar root yield as Huay Bong 60 **(Table 1).**

The Rayong Field Crops Research Center has recently released Rayong 7 and Rayong 9 in 2005. Both cultivars have high yields and high root starch contents, as shown in **Tables 2** and **3.** Rayong 7 was selected as a cultivar for planting in the late rainy season (October-February) and now accounts for 30% of the cassava planted area in the late rainy season; moreover, this cultivar also performs well when planted in the early rainy season **(Table 2).**

Both Rayong 7 and Rayong 9 shared the high yielding male parent OMR 29-20-118 (from the open pollination of V3, **Figure 1**). V3 is one of several clones introduced from the Virgin Islands in 1965 (Srinives and Rojanaridpiched, 1986). The female parents of Rayong 7 and Rayong 9 are clones CMR 30-71-25 and CMR 31-19-23, respectively, both having a high root starch content.

When compared with Rayong 1, all the new cassava cultivars have higher harvest indices and root starch contents. The higher harvest indices result from increased root yields and decreased stem weights, as illustrated in **Figure 2.**

However, the latest cultivars, such as Huay Bong 80, Rayong 7 and Rayong 9, have a smaller plant type with less branching. All of these cultivars adapt well to highly fertile soil or a productive environment. Regression analysis of the root yields and starch contents of Rayong 7, Rayong 72, Rayong 5, and Kasetsart 50 on the mean of all cultivars at each location (**Tables 4** and **5**) show that the regression (b) of root yield of Rayong 7 and Rayong 72 were greater than 1, while those of Kasetsart 50 and Rayong 5 were less than 1, indicating that Rayong 7 and Rayong 72 were suitable for high yielding environments, while Kasetsart 50 and Rayong 5 were particularly well-adapted to low yielding environments. For root starch content, Rayong 72, Kasetsart 50 and Rayong 5 had regression coefficients below 1, indicating that under environmental conditions which result in low root-starch contents, these three cultivars will have higher root starch contents than Rayong 7.

From our experience, successful industrial cassava cultivars should have both high fresh root yields and high fresh root starch contents, because the price of cassava roots is generally based on the root starch content. Some cultivars, such as Rayong 60 and later Rayong 72, are not well accepted in this industry because of their relatively low root starch

contents. Selection for parents of a cross, either male or female, should posses a character for high root starch content.

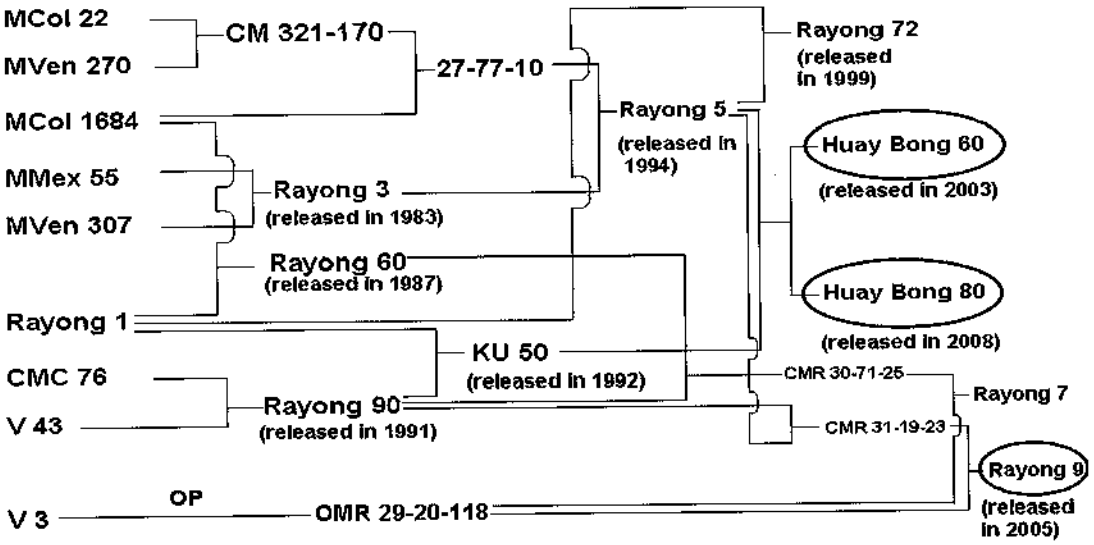

Figure 1. Pedigree of new cassava cultivars released from 1983 to 2008 in Thailand. (OP = open pollinated)

Table 1. Average yield parameters of recently released cassava cultivars from 51 trials conducted during 1999–2006 in various locations in Thailand.

Cultivars	Fresh root yield (t/ha)	Root starch content (%)	Root dry matter content (%)	Fresh top yield (t/ha)	Harvest index
Rayong 5	28.88	24.5	37.5	16	0.63
Kasetsart 50	29.91	25.8	37.4	20	0.60
Rayong 72	30.50	22.4	34.0	13	0.70
Huay Bong 60	31.35	25.8	37.3	19	0.62
Huay Bong 80	31.03	27.6	39.0	16	0.65

** Data from Kasetsart University ' s cassava breeding program.*

Varietal Adoption

Both Kasetsart 50 and Rayong 5 were massively multiplied and distributed by TTDI (Thai Tapioca Development Institute Foundation) between 1995 and 2001. During this period, 19.2 million stakes of Kasetsart 50 and 4.2 million stakes of Rayong 5 were distributed free of charge to farmers **(Table 6)**.

Table 2. Average yields and starch contents of Rayong 7 from 42 trials planted in the late rainy season (LRS) and 12 trials planted the in early rainy season (ERS) during 1998-2004.

	Root yield (t/ha)					
	Fresh		Dry		Starch content (%)	
Cultivars	LRS	ERS	LRS	ERS	LRS	ERS
Rayong 7	39.37	39.75	15.18	14.75	27.6	27.2
Rayong 90	32.87	32.12	12.43	11.93	26.8	25.8
Rayong 5	33.50	32.93	12.18	12.0	24.7	25.0
Kasetsart 50	34.25	37.37	12.81	13.68	26.1	24.4
Rayong 72	34.68	36.31	12.00	12.81	22.5	22.9

Source: *Boonseng et al., 2006.*

Table 3. Average yields and starch contents of Rayong 9 as compared to three check varieties in 20 trials conducted in various locations in Thailand.

Cultivars	Fresh root yield (t/ha)	Starch content (%)
Rayong 9	30.87	24.4
Rayong 72	34.18	21.1
Rayong 5	30.06	21.9
Kasetsart 50	29.62	22.9

Source: *Rayong Field Crop Research Center, 2005.*

Rayong 90 was also widely distributed to farmers by the Department of Agricultural Extension and by the Department of Cooperative Promotion from 1994 to 2001, enough stakes to plant 8,151 ha (Rojanaridpiched *et al.*, 2002), while only 105,375 stakes of Rayong 72 were distributed in 2001.

Huay Bong 60 has been multiplied and distributed from 2002 to 2007 in the amount of 24.2 million stakes **(Table 6).** TTDI is currently multiplying Huay Bong 80 and the distribution to the farmers is planned for 2009 or 2010.

A survey on Thai cassava production conducted by the Office of Agricultural Economics (OAE) in 2006, found that Rayong 1 covered only 0.31% of the cassava planted area, while Kasetsart 50, Rayong 5 and Rayong 90 covered 57.12, 22.21 and 10.74% of the cassava planted area, respectively **(Table 7).**

The trend of replacing Rayong 1 by new cultivars is shown in **Figure 3,** which indicates that the rate of replacement was fastest during 1994 to 1999.

The national average cassava yield in Thailand was rather stable at about 14-15 t/ha during 1967 to 1996, but has since increased dramatically to 22.92 t/ha in 2007, as shown in **Table 8** and **Figure 4.**

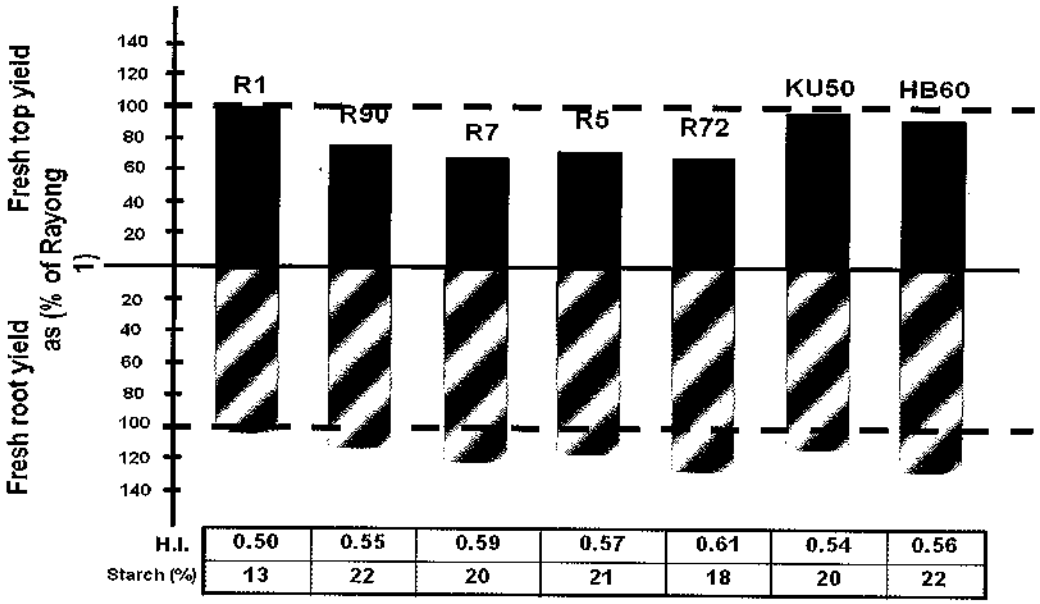

Figure 2. Fresh root yield and top yield of six cassava cultivars averaged over seven locations in Thailand in 2004/05.

Table 4. Regression coefficients of the yields and starch contents of four cassava cultivars on the location means of 46 locations during 1998-2002.

Cultivars	Fresh root yield	Dry root yield	Fresh root starch content (%)
Rayong 5	1.14	1.23	0.91
Kasetsart 50	0.86	0.84	0.92
Rayong 72	0.83	0.82	0.86
Rayong 7	1.14	1.00	1.29

Source: *Boonseng et al., 2006.*

Two factors that attributed to this increase in the national yield are the planting of new cultivars and the adoption of fertilizer application. As shown in **Table 7,** Kasetsart 50, Rayong 5 and Rayong 90 under farmer field conditions yielded 23-26% higher than Rayong 1. Farmers also applied more chemical fertilizer, as indicated in the survey by OAE (2006). On average, 80% of cassava farmers applied chemical fertilizers at the rate of 204 kg/ha **(Table 9).**

Future Direction

The policy of the Thai government for cassava is aimed at increasing the productivity of cassava from the current average yield of 20 to 31 t/ha within five years.

Replacing Kasetsart 50, Rayong 5 and Rayong 90 by the new, higher yielding cultivars Huay Bong 80, Rayong 7 and Rayong 9 is currently under way.

Table 5. Regression coefficients (b) of the yields and root starch contents of five cassava cultivars on the location means of 51 locations during 1999-2006.

Cultivars	Fresh root yield	Dry root yield	Starch content
Rayong 5	0.88	0.90	1.09
Kasetsart 50	0.91	0.94	0.94
Huay Bong 60	0.99	0.99	1.02
Huay Bong 80	1.10	1.10	0.89
Rayong 72	1.13	1.07	1.06

** Data from Kasetsart University ' s cassava breeding program.*

Table 6. Number of stakes of new cassava varieties distributed by the Thai Tapioca Development Institute (TTDI) from 1995 to 2007.

	Varieties				
Year	Kasetsart 50	Rayong 5	Rayong 72	Huay Bong 60	Total
1995	1,825,500	-	-	-	1,825,500
1996	6,233,501	878,160	-	-	7,111,661
1997	4,806,825	1,334,411	-	-	6,141,236
1998	3,220,180	711,180	-	-	3,931,360
1999	2,598,330	1,113,570	-	-	3,711,900
2000	343,320	-	-	-	343,320
2001	169,330	121,150	105,375	-	395,855
2002	-	-	-	152,425	152,425
2003	-	-	-	1,493,350	1,493,350
2004	-	-	-	3,442,905	3,442,905
2005	-	-	-	7,548,050	7,548,050
2006	-	-	-	2,518,250	2,518,250
2007	-	-	-	9,093,777	9,093,777
Total	**19,196,986**	**4,158,471**	**105,375**	**24,248,757**	**39,720,934**

** Data from Thai Tapioca Development Institute Foundation (TTDI).*

However, breeding for still greater productivity in terms of higher fresh root yields and root starch contents is the main objective. Crossing Thai elite lines with a new set of germplasm having clones with high root starch content is necessary to make further progress in the breeding program.

Special attention should also be paid to the clones' susceptibility to diseases and insect pests, because the incidence of high populations of whitefly and mealybugs have been observed in several locations in 2008.

Table 7. Planted area, production and yield of various Thai cassava cultivars in 2006.

Cultivars	Planted area ('000 ha)	%	Production ('000 tonnes)	Yield (t/ha)	(%)
Kasetsart 50	633.7	57.12	12,940	21.1	123
Rayong 5	246.4	22.21	5,193	21.8	126
Rayong 90	119.2	10.74	2,479	21.6	125
Others	51.8	4.66	873	17.4	101
Rayong 60	33.4	3.01	646	20.2	117
Huay Bong 60	15.6	1.40	290	19.6	114
Rayong 3	5.2	0.46	100	20.3	118
Sriracha 1	0.02	N.A.	3	19.0	110
Rayong 1	3.5	0.31	57	17.2	100
Total/Average	**1,109.3**	**100**	**22,584**	**21.09**	**123**

Source: *Office of Agricultural Economics, 2006.*

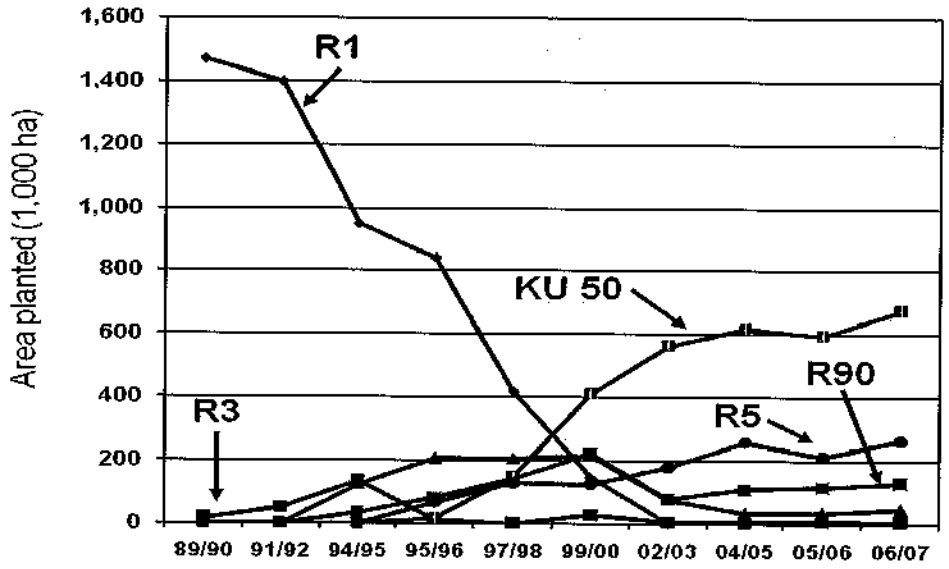

Figure 3. Trend in planted area of some important cassava cultivars in Thailand from 1989/90 to 2006/07.

Table 8. Planted area, production and yield of cassava in Thailand from 1976 to 2007.

Year	Planting area ('000 ha)	Production ('000 tonnes)	Yield	
			(t/ha)	(%)
1976 -1996	1,022	14,425	14.48	100
1997	1,265	18,084	14.70	101
1998	1,071	15,591	14.92	103
1999	1,152	16,507	15.49	107
2000	1,184	19,064	16.85	116
2001	1,106	18,396	17.53	119
2002	988	16,868	17.06	117
2003	1,029	19,718	19.29	133
2004	1,081	21,440	20.27	140
2005	1,043	16,938	17.18	118
2006	1,109	22,584	21.09	145
2007	1,196	26,411	22.92	158

Source: *Office of Agricultural Economics, 2007, Rojaridpiched 2007.*

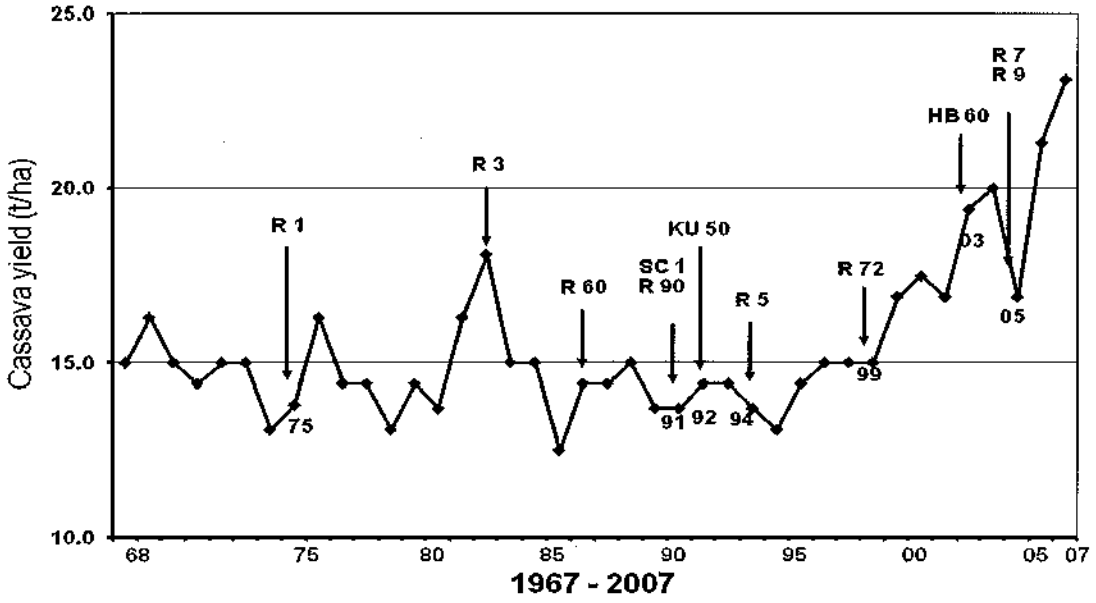

Figure 4. Trend in the average cassava yield in Thailand from 1968 to 2007.

Table 9. Area and rate of application of chemical and organic sources of fertilizers for cassava production in three regions of Thailand in 2006.

	Area with fertilizer applied (%)			Rate (kg/ha)		
Region	Chemical	Manure	Compost	Chemical	Manure	Compost
North	85	5	0.41	182	870	1,726
Northeast	79	12	0.27	198	1,252	1,173
Central	79	6	0.25	201	964	576
Average	**80**	**9**	**0.27**	**197**	**1,165**	**1,158**

Source: Office of Agricultural Economics, 2006.

Also, breeding for specific utilization characters is necessary in order to increase their market potential, such as for low amylose (waxy) or high amylose starch, or for sugary or high protein roots are also important for the starch, ethanol and animal feed industries.

Strengthening the cooperation between the Thai cassava breeding programs and CIAT is necessary because of CIAT's supportive role in disseminating technologies and germplasm resources.

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RECENT PROGRESS IN CASSAVA BREEDING IN INDONESIA

Sholihin[1]

ABSTRACT

It is expected that demand for cassava in Indonesia will increase markedly in the future. This is because of increases in the human population and in industrial processing using cassava as the raw material. The demand for cassava in 2025 is predicted around 62.9 millions tonnes, which is over three times the current level of production. On the other hand, the planting area of cassava has decreased at an annual rate of 0.5%. Increasing cassava yields should therefore be our main goal for increasing cassava production. The planting of high-yielding varieties is one of the main components in increasing productivity. Cassava breeding will thus become more important in the future.

Progress in cassava breeding in Indonesia has been relatively slow because of limited financial resources for cassava research. Most cassava breeding in Indonesia has been done by ILETRI (Indonesian Legume and Tuber Crops Research Institute) in Malang, E. Java. This institute has the national mandate for conducting research on legumes and on root and tuber crops such as cassava. The cassava breeding methodology used in ILETRI is conventional breeding, which involves hybridization, single plant selection, single row selection, preliminary yield trial, advanced yield trials, and multi-location trials. Only ten cassava varieties have been officially released since 1978. The last two new varieties were released in 2001, namely Malang 4 and Malang 6. These varieties were obtained through both controlled and open pollination. Another two varieties were released in 2000, i.e. UJ 3 and UJ 5, both introduced from the Thai-CIAT program. UJ 3 is Rayong 60 and UJ 5 is Kasetsart 50.

Cassava breeding conducted by ILETRI has produced a number of promising clones. Based on the advanced yield trials in 2003-2005 in acid upland soils, it can be seen that clone CMM 99008-3 and OMM 9908-4 produced higher yields than UJ 5. The fresh root yield of these two varieties were significantly higher than those of UJ 5 in Pekalongan, and both had fresh root yields similar to UJ 5 in Menggala, Punggur, Tegineneng, and Natar. Clone OMM 9908-4 and CMM 99008-3 were also more efficient than UJ 5 in producing bioethanol. The mean fresh root yield of OMM 9908-4 over five locations was 19% higher than UJ 5. Clones OMM 9908-4 and CMM 99008-3 were 7 and 13% more efficient, respectively, in producing bioethanol than UJ 5. These and other promising lines are included in multi-location trials in 2008. Possibly, four new varieties will be released in 2009.

An evaluation of cassava germplasm of ILETRI for early maturity was made in 2007. It was found that the fresh root yield at six months after planting ranged from 0.21–2.63 kg/plant, with an average of 1.2 kg/plant. The yields of BIC 556, BIC 137, and MLG 10312 were 160, 158, and 136% higher, respectively, than that of Adira 1, a released variety classified as having early maturity.

A single row trial was also conducted in peat soil in 2007. Clone CMM 03001-30 was better than Malang 1. The fresh root yield of this clone at six months after planting was 8% higher than that of Malang 1. Malang 1 is a released variety which performed better than other released varieties in peat soil. Advanced yield trials were conducted during 2004/05 in Lumajang, Pati, Kediri, and Tulangbawang. The average starch yield of MLG 10311 was the highest, followed by CMM97006-52. In addition, roots of clone MLG 10311 were 7% more efficient in producing bioethanol compared to Adira 4.

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An evaluation of the starch contents of roots of some cassava varieties at different times of storage was conducted in 2008. The root starch contents of Malang 4, CMM 97006-44, Malang 6, Darul Hidayah, Malang 1, and MLG 97007-145 did not significantly decrease in two days after harvesting, while the root starch contents of Adira 1, UJ 5, and L. Nganjuk decreased significantly in two days after harvesting by 5, 10, and 6% respectively. The root starch contents of CMM 97006-44, and Darul Hidayah did not decrease significantly even in six days after harvesting, while the starch contents of Malang 4, Malang 6, Adira 1, U J5, Malang 1, L. Nganjuk, and CMM97007-145 decreased significantly in six days after harvesting. by 12, 6, 6, 14, 8, 6, and 6%, respectively.

INTRODUCTION

In Indonesia cassava is used as human food, industrial raw material, in animal feeds, and for export. Many human food products are made from fresh cassava roots, such as cooked cassava, fried cassava, fried cassava chips, and fermented cassava. Many industrial products are made from cassava, such as starch, sorbitol, fructose, glucose, crackers, and ethanol. Many types of traditional foods are made from cassava flour, such as steamed crackers, cakes and meal (tiwul). Many kinds of human food use cassava flour as a partial or total substitute for other ingredients, such as in cakes, cookies, *bala-bala, cimplung, nagasari, jongkong, ongol-ongol, dodongkal, biji salak,* and *bika ambon.* For animal feeds, different parts of cassava are used in many types of feeds, such as cassava leaves, cassava roots, cassava dry chips, and cassava pulp. For export, cassava is exported in the form of various products such as cassava starch, sorbitol, and dry chips. It was reported that 47 % of cassava is used for human food, 2% for feeds, 7 % for export and 44 % for other utility (FAOSTAT, 2005).

There are several issues in Indonesia related to cassava; one is the energy crisis, food crisis, unemployment, and poverty. During recent years, the cost of fossil fuel has been high. So, there is a presidential regulation No. 5, 2006 about national energy; one of these is that bio-fuels should be used in more than 5% of the national energy consumption in 2025. Cassava is one of the potential raw materials for the ethanol industry and ethanol is one of the bio-fuels. At the moment, in Indonesia, most ethanol industries use molasses as raw material; however, some private companies will produce ethanol from cassava.

During 2008, the price of most foods in the world has been high; in 2007, the price of wheat flour in Indonesia was around Rp 3500 per kg equal to US $ 0.30. In 2008, the price of wheat flour increased to Rp 8500 - Rp10.000 equal to US $ 0.70-US $ 0.80. Because of this condition, modified cassava flour is developing in Indonesia to partially replace wheat flour. Related to the food crisis, food diversification is still one of the government programs. Cassava can be used in this food diversification program. Unemployement and poverty in Indonesia are still relatively high. The development of some industries using cassava as the raw material can reduce unemplyment and poverty

Most cassava in Indonesia is planted in East Java, Lampung, Central Java and West Java. The type of land used for growing cassava in East Java, Lampung, West Java is upland, while that of Lampung is acid upland. Howeler (1992) reported that most cassava in Indonesia is grown on Alfisols 25%, Ultisols 22%, Entisols 20%, and Inceptisols 18%. In East Java and Central Java, most cassava is planted in climate type C2, C3 and D3 in which there are 2-6 dry months of <100 mm rainfall. In West Java and Lampung, most cassava is planted in climate type B and C2 in which there are 2-3 dry months.

It is predicted that demand for cassava in Indonesia will increase markedly in the near future. So, cassava production in Indonesia should be increased. Cassava production

can be increased by intensification and extensification. Intensification can be done by using higher yielding varieties, or better agronomic practices to increase yields, while extensification means the planting of cassava on more land such as on peat soil.

Until now, there are ten released varieties, one of them is UJ 5, and this variety has already developed in Lampung. UJ 5 has been released in 2000. This variety was introduced from Thailand with the name Kasetsart 50. Yield trials of this variety mostly were done in Lampung. The other released variety is Adira 4, which is popular in Java. This variety resulted from the open pollination of BIC 528; it was released in 1987. Red mites are an important insect pest in Java. Adira 4 is more tolerant of red mites than UJ 5.

RECENT CASSAVA BREEDING ACTIVITIES

Recent cassava breeding activities includes the conducting of advanced yield trials in 2003-2005 in acid upland soils, an evaluation of cassava germplasm of ILETRI for early maturity in 2007, a single-row trial in 2007 in peat soils, advanced yield trials in 2004/05, and an evaluation of the starch content of roots of some cassava varieties at different times of storage after harvest.

1. Advanced yield trials in 2003-2005 in acid upland soils

Crosses were made in 1999 and these resulted in a total of 4,500 seeds. These seeds have been evaluated through single plant selection, single row selection, a non-replicated preliminary yield trial and a replicated trial in acid upland soils. From 4,500 seeds, 12 clones were included in Advanced Yield Trials, which were conducted during 2003-2005 in Punggur, Menggala, Natar, Tegineneng, and Pekalongan, all in Lampung province. The results of these Advanced Yield Trials is shown in **Table 1**. It can be seen that clone CMM 99008-3 and OMM 9908-4 produced higher yields than UJ 5. The fresh root yield of these two varieties were significantly higher than those of UJ 5 in Pekalongan, and both had fresh root yields similar to UJ 5 in Menggala, Punggur, Tegineneng, and Natar. The mean fresh root yield of OMM 9908-4 over five locations was 19% higher than that of UJ 5. Clones OMM 9908-4 and CMM 99008-3 were stable (**Table 2**). Clones OMM 9908-4 and CMM 99008-3 were also 7 and 13% more efficient, respectively, in producing bio-ethanol than UJ 5 (**Table 3**).

2. Evaluation for early maturity of cassava germplasm of ILETRI

Some farmers want early maturing varieties. ILETRI has currently a cassava germplasm collection of 350 accessions. A total of 200 accessions from this collection were evaluated for early maturity in 2007 by harvesting the roots at six months after planting. The results shown in **Table 4** indicate that the fresh root yield of BIC 556 was the highest (2.63 kg/plant) and significantly higher than that of UJ 5 (1.63 kg/plant). Fresh root yield of BIC 137, MLG 10312, BIC 154, BIC 280, BIC 146, BIC 529, BIC 504, and BIC 548 were equel to that of BIC 556 (**Table 4**).

3. Single row selection on peat soils

Potential areas of expansion of cassava are often characterized by peat soils. A total of 200 promising breeding lines were evaluated in a single row trial conducted on peat soil in South Kalimantan province. The results, shown in **Table 5**, indicate that line CMM 03001-30 produced the highest root and starch yield per plant, while CMM 03082-3 had the

highest root starch content of 21.86%. The released variety Malang 1 also had a high root and starch yield and an intermediate starch content.

Table 1. Fresh root yields of 12 promising cassava lines in comparison with UJ5 at five locations in Lampung in 2003-2005.

Clones	Natar	Tegineneng	Pekalongan	Punggur	Menggala
CMM 99023-12	51.77 a	73.67 a	22.00 bc	53.53 a	23.43 abcde
OMM 9906-12	41.73 b	65.57 ab	20.67 bcd	27.53 d	27.400 abcde
OMM 9906-19	27.93 gh	50.53 bcd	20.33 bcd	42.20 abc	30.63 a
OMM 9908-4	31.20 ef	63.23 abc	21.67 bc	37.73 bcd	29.67 ab
CMM 99027-35	33.53 de	57.53 bcd	16.33 fg	43.33 abc	25.2 abcd
CMM 99004-2	34.87 d	60.77 abcd	22.67 b	27.63 d	22.73 abcde
CMM 99023-4	38.57 c	61.13 abcd	14.67 gh	26.13 cd	14.97 e
CMM 99008-3	27.43 gh	57.43 bcd	19.33 cde	32.63 cd	23.07 abcde
CMM 99017-11	27.67 gh	45.53 d	12.00 h	49.83 ab	29.8 ab
CMM 99027-54	36.00 cd	50.67 bcd	17.00 efg	35.53 cd	28.17 abc
CMM 99029-5	27.20 h	49.67 cd	18.67 def	33.13 cd	19.83 cde
CMM 99029-31	28.90 fgh	55.90 bcd	20.33 bcd	28.80 d	18.3 ef
UJ 5	30.43 fg	59.77 abcd	13.33 h	28.47 d	21.7 bcde
Average	**33.63**	**57.80**	**18.38**	**35.88**	**24.22**
CV (%)	5.81	17.55	9.63	21.99	21.11

Note: Numbers within each column followed by the same letter are not significantly different at 5%.
***Source**: Sundari and Sholihin, 2007.*

Table 2. Average fresh root yields, regressing coefficients (bi) and mean squares of standard deviation (Sdi^2) of 12 cassava lines and UJ5 harvested at nine months after planting in five locations in Lampung province in 2003-2005.

Clones	Fresh root yields (t/ha)	Regression coefficients (bi)	Mean square stand deviation S_{di}^2
CMM 99023-12	44.88	1.39	39.54**
OMM 9906-12	36.58	1.11	37.46**
OMM 9906-19	34.33	0.72	15.22
OMM 9908-4	36.70	1.03	-4.18
CMM 99027-35	35.19	1.03	-0.5
CMM 99004-2	33.73	1.00	14.88
CMM 99023-4	34.01	1.15	-4.87
CMM 99008-3	29.06	1.06	14.05
CMM 99017-11	32.97	0.76	113.63**
CMM 99027-54	33.47	0.79	-6.73
CMM 99029-5	29.7	0.83	-12.95
CMM 99029-31	30.45	0.97	-0.83
UJ 5	30.74	1.15	-8.79

** Significantly different at 1%.
***Source**: Sundari and Sholihin, 2007.*

Table 3. Conversion of fresh cassava roots of lines OMM 9908-4, CMM 99008-3, and the check variety UJ 5 to ethanol.

Clone	Conversion of fresh roots to ethanol (kg/liter)
OMM 9908-4	4.52 h
CMM 99008-3	4.23 i
UJ 5	4.52 h

***Source**: Ginting et al., 2006.*

Table 4. Root yield and starch content of some selected clones and check varieties harvested at six months after planting in Probolinggo, East Java, Indonesia, in 2007.

No.	Clone	Fresh root yield (kg/plant)	Root starch content (%)
1	Adira 1	1.01	17.5
2	UJ5	1.63	22.2
3	BIC 548	1.93	17.3
4	BIC 504	1.96	18.2
5	BIC 529	1.99	19.1
6	BIC 146	2.07	17.9
7	BIC 280	2.16	17.1
8	BIC 154	2.18	18.8
9	MLG 10312	2.38	17.9
10	BIC 137	2.61	18.8
11	BIC 556	2.63	18.2
	LSD 5%	0.72	3.51

***Source**: Sholihin and T. Sundari, 2008.*

4. Advanced Yield Trials in 2004/05.

In Indonesia cassava is planted in dry areas with varied environmental conditions. When clones are tested in different environments, there will be two possible results. The first, the ordinal of the yield of clones tested is the same between environments. The second, the ordinal of the yield of clones tested is different between environments. Plant breeders should select one or more superior clones. If there is no clone x environment interaction, then the selection of superior clones will be easy as the selection is based on the mean yield. However, the selection of superior clones will be difficult if there is a clone x environment interaction; in that case, the selection of superior clones based on the mean yield would not be very effective. Starch yields are calculated by multiplying the root yield and the starch content. The starch yield is also determined by genetic and environmental factors, including plant maturity (Soenarjo and Hardono, 1986). Generally, the starch content will increase up to a certain point with an increase in plant maturity. There is a positive correlation between starch content and total rainfall in the first 6-9 month period

after planting; however, in 1 or 2 months before harvesting, the correlation is negative (Howeler, 2001). Sholihin and Sundari (2007) reported that the interaction effect between clones and locations was significant for starch yield, fresh root yield and starch content at nine months after planting.

Table 5. Fresh root yield, root starch content, and starch yield at six months after planting of some selected cassava clones in a single-row trial conducted in South Kalimantan in 2007.

No	Clones	Fresh root yield (kg/plant)	Root starch content (%)	Starch yield (kg/plant)
1	CMM03034-9	3.028	20.63	0.625
2	CMM03021-14	3.038	17.84	0.542
3	CMM03082-3	3.038	21.86	0.664
4	OMM9904-122	3.088	17.81	0.550
5	CMM97002-36	3.113	20.27	0.631
6	CMM03038-8	3.163	21.71	0.687
7	CMM03009-8	3.200	21.06	0.674
8	CMM03002-14	3.213	19.70	0.633
9	CMM03001-3	3.225	18.99	0.612
10	369-1	3.238	21.42	0.694
11	CMM03002-13	3.250	18.16	0.590
12	CMM03002-16	3.250	20.84	0.677
13	CMM03036-7	3.275	19.43	0.636
14	CMM03009-1	3.381	20.99	0.710
15	CMM03001-10	3.503	19.02	0.666
16	CMM03097-6	3.563	18.03	0.642
17	Malang 1	4.150	20.27	0.841
18	CMM03022-2	4.288	19.21	0.824
19	CMM03001-30	4.475	19.20	0.859
20	UJ5	2.613	24.1	0.630

***Source**: Sholihin and T.Sundari, 2008.*

Crosses made in 1999 resulted in a total of 3,600 seeds. These seeds have been evaluated through single-plant selection, single row selection, non-replicated preliminary yield trials and replicated trials in upland soils. From these 3,600 seeds, 10 clones were selected for inclusion in the Advanced Yield Trials, which were conducted during 2004/05 in Lumajang, Pati, Kediri, and Tulangbawang. The results of these Advanced Yield Trials are shown in **Tables 6a, 6b, 6c** and **6d**. The average starch yield of MLG 10311 was the highest, followed by CMM97006-52. Moreover, the roots of clone MLG 10311 were 7% more efficient in producing bioethanol compared to Adira 4 (Ginting *et al.*, 2006). However, CMM97006-52 and MLG 10311 were classified as unstable clones based on AMMI models. While Adira 4, CMM97007-145, CMM97007-235, Malang 2, CMM97002-183, CMM97002-36, and CMM97006-44 were classified as stable clones. (Sholihin, 2006). The most important environmental factors in determining the stability of

clones or varieties based on their starch yields at nine MAP were the bulk density of the soil or subsoil, number of rainy days in the fifth month, the minimum air temperature in the fourth month and the minimum air humidity in the seventh month after planting (Sholihin, 2006).

Table 6a. Fresh root yield and starch content at 9 MAP of 15 clones in Advanced Yield Trials conducted in four locations in Java, Indonesia.

	Fresh root yield(t/ha)					Starch content(%)				
	Lumajang	Pati	T.bawang	Kediri	Mean	Lumajang	Pati	T.bawang	Kediri	Mean
1.CMM97001-87	40.21	35.69	14.53	24.81	28.81	19.47	17.27	13.54	16.48	16.69
2.CMM97015-255	43.54	35.52	20.90	31.30	32.82	18.19	18.04	15.01	16.18	16.85
3.CMM97011-191	47.04	38.31	21.21	26.49	33.26	20.76	20.11	16.88	17.84	18.90
4.CMM97002-183	38.72	37.84	15.68	34.30	31.63	18.39	18.94	15.61	17.54	17.62
5.CMM97002-36	42.66	32.73	21.64	33.23	32.57	20.52	21.53	17.93	19.48	19.86
6.CMM97007-145	43.02	38.28	22.25	35.91	34.87	20.18	21.34	16.74	19.62	19.47
7.CMM97007-235	42.53	36.81	18.07	32.33	32.44	19.64	20.75	15.99	17.24	18.40
8.CMM97006-52	39.53	39.79	22.05	41.72	35.77	21.59	22.35	17.81	19.96	20.43
9.Adira 1	27.84	16.59	14.41	25.14	21.00	18.50	18.41	19.24	16.73	18.22
10.Malang 2	39.71	36.09	16.67	33.10	31.39	20.61	19.77	17.62	18.77	19.19
11.CMM97006-44	50.51	43.66	18.62	42.48	38.82	17.63	17.52	12.54	15.61	15.82
12.CMM97001-12	40.21	34.21	15.81	38.10	32.08	21.69	20.63	17.00	20.58	19.97
13.UB 1-2	45.18	41.21	16.30	34.97	34.42	21.16	21.91	16.89	19.26	19.80
14.Adira 4	51.43	36.72	18.36	37.01	35.88	20.75	21.59	18.44	19.98	20.19
15. MLG 10311	52.73	47.66	19.22	44.37	40.99	21.55	20.56	17.50	18.90	19.63
LSD 5%	9.09					1.152				

***Source:** Sholihin, 2006.*

Table 6b. Starch yield at 9 MAP of 15 clones in Advanced Yield Trials conducted in four locations in Java, Indonesia.

	Starch yield(kg/ha)				
	Lumajang	Pati	T.bawang	Kediri	Mean
1.CMM97001-87	7.84	6.40	1.98	4.10	5.08
2.CMM97015-255	7.91	6.41	3.29	5.05	5.66
3.CMM97011-191	9.78	7.66	3.76	4.74	6.48
4.CMM97002-183	7.15	7.21	2.43	5.98	5.69
5.CMM97002-36	8.78	7.03	3.88	6.46	6.54
6.CMM97007-145	8.72	8.20	3.79	7.04	6.94
7.CMM97007-235	8.36	7.68	2.89	5.59	6.13
8.CMM97006-52	8.51	8.91	3.95	8.28	7.41
9.Adira 1	5.14	3.06	2.77	4.22	3.80
10.Malang 2	8.17	7.11	3.00	6.19	6.12
11.CMM97006-44	8.88	7.66	2.34	6.60	6.37
12.CMM97001-12	8.69	7.07	2.78	7.83	6.59
13.UB 1-2	9.57	9.03	2.80	6.74	7.04
14.Adira 4	10.64	8.00	3.37	7.39	7.35
15. MLG 10311	11.33	9.96	3.55	8.38	8.31
LSD 5%	1.31				

***Source:** Sholihin, 2006.*

Table 6c. Fresh root yield and starch content at 9 MAP of 15 clones in Advanced Yield Trials conducted in four locations in Java, Indonesia. Data are standardized on the trial mean and standard deviation (= (Yi – mean) /standard deviation).

	Fresh root yield(t/ha)					Starch content(%)				
	Lumajang	Pati	T.bawang	Kediri	Mean ($\times 10^{-18}$)	Lumajang	Pati	T.bawang	Kediri	Mean ($\times 10^{-18}$)
1.CMM97001-87	0.991	0.598	-1.241	-0.348	0.000	1.13	0.24	-1.29	-0.09	545
2.CMM97015-255	1.138	0.287	-1.264	-0.161	41.63	0.87	0.77	-1.20	-0.44	-291
3.CMM97011-191	1.184	0.434	-1.035	-0.582	333.1	1.01	0.66	-1.10	-0.57	500
4.CMM97002-183	0.656	0.574	-1.476	0.246	20.82	0.53	0.90	-1.38	-0.05	-854
5.CMM97002-36	1.174	0.020	-1.271	0.077	-20.82	0.43	1.08	-1.26	-0.25	-1110
6.CMM97007-145	0.915	0.383	-1.415	0.117	-412.9	0.36	0.96	-1.40	0.08	1350
7.CMM97007-235	0.966	0.419	-1.375	-0.010	-4.337	0.57	1.08	-1.11	-0.53	-666
8.CMM97006-52	0.409	0.437	-1.492	0.646	0.000	0.58	0.96	-1.30	-0.23	-55.5
9.Adira 1	1.053	-0.678	-1.013	0.638	27.76	0.26	0.18	0.96	-1.41	0.00
10.Malang 2	0.817	0.462	-1.446	0.167	-6.939	1.10	0.45	-1.22	-0.33	-638
11.CMM97006-44	0.840	0.348	-1.451	0.263	0.000	0.76	0.71	-1.38	-0.09	0.00
12.CMM97001-12	0.730	0.191	-1.462	0.541	-55.51	0.84	0.32	-1.45	0.29	458
13.UB 1-2	0.842	0.531	-1.417	0.044	298.4	0.60	0.94	-1.30	-0.25	6.94
14.Adira 4	1.148	0.062	-1.293	0.083	3.469	0.42	1.04	-1.31	-0.15	48.6
15. MLG 10311	0.787	0.447	-1.460	0.226	-6.939	1.07	0.52	-1.19	-0.41	514

Table 6d. Starch yield at 9 MAP of 15 clones in Advanced Yield Trials conducted in four locations in Java, Indonesia, data are standardized on the trial mean and standard deviation (= (Y_i – mean) /standard deviation).

	Starch yield(kg/ha)				
	Lumajang	Pati	T.bawang	Kediri	Mean ($\times 10^{-17}$)
1.CMM97001-87	1.07	0.51	-1.20	-0.38	5.55
2.CMM97015-255	1.14	0.38	-1.21	-0.31	41.6
3.CMM97011-191	1.20	0.43	-0.99	-0.63	0.00
4.CMM97002-183	0.65	0.67	-1.45	0.13	16.0
5.CMM97002-36	1.11	0.24	-1.31	-0.04	11.8
6.CMM97007-145	0.81	0.57	-1.42	0.05	-1.56
7.CMM97007-235	0.91	0.63	-1.32	-0.22	-6.25
8.CMM97006-52	0.47	0.64	-1.49	0.37	-15.3
9.Adira 1	1.23	-0.68	-0.94	0.39	19.4
10.Malang 2	0.92	0.44	-1.40	0.03	1.39
11.CMM97006-44	0.88	0.45	-1.42	0.08	-21.5
12.CMM97001-12	0.80	0.18	-1.45	0.47	5.55
13.UB 1-2	0.82	0.65	-1.38	-0.10	-1.39
14.Adira 4	1.09	0.22	-1.33	0.01	-8.76
15. MLG 10311	0.89	0.49	-1.40	0.02	4.25

5. Evaluation of root starch contents of some cassava varieties at various times of storage after harvest.

Root starch content is an important parameter for breeders, the processing industry, and farmers. In the large starch factories, the starch content determines the price of roots. Roots with a high starch content are more expensive than those with a low starch content. For breeders, starch content is an important parameter because most users want roots with a high starch content. For those farmers that sell the roots to the starch factory, the starch content is an important parameter, but for those farmers which sell the roots for eating, the starch content may not be so important.

For ethanol production, the starch content of roots is also important. Results of a biplot analysis of data reported by Ginting *et al.* (2006) indicate that starch content was negatively correlated with the value of conversion of roots to ethanol (r = -0.68*). This means that the roots with a high starch content produce more ethanol than the roots with a low starch content.

In some starch factories, it is difficult to process the roots immediately after harvest. Usually, farmers store the roots one day after harvesting before selling to the starch factory. And in some starch factories the roots are stored a few days before processing. The question becomes, how long the roots can be stored before processing. Broto and Richana (2007) reported that the roots will deteriorate and the starch content will decrease in two days after harvest. Aryee *et al.* (2006) reported that the roots of cassava start to deteriorate within two to three days after harvest if not processed. Processing is undertaken primarily to detoxify the cassava product to improve its palatability or to convert it into a storable form. Sholihin (2008) reported that there was a siginificant interaction between clones and time of storage in terms of starch content.

An evaluation of root starch content of some cassava varieties at various length of time of storage was conducted in 2008. **Table 7** shows that the starch contents of roots of Malang 4, CMM 97006-44, Malang 6, Darul Hidayah, Malang 1, and MLG 97007-145 did not significantly decrease in two days after harvesting, while those of Adira 1, UJ 5, and L. Naganjuk decreased significantly in two days after harvest by 5, 10 and 6%, respectively.

UJ 5 is a released variety which has the highest starch content among released varieties (Sholihin, 2008). This variety is widely disseminated in Lampung. The roots of this variety should be processed as soon as possible after harvesting, because two days after harvesting the starch content decreased 10%.

The root starch contents of CMM 97006-44, Malang 6, Malang 1, and Darul Hidayah did not significantly decrease in four days after harvesting, while those of Malang 4, Adira 1, UJ 5, L. Nganjuk, and CMM 97007-145 had decreased significantly after four days of storage by 6, 5, 10, 6 and 4%, respectively. Moreover, the starch contents of CMM 97006-44 and Darul Hidayah had not significantly decreased after six days while those of Malang 4, Malang 6, Adira 1, UJ 5, Malang 1, L. Nganjuk, and CMM 07007-145 had decreased significantly by 12, 6, 6, 14, 8, 6, and 6%, respectively. So, some clones could maintain their starch content during storage much longer than other clones. The decrease in starch content after harvest is the result of primary and secondary deterioration. The primary deterioration is an endogenous physiological process called vascular streaking, which results in a fine blue-black or brown discoloration. The physiology and biochemistry of primary deterioration involves the increase in activity of various enzymes, the production of catechin and coumarin components, including scopoletin, scopolin and

esculin and other metabolites (Rickard, 1985). This physiological deterioration also caused a reduction in the β-carotene content of Golden Yellow cassava variety (Gloria and Uritani, 1984). It is followed by secondary deterioration which involves microbial rotting or sometimes softening or fermentation of the tissue (Rickard and Coursey, 1981). Mechanical damage to the root during and after harvesting may enhance primary deterioration and facilitates secondary deterioration. This may be reduced by the process of curing which involves exposure of the roots to about 35°C at 80-85% relative humidity.

Table 7. The root starch content of nine clones at four times of storage.

	Root starch content (%)			
Clones/varieties	0 day after harvest	2 days after harvest	4 days after harvest	6 days after harvest
1. Malang 4	22.10	21.97	20.67	19.53
2. CMM97006-44	20.47	19.77	20.03	20.13
3. Malang 6	21.10	20.77	20.77	19.93
4. Darul Hidaya	20.83	20.03	20.53	20.37
5. Adira 1	20.07	19.10	19.03	18.80
6. UJ 5	24.30	21.87	21.87	20.80
7. Malang 1	21.07	20.57	20.43	19.33
8. L.Nganjuk	20.43	19.13	19.13	19.17
9. CMM97007-145	21.90	21.07	21.00	20.53
Mean	21.36	20.47	20.38	19.84
LSD 5%	0.83	0.83	0.83	0.83
CV (%)	2	2	2	2

Source: *Sholihin, 2008.*

There are some ways to improve the storage of roots. First, by leaving the roots in the ground until needed. Second, the pruning of all the branches from the plants up to three weeks before harvest causes changes in the roots which improves their storage (Rickard and Coursey, 1981. Third, by packing roots in moist sawdust in boxes to reduce their exposure to air and by reducing moisture loss (Booth *et al.,* 1976). Fourth, by storing the roots in clamps or interlayering between cassava leaves, or by coating roots with wax. Fifth, by storing the roots in cold storage at 3°C. Sixth, by storing the roots in the deep freeze at -20°C. They remain stable for long periods, although over 6-8 months of storage the bound cyanide (linamarin) is broken down and appears as free cyanide (Bradbury and Holloway, 1988).

Some other changes occur during storage of cassava roots. There is a conversion of starch to sugar. Booth *et al.* (1976) reported that the conversion of starch to sugars resulted in the sugar content being two to three times higher than the original level after two weeks of storage. Pillai *et al.* (1970) also reported an increase in sugar content and a decrease in starch on storage of roots in soil. Kawabata *et al.* (1984) found an increase in the amounts of glucose and fructose and a decrease in the amount of sucrose during storage at ambient temperature. Beside that, softening of the central part of the roots also occurs.

As mentioned before, different clones reacted differently after storage in terms of root starch content. So, there is the possibility to breed for this character. CIAT (2008) reported that an interspesific cross between *Manihot esculenta* and M. *walkerae* produced a progeny with roots that did not deteriorate for at least three weeks after harvesting.

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RECENT PROGRESS IN CASSAVA BREEDING AND THE SELECTION OF IMPROVED CULTIVARS

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ABSTRACT

A large number of field trials have been conducted to evaluate cassava varieties for improved ethanol production, both from the CIAT collection that is being held in Vietnam and from the breeding programs of the Vietnam National Cassava Program (VNCP) research partners. From 2001 to 2007, a total of 24,073 cassava sexual seeds from CIAT-Colombia and 37,210 seeds from 9-15 cross combinations made in Vietnam, 38 breeding lines (mainly from Thailand), and 31 local farmers' varieties have been planted. Of these, 98 of the best lines are now in the final stages of the selection process and three of the most promising, KM140, KM98-5 and KM98-7, have recently been released in the period 2007-2009. The new advanced cassava varieties KM297, KM228, KM318, KM325, KM397, KM21-12, SC5, HB60 are still being evaluated in the Regional Yield Trials (RYT) in Tay Ninh, Ninh Thuan and Yen Bai provinces.

THE SELECTION OF CASSAVA VARIETIES DERIVED FROM CIAT

The objectives of the cassava genetic improvement program in Vietnam are: 1) to increase the yield potential, dry matter content and starch content; 2) to enhance early harvestability; 3) to identify high-yield varieties suitable for different agro-ecological zones and to promote the integration of these into smallholder farming systems; and 4) to select the best cassava varieties for bio-ethanol production. Thus, the work above on breeding and pre-breeding will help to define the breeding strategies for increased crop productivity and bio-ethanol production.

The largest number of field trials are being conducted in Tay Hoa village, Trang Bom district of Dong Nai province in south Vietnam. These include trials to evaluate cassava varieties for improved ethanol production from the CIAT cassava collection in Vietnam as well as the breeding programs of VNCP research partners (**Table 1**).

Every year the trials include two trials for the Conservation of Elite Germplasm (CEG), an F1 Seedling trial (F1), two Single Row trials (SRT), two Preliminary Yield trials (PYT), and two Standard Yield trials (SYT) . Some new crosses of cassava elite clones and

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promising partially inbred lines (Letini and Ceballos, 2003; Ceballos *et al.*, 2007 a,b) were made, evaluated and tested in the field in Tay Hoa (Dong Nai). The screening for quality characteristics that are likely to be related to improved fermentability continues. Three pre-breeding accessions that have interesting traits have been selected for crossing with high-yielding varieties. The new advanced cassava varieties KM297, KM228, KM318, KM325, KM397, KM414, KM419, KM21-12, SC5 and HB60 are being evaluated in the Regional Yield Trials (RYT) of Tay Ninh, Ninh Thuan and Yen Bai provinces (**Tables 2-6**).

Table 1. Present size of the cassava collection in Nam Long University (NLU) and the Institute of Agric. Science (IAS) in July 2008.

Type of cassava germplasm	Donor	No of accessions	No. of selected plants in		
			F_1C_1 [1)]	OT	PYT
Total		**344**	**139,667**	**3,495**	**668**
Farmers' varieties	VNCP	31	31	31	31
Breeders' varieties		38	38	38	38
-Thailand	FCRI, KU	7	7	7	7
-Colombia	CIAT	5	5	5	5
-Brazil	EMBRAPA	4	4	4	4
-China	CATAS	11	11	11	11
-India	CTCRI	2	2	2	2
-Indonesia	BORIF	1	1	1	1
-Malaysia	MARDI	1	1	1	1
-Vietnam	NLU, IAS	7	7	7	7
Experimental access.		275	139,598	3,426	599
-Introduced access.		242	96,148	2,551	435
CIAT before 2000	CIAT	18	72,075	18	18
CIAT 2001-2008	CIAT	224	24,073	2,533	417
-Vietnam hybrids	NLU, IAS	27	37,210	386	164
-Mutation access.	NLU, IAS	6	6,240	489	125

[1)] F_1C_1 = Seedling trial; OT = Observational trial; PYT = Preliminary Yield trial

RECENT PROGRESS IN CASSAVA BREEDING AND IMPROVEMENT OF CROP PRODUCTIVITY

1. Recent Progress in Cassava Breeding

The specific objectives of the cassava breeding program are: to select and release new varieties with a high-yield capacity of 35-40 t/ha, a starch content of 27-30%, a growing period of 8-10 months, erect stems, short internodes, less branching, compact canopy, uniform root size, white root flesh and suitable for industrial processing. As a result, two new cassava varieties, KM140 and KM98-5, have been identified and released in South Vietnam in 2007 and 2009, respectively; one new cassava variety, KM98-7, has also been released in North Vietnam in 2008. These three varieties all have a yield potential higher than that of the local check, KM94. These varieties are now being disseminated to a large number of farm households in Vietnam.

Table 2. Some new advanced breeding lines and varieties evaluated in Tay Hoa, Dong Nai, South Vietnam in 2009.

NLU code	Cassava hybrid elite clones (F_1 C_4) and advanced varieties	Root yield (t/ha)		Root DM content (%)	Root starch content (%)	Root starch yield (t/ha)
		Dry	Fresh			
KM414 *	KM146-7-2 x KM143-8-1	17.17	44.60	38.5	28.7	12.80
KM397 *	(SM937-26xSM937-26)xBKA900	16.80	43.40	38.7	28.8	12.50
KM325 *	SC5 x SC5	15.34	40.58	37.8	27.6	11.20
KM140 *	KM140 x KM140	14.99	38.94	38.5	28.2	10.98
KM419 *	BKA900x (KM98-5 x KM98-5)	14.86	37.72	39.4	28.9	10.90
KM98-1*	KM98-1 x KM98-1	14.85	39.30	37.8	27.7	10.88
KM297 *	KM297 x KM297	14.75	36.70	40.2	29.5	10.83
KM228 *	KM228 x KM228	14.74	39.10	37.7	27.6	10.80
KM318 *	CM9582 x CM9582	14.44	37.60	38.4	28.4	10.68
KM363 *	KM21-12 x KM21-12	13.76	36.04	38.2	28.3	10.20
KM140	KM98-1 x KM36	13.43	35.72	37.6	27.8	9.93
KM225	SC5 = ZM8625 x SC8013	12.92	36.28	35.6	25.8	9.36
KM97	SM937-26	12.68	31.85	39.8	29.2	9.30
KM390	HB60 = (R1xR5) x KU50	12.59	32.97	38.2	27.9	9.20
KM331	SM9947-3	12.37	32.72	37.8	27.9	9.13
KM228	KM94 (6 Kr)	12.42	31.93	38.9	28.5	9.10
KM219	BKA900	12.55	34.20	36.7	26.5	9.06
KM222	GM911	12.49	34.88	35.8	25.8	9.00
KM94	KM94	12.03	31.00	38.8	28.7	8.90
KM320	SC6 = OMR33-10-4	10.04	27.83	36.1	25.4	7.07
KM333	CM9966-1	9.50	26.34	36.8	26.3	6.93
KM36	XVP-2	8.94	22.93	38.0	27.6	6.33
KM23	HL23	8.34	22.30	37.4	27.5	6.13
KM27	XVP-1	8.83	25.10	35.2	24.3	6.10
CV %			12.46		3.42	
LSD 0.05			3.18		1.24	

* elite clones; KM146-7-2 = KM98-5 x KM98-5; KM143-8-1= KM98-1 x KM98-1

Cassava variety KM140 is a hybrid selected from the cross of KM98-1 with KM36 made in 1998 (**Figure 1**). Thirty cassava varietal experiments and two experiments for determining the best harvesting time of some cassava cultivars were carried out. The latter two trials were conducted on a red soil in the Southeastern region; they were planted at the beginning of the rainy season and harvested at 6, 7, 8, 9, 10, 11 and 12 months after planting; as well as on grey soil planted at the beginning of the rainy season and harvested after 10, 11 and 12 months.

The results of these experiments indicate that KM140 had fresh root yields of 33.4-35.0 t/ha, starch contents of 26.1-28.5%, starch yields of 9.5-10.0 t/ha; in general it is better than KM94. The HCN content of KM140 roots was 105.9 mg/kg dry matter, so this variety can be used for fresh consumption, unlike KM94 which has a higher HCN content; KM 140 had a harvest index of 0.65 and has good resistance to pests and diseases.

Table 3. Results of a Standard Yield Trial conducted in Tay Hoa village, Trang Bom district of Dong Nai province in 2009.

Varieties	Root yield (t/ha)		Root starch content (%)	Root DM content (%)	Root starch yield (t/ha)	Harvest index (%)	Plant type & stake quality (1-10)	Root shape & uniformity (1-10)
	Dry	Fresh						
KM414	18.00	46.80	27.6	38.5	12.91	63	9	9
KM325	16.97	44.91	26.8	37.8	12.08	65	9	9
KM228	16.47	43.69	26.7	37.7	11.66	64	8	9
KM140	16.36	42.50	27.3	38.5	11.60	63	9	9
KM98-5	14.37	36.48	28.5	39.4	10.40	58	9	9
KM 397	13.80	35.65	28.7	38.7	10.23	64	9	9
KM297	13.78	34.27	28.2	40.2	9.66	56	8	9
KM308	11.48	32.35	25.1	35.5	8.12	60	9	8
KM206	10.80	29.68	26.2	36.4	7.78	57	9	8
KM315	9.78	27.17	25.4	36.0	6.90	53	8	8
KM94(c/k)	13.24	34.12	27.9	38.8	9.52	54	8	9
CV%		9.18	4.05		7.80			
LSD 0.05		3.68	2.89		2.24			

Table 4. Results of three Regional Yield Trials conducted in Tay Ninh province in 2008- 2009.

Varieties	Fresh root yield (t/ha)				Root starch content (%)	Root DM content (%)	Root starch yield (t/ha)	Root DM yield (t/ha)
	RYT1	RYT2	RYT3	Aver.				
KM 325	27.90	60.00	48.69	45.53	27.20 cde	37.9	12.38	17.26
KM 98-5	27.50	58.60	42.28	42.79	27.20 cde	37.9	11.64	16.21
KM 98-1	26.70	52.34	38.46	39.17	26.82 de	37.0	10.51	14.49
KM140	24.80	47.90	35.80	36.16	27.50 bcd	38.5	9.94	13.92
KM94	26.93	39.10	34.70	33.58	28.70 a	39.6	9.97	13.30
KM297	28.00	50.40	-	-	29.10 a	-	-	-
KM318	26.80	45.20	-	-	27.50 bcd	-	-	-
KM315	21.60	40.54	-	-	28.10 abc	-	-	-
KM307	22.13	36.30	-	-	27.20 cde	-	-	-
KM228	23.47	33.67	-	-	28.40 ab	-	-	-
KM206	24.26	28.63	-	-	27.60 bcd	-	-	-
CV%	10.84	13.16	11.76		2.32			

When the varieties were planted in the Southeastern region in the middle of the rainy season and harvested at 10 months all had low starch contents (16.6-22.5%). When harvested at 11 months after planting, almost all cultivars had starch contents around 25%, which would satisfy the requirements of processors. If harvested at 12 months after planting, most of the cultivars had high fresh root yields and starch contents, but this would

cause inconveniences for the next crop cycle. Planting at the beginning of the rainy season and harvesting at 7, 8 and 9 months, KM140 gave fresh root yields of 23.5. 26.7 and 28.7 t/ha, respectively, equal to those of KM94 (**Figure 2**). The starch content of KM140 harvested at 8 months after planting was 28.4%, significantly higher than that of KM94 (26.2%) (**Figure 3**).

Table 5. Results of a Regional Yield Trial conducted in Quang Son village, Ninh Son district of Ninh Thuan province in 2009.

Varieties	Fresh root yield (t/ha)	Root starch content (%)	Root starch yield (t/ha)	Total biomas yield (t/ha)	Harvest index (%)
KM140	37.50 b	30.40 ab	11.80 a	55.50 bc	68.88 a
KM228	47.33 a	26.03 c	11.47 ab	68.61 a	65.59 a
KM206	36.94 b	29.70 ab	10.35 bc	54.78 bc	67.54 a
KM318	34.67 b	29.57 ab	10.15 c	54.87 bc	63.66 a
KM94	32.67 b	32.77 a	9.55 c	61.17 b	53.50 b
CV%	8.42	5.68	5.91	6.97	5.07
LSD 0.05	5.69	3.06	1.13	7.32	5.92

Table 6. Results of three Regional Yield Trials conducted in Yen Bai province in 2009.

Varieties	Fresh root yield (t/ha)				Root starch content (%)	Root DM content (%)	Root starch yield (t/ha)	Root DM yield (t/ha)
	RYT1	RYT2	RYT3	Aver.				
KM 21-12	32.10	44.58	33.00	36.56	29.70	39.80	10.86	14.55
KM98-7	28.77	40.92	23.63	31.10	28.40	39.60	8.83	12.32
KM98-1	23.17	36.82	26.45	28.81	28.60	39.20	8.24	11.29
KM94	26.87	32.25	29.33	29.48	29.70	40.60	8.76	11.97
KM21-10	30.70	31.00	23.18	28.29	28.70	39.80	8.12	11.26
HB60	-	-	23.40	-	29.33	40.00	-	-
Rayong 9	-	-	23.00	-	29.47	40.10	-	-
CV%	11.60	9.20	17.80					
LSD .05	5.33	3.56	3.05					

* KM98-1 = NA1 (Nghe An 1)

Figure 1 shows that KM98-5 is a hybrid selected from the cross between KM98-1 with Rayong 90 made in 1998. On a grey soil in Tay Ninh province, KM89-5 had a fresh root yield of 34.5-37.8 t/ha, a starch content of 27.2-29.8%, and starch yields of 10.0-11.7 t/ha; these are higher than those of KM94 and KM140.

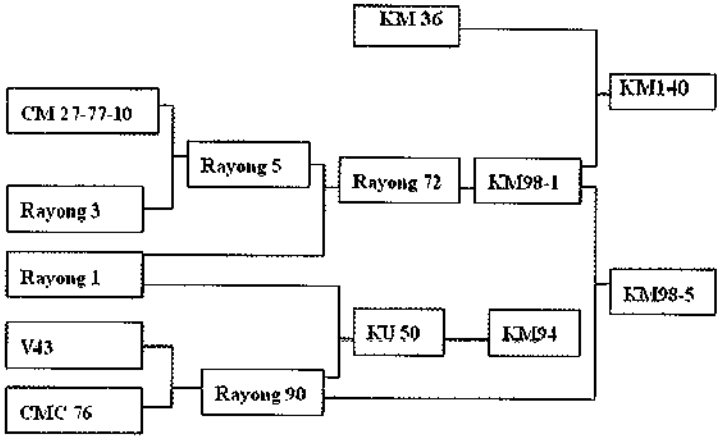

Figure 1. Genetic background of the newly released varieties KM140 and KM98-5.
Note: KM36= XVP2.

Figure 2. Roots of KM140 at nine months after planting in Hung Loc Agric. Research Center in Dongnai, south Vietnam.

KM140, KM98-5, KM98-1 and SM937-26 are newly released varieties which are now playing an important role in cassava production in the Southeastern and Central Coastal regions, as well as in the Central Highlands in the South (Hoang Kim *et al.*, 2007; Nguyen Thi Cach *et al.*, 2007; Tran Cong Khanh, 2007; Tran Cong Khanh *et al.*, 2007; 2009; Le Van Luan 2008).

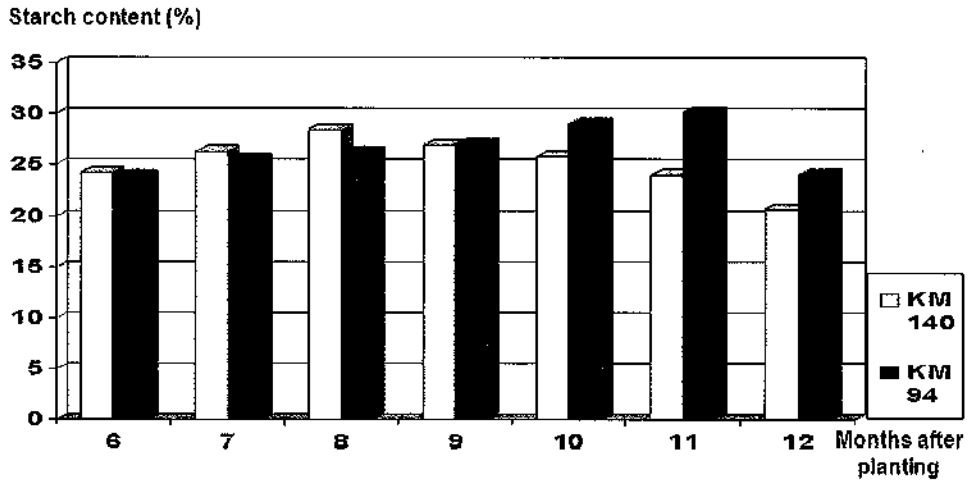

Figure 3. The starch content of KM140 and KM94 harvested at monthly intervals between six and twelve months after planting in the Southeaster region of Vietnam.

Two other new cassava varieties, KM98-7 and KM21-12, are being disseminated to a large number of households in the northern mountainous areas (Tran Ngoc Ngoan. 2008, Trinh Thi Phuong Loan *et al.*, 2008).

2. Improvement of Crop Productivity

The productivity of cassava can be increased by the use of the most appropriate varieties as well as by using the most improved cultural methods of production, including appropriate fertilizer applications, soil erosion control, and intercropping. Trials have been established at pilot sites in Dong Nai, Yen Bai, and Thua Thien Hue provinces to determine: (i) the agronomic potential of intercropping systems of cassava with sweet sorghum, maize or groundnut; (ii) the best management practices for these cropping systems, with particular reference to integrated soil fertility management and soil erosion control; and (iii) the best high-yielding varieties of sweet sorghum, maize and groundnut to intercrop with cassava.

The crops and varieties evaluated as intercrops with cassava included six sweet sorghum lines from ICRISAT: ICSB38, PVK801, ICSR93034, ICSV574, NTJ2 and IS41333; one groundnut cultivar from ICRISAT: ICGV91114; and six new maize varieties from NLU and HARC in Vietnam. In addition, two pigeon pea cultivars, ICP7035 and ICPL 20092, were obtained from ICRISAT for evaluation.

Two on-farm trials using cassava variety KM140 intercropped with maize variety VN25-99 were conducted at the pilot site in Tay Hoa village, Trang Bom district of Dong Nai province, to determine the best management practices for cassava-maize intercropping systems (**Table 7**).

Table 7. Results of two on-farm trials using cassava variety KM140 intercropped with maize variety VN25- 99 in Tay Hoa village, Trang Bom district of Dong Nai province in South Vietnam in 2009.

	Cassava				Maize	
Cropping systems[1)]	Root yield (t/ha)	Top yield (t/ha)	DM content (%)	DM yield (t/ha)	grain yield (t/ha)	Net profit[4)] (million d)
Grey soil						
Cassava monoculture	34.5	27.8	39.7	13.69	0	15.38
Cassava + Maize[1)]	25.0	24.7	38.5	9.63	3.50	20.76
Cassava + Maize[2)]	32.7	25.4	38.9	12.72	1.44	18.64
Cassava + Maize[3)]	33.9	28.4	41.3	14.00	2.68	25.40
Red soil						
Cassava monoculture	38.6	32.5	38.7	14.93	0	17.86
Cassava + Maize[1)]	28.9	28.3	37.0	10.69	4.40	27.38
Cassava + Maize[2)]	37.5	30.6	37.6	14.10	2.20	25.20
Cassava + Maize[3)]	36.9	31.8	38.2	14.10	3.56	30.00

[1)]One row of cassava intercropped with one row of maize; cassava 1.00x0.75 m; maize 1.00x0.2 m.
[2)]Two rows of cassava intercropped with one row of maize; cassava 1.00x0.75 m; maize 2.00x0.2 m.
[3)]Two rows of cassava intercropped with two rows of maize; cassava (0.75 m x 2 rows) x 0.75 m; maize (0.75 m x 2 rows) x 0.2 m.
[4)]Cassava chips: 2,700 d/kg; maize dry seeds: 5,000d/kg. 1USD = 18,000d.
Net profit = Net income - Total variable costs.

Similar on-farm trials using cassava variety KM94 intercropped with groundnut, varieties L14 and HL25, were conducted to determine best management practices for cassava-peanut intercropping systems (**Table 8**). Three of the cassava-peanut on-farm trails were conducted at the pilot site in Phong My village, Phong Dien district of Thua Thien Hue province; another in Tay Hoa village, Trang Bom district of Dong Nai province; and one in Mau Dong village, Van Yen district of Yen Bai province.

A large number of field trials were conducted to evaluate cassava varieties and breeding lines for improved ethanol production from the CIAT variety collection in Vietnam and from the breeding programs of VNCP research partners. A total of 24,073 cassava sexual seeds from CIAT and 37,210 seeds from 9-15 cross combinations made in Vietnam, 38 breeding lines (mainly from Thailand), and 31 local farmer's varieties have been planted. Of these, 98 of the best lines are now in the final stages of the selection process, and three of the most promising, KM140, KM98-5 and KM98-7, have been released in the period 2007-2009.

The new advanced breeding lines KM297, KM228, KM318, KM325, KM397, KM414, KM419, KM21-12, SC5, HB60 are being evaluated in the Regional Yield Trials (RYT) in Dong Nai, Tay Ninh, Ninh Thuan and Yen Bai provinces.

Table 8. Results of three on-farm trials using cassava variety KM94 intercropped with groundnut varieties L14 or HL25 at Phong My (Thua Thien Hue), Tay Hoa (Dong Nai) and Mau Dong (Yen Bai) in 2009.

Cropping systems	Yield (t/ha)		Groundnut biomass yield (t FW/ha)	Net profit (million d)[3]	Selection from farmers (%)
	Cassava (fresh root)	Groundnut (dry seed in pod)			
Phong My (sandy soil)					
Cassava monoculture	22.7	0	0	12.70	20.0
Cassava + Groundnut[1)]	18.9	0.90	4.20	20.10	13.3
Cassava + Groundnut[2)]	16.5	1.44	7.20	26.42	66.7
Tay Hoa (grey soil)					
Cassava monoculture	34.5	0	0	22.50	26.7
Cassava + Groundnut[1)]	32.8	1.00	4.60	32.80	20.0
Cassava + Groundnut[2)]	31.6	1.20	6.90	35.20	53.3
Mau Dong (grey soil)					
Cassava monoculture	28.3	0	0	11.32	40.0
Cassava + Groundnut[2)]	26.2	2.25	7.60	21.73	60.0

[1)] Cropping pattern: Cassava spacing 1.00 x 0.80 m; one row of cassava intercropped with one row of groundnut spaced 0.50 m from cassava row x 0.20 m between plants x 2 seeds/hill)

[2)] Cropping pattern: Cassava spacing 1.00 x 0.80 m; one row of cassava intercropped with two rows of groundnut, spaced 0.30 m between rows x 0.20 m between plants x 2 seeds/hill)

[3)] Cassava fresh roots: 1,000 d/kg; groundnut with shell:18,000 d/kg. 1USD = 18,000 d. Net profit = Net income - Total variable costs.

RECOMMENDATIONS

After twenty years of development (1991-2010), intensive cassava research and extension have changed cassava from being a food crop to being an industrial crop. Cassava is now a very promising crop for both export and domestic use. VNCP agreed to emphasize the following five topics:

1. Determination of an appropriate strategy for cassava research and development in cooperation with processing factories to establish areas with a stable source of raw materials; use of cassava for bio-ethanol production.
2. Selection and dissemination of high-yielding varieties with high starch contents and high resistance/tolerance to mealybugs and other pests and diseases. Selection of cassava partially inbred lines derived from materials from CIAT and applying mutation in cassava breeding. Selection and development of varieties with high root yield, short duration and improvement of quality and nutritional value of cassava roots.
3. Research on integrated cultivation techniques and transfer of appropriate cultivation techniques to farmers to increase the productivity and economic efficiency of cassava production in different eco-regions.
4. Research on the development of cassava processing technologies. Use of cassava leaves and roots in animal feeds and food processing. Cassava starch, ethanol effluent and

by-products transformation into animal feed and fertilizers.

5. Development of local and export markets for cassava products.

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RECENT PROGRESS IN CASSAVA BREEDING IN INDIA

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ABSTRACT

Cassava is an important crop in India and has two well-defined roles in the Indian context, such as a food crop and an industrial crop. It is primarily a food crop in the southern State of Kerala and the north eastern States of Assam, Nagaland, Chhatisgarh and Orissa, whereas in the other States like Tamil Nadu, Karnataka, Andhra Pradesh and Maharashtra, the crop is an industrial raw material for starch and sago production. As a food crop, cassava is being considered both a delicacy in the affluent regions and a poverty alleviation crop among the poor. CTCRI has been catering to the various national needs of cassava cultivation and utilization.

Two of the earliest hybrid varieties developed at CTCRI, i.e. H-165 and H-226 have remained popular for the past four decades, and are still the predominant varieties cultivated in about 100,000 ha in the industrial areas of Tamil Nadu. The newly generated triploid hybrids 4-2 and 5-3 have recently created an impact in the industrial areas in Tamil Nadu because of the substantially higher extractable starch contents of the roots. The high yielding, high starch triploids were identified using a farmer participatory approach from the early stages of selection.

Recently, the first CMD resistant cassava variety was released by CTCRI for Tamil Nadu i.e. Sree Padmanabha (MNga 1 of Nigeria). Furthermore, the CMD resistance traits (from the IITA and CIAT accessions) are being utilized in the conventional breeding program at CTCRI by taking recourse to extensive hybridizations. Among the 164 African cassava mosaic resistant clones received from CIAT, 57 were found to be also resistant to mosaic in India.

Another major promising program is the production of inbreds in cassava for the utilization in the heterosis breeding program. In CTCRI, up to sixth generation inbreds have been produced and some of the inbreds are exceptionally vigorous and are high yielding; they exhibit wide variations in dry matter, starch and carotene contents. Inbreeding was also found to release several desirable recessive alleles such as those for starch quality. Two high yielding table varieties, Sree Rekha and Sree Prabha, were isolated from the top-cross of early generation inbreds. The advanced inbreds with high combining ability will be used for the production of heterotic hybrids, and for the identification of molecular markers. The future strategies are to produce short-duration lines, high yielding varieties with very good palatability for table purpose, and to refine the true seed propagation of cassava to ensure uniform progeny with excellent cooking qualities for eating purposes.

INTRODUCTION

Cassava is the most important tropical root crop in India; it is used for food, animal feed and industry. It is grown in about 0.27 million ha which is about 1.4% of the total cassava cultivated area in the world. Cassava production in India is about 9.0 million tonnes, which is about 3.9 per cent of the world cassava production. The crop is cultivated predominantly in the southern states, two of which, Kerala and Tamil Nadu, contribute 88% of the area and 97% of total production. The crop is also grown in Andhra Pradesh, Karnataka, Maharashtra, Gujrat, Madhya Pradesh, Tripura, Mizoram, Nagaland and Andaman and Nicobar Islands. The high yield of cassava (33.5 t/ha in 2008) in India

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derives from the very high root yields in the southern state of Tamil Nadu (38 t/ha), where the improved CTCRI varieties have been widely adopted and the crop is largely grown under irrigation and with fertilizer application.

Cassava research in India has been conducted for the past 46 years in the Central Tuber Crops Research Institute (CTCRI), in Trivandrum, Kerala, which is in the south of the country, and at its Regional Station in Bhubaneswar in the North eastern region. Apart from CTCRI, the Agricultural Universities in Kerala and Tamil Nadu states have also been carrying out cassava research. Besides, the All India Coordinated Research Project on Tuber Crops, with its 12 centers in different agro-climatic regions of the country, has been engaged in the advanced testing of varieties and technologies as well as in tackling location-specific problems.

Cassava as a Food Crop and the Table Varieties

Cassava has two well defined roles in India; one as a food crop for both the rich and the poor, and the other as an industrial crop, mainly for the production of starch and sago (tapioca pearls). As a food crop cassava is largely cultivated in the southern state of Kerala as well as in the North eastern states of Assam, Meghalaya, Nagaland, Tripura and Mizoram. To a lesser extent, it is also used as food in the states of Tamil Nadu, Andhra Pradesh and in a few others. Kerala is the only state where over 90% of the produce is used for human consumption as food, and the rest in various animal feeds. In Kerala, there are about 165 local varieties and land races of cassava developed by the farmers, in addition to several improved varieties from CTCRI. The variety M4 or Malayan 4, is the preferred variety for table use; this variety is also known under different names in different localities. The improved varieties from CTCRI for table use include 'Sree Visakham', a carotene rich variety, 'Sree Sahya, a drought tolerant variety, three early maturing varieties, 'Sree Prakash, 'Sree Jaya' and 'Sree Vijaya', two varieties suitable for upland and lowland cultivation, 'Sree Rekha' and 'Sree Prabha', and the CMD resistant variety 'Sree Padmanabha' (which is MNga 1 received from CIAT, Cali, Colombia). The Kerala Agricultural University has released three short-duration varieties for table use. They are, 'Nidhi', 'Kalpaka' and 'Vellayani Hraswa', which are suited to different localities and soil types such as sandy tracts, reclaimed soils and red loam soils, respectively, as well as for intercropping in coconut plantations.

While the improved cassava varieties and many other locally preferred varieties, can produce root yields of 30-40 t/ha, the preferred table variety M4 yields only 20-25 t/ha. Hence, improving the root yield along with the root quality similar to that of M4, and incorporating CMD resistance is a major challenge in the breeding of superior table varieties. Intervarietal hybridization among the good quality varieties like M4, Vellayani Hraswa, Sree Jaya and other superior landraces are routinely carried out and the segregants are evaluated for root quality and yield. Triploids of M4 have also been generated, expecting higher yields along with good root quality. Besides, several inbreds were also found to combine higher yields with good cooking quality. For incorporating CMD resistance, the resistant variety Sree Padmanabha (MNga 1), and various resistant lines received from CIAT, were also included as parents in the hybridization program. As a result of the initial evaluations of the segregants, several promising selections were made for higher yields combining good cooking quality as well as mosaic resistance. Among the selections there were eight triploid lines of M4, 17 lines of M4 x mosaic resistant lines

from CIAT, 21 selections of inbreds of mosaic resistant lines from CIAT, 22 selections of triploids involving M4 and MNga 1, and five selections of triploids of MNga 1. The triploids in general show shade tolerance and early harvestability, with substantially higher root yields even at eight months after planting.

Cassava as an Industrial Crop and the High Starch Varieties

Apart from Kerala and the northeastern states, cassava is cultivated predominantly as an industrial crop in India. The industrial products are mainly starch and sago, and the highest cultivation as an industrial raw material and the highest production of industrial products are in Tamil Nadu in the south. In Tamil Nadu cassava is cultivated in about 100,000 ha, supplying the raw material to about 800 factories. The highest root yield of cassava is obtained in Tamil Nadu (up to 48 t/ha) where the two improved varieties of CTCRI, i.e., H-165 and H-226 have been the ruling varieties for about four decades. Although there are two other industrial varieties developed by CTCRI (H-96 and Sree Harsha) and five varieties developed by Tamil Nadu Agricultural University (CO-1, CO-2, CO-3, CO-4 and H-119), they are limited to small pockets of cultivation. The high root yields obtained in Tamil Nadu is due to the suitability of the varieties and the farmers' practice of irrigation and fertilization, which are often arbitrary and exceeding the optimum. Hence, superior lines selected elsewhere, when evaluated in Tamil Nadu, often show greater vegetative luxuriance than higher root yields. Therefore, more recently, a farmer participatory approach in selection of segregants is practiced, even from early clonal generations of hybrid seedlings.

Triploid Varieties for Higher Yield and Higher Starch Content

Artificially produced triploid hybrids in cassava (2n = 54) were generally found to have higher root yield (>35 t/ha), higher dry matter content (>45%) and higher extractable starch content (>30%), compared to diploid hybrids. The triploids also have higher leaf retention capacity, higher harvest index, stout, tall and vigorous plant type, which could be contributing to higher root yields.

Triploids are artificially produced by crossing diploid (2n = 36) and tetraploid lines (2n = 72). The tetraploid lines are first produced by treatment of diploid stem buds with a 0.5% colchicine solution for 12 hours. Following the colchicine treatment, apparent tetraploids are identified on the basis of increased leaf size with broader and thicker leaf lobes and acuminate tips. The tetraploids are then screened for flowering and pollen fertility and the fertile tetraploid males are used as parents to cross elite diploid females. The success of viable seed set depends on using tetraploid as the male parent and not *vice versa*. From the diploid x tetraploid crosses, triploid seedlings are identified by the dark green, thick and broad leaf lobes with acuminate tips, similar to those of tetraploids. The triploid hybrids in the first clonal generation were evaluated in row trials, and superior ones having higher yield and higher starch content were identified.

Impact of New Triploids in the Industrial Areas in Tamil Nadu

The first triploid hybrid in cassava named 'Sree Harsha' was released from CTCRI during 1996. It is a high yielding variety with a root yield of 35-40 t/ha and a starch content of 38%. The variety was evaluated and developed under rainfed conditions in CTCRI,

Trivandrum, and when it was tested in the industrial areas of Tamil Nadu under irrigated conditions, the variety produced excessive vegetative growth rather than higher root yields.

Subsequent production of triploid hybrids was followed by farmers' participatory evaluation in Tamil Nadu from the early clonal generation itself. Thus, superior triploid hybrids were selected by conducting farmers' participatory trials in various locations in five districts in the hills and plains of Tamil Nadu. During the harvest, the root yield and extractable starch content of the hybrids were recorded in the presence of farmers and factory owners, and the best hybrids were selected for cultivation in the irrigated plains of Tamil Nadu for industrial purpose. Two highly preferred triploids, such as 4-2 and 5-3 were selected by farmers from 14 triploid selections evaluated in their fields. The selected hybrids have recorded root yields of 35-45 t/ha in farmers' fields and have an extractable starch content of 29-32%. This is in comparison to the yield of 22-25 t/ha of roots and an extractable starch content of 20-24% of the prevailing diploid varieties. Between the two selections, 4-2 was found to be superior to the other and was preferred by the farmers and the factory owners as it yields 5-6% more starch than the prevailing varieties. Because of the higher starch yield, the factory owners encourage the farmers to supply the roots of the new triploids, and farmers also prefer this variety as it is higher yielding, giving them an additional income of about Rs 21,000 per ha due to the higher root yield. The overall increase of root yield and extractable starch content of the new triploid hybrids were about 54% and 25%, respectively, as compared to the prevailing diploid varieties.

CMD Resistance Breeding

The prevailing industrial varieties of cassava in Tamil Nadu and other states, as well as and the table varieties in Kerala, are all susceptible to cassava mosaic disease. The triploid hybrids are also susceptible but more tolerant than the diploids. Hence, developing CMD resistant varieties for table and industrial purposes has become a major breeding objective. Recently, the CMD resistant lines from CIAT, such as MNga 1 (TMS30001), having the CMD 1 gene, and other CR lines having the CMD 2 gene, were extensively used in hybridizations, and the segregants were evaluated for disease resistance and other desirable attributes.

The variety MNga 1, besides being resistant to cassava mosaic disease, is also a moderately high yielder (27-30 t/ha) with low cyanoglucoside content in the roots. This variety was evaluated in farmers' fields and also in multi-location trials for several years, and the root yield and CMD resistance was confirmed. In 2007, MNga 1 was released under the name 'Sree Padmanabha' as the CMD resistant cassava variety for cultivation in the irrigated plains of Tamil Nadu. Sree Padmanabha is the first mosaic disease resistant variety of cassava released in India.

The variety Sree Padmanabha has also been used in conventional breeding by hybridization with various released varieties such as Sree Jaya, Sree Vijaya, Sree Rekha, Sree Prabha and other superior indigenous lines and popular varieties. Large numbers of F1 populations were screened and 48 superior segregants showing CMD resistance and other desirable root characters were identified for evaluation trials. Farmers' participatory evaluations of CMD resistant hybrid lines since 2006 in the hills and plains of Tamil Nadu have confirmed the suitability of three lines for the hills and five lines for the plains, of which the hybrid, CMR-1 has been widely accepted by the farmers for the irrigated plains for its high yield, high extractable starch content (28%) and CMD resistance.

Triploidization of CMD resistant lines of cassava (MNga 1 and CR lines from CIAT) is also being attempted to develop high yielding, high starch triploid hybrids with CMD resistance. Among the 164 CR lines received from CIAT, which are resistant to African Cassava Mosaic Virus, 57 were found to be CMD resistant under field conditions in CTCRI for the past few years. The superior lines were confirmed for resistance by graft transmission studies as well as by SSR markers, and 17 high yielding, CMD resistant lines were identified. Among them two exceptionally high yielding, CMD resistant lines, i.e., CR43-7 and CR43-11 were identified, the latter having good plant type and high leaf retention as well.

Inbred Lines and Heterosis Breeding

Although cassava is a cross pollinated crop, it tolerates inbreeding to a great extent. Inbreds were produced up to the fifth generation by selfing and sib mating in the 1990s. The S_5 lines were weak and sparse flowering or non-flowering. But after eight generations of clonal propagation, the S_5 lines were found to revive in vigor and flowering and the inbreeding was resumed to produce the sixth generation of inbreds.

The effect of inbreeding varied among the genetic stocks for various characters. Significant inbreeding depression for morphological characters was observed only in 6.5% of the S_1 population. In other cases, inbreds exhibited more vigor and had a wider variation for several traits. In fact, selfing resulted in the release of a wide spectrum of variation conserved in cassava genotypes. The plant height of the S_1 population ranged from 0.1 to 3 m. In the S_2 generation, height of the inbred seedlings ranged from 0.6 to 4.5 m, and the canopy spread ranged from 0.45 to 4.5 m due to increased branching and more biomass production of the top growth. The major deleterious effect of inbreeding was the decrease of sexual fertility on selfing, as evidenced by the reduction in fruit set and seed set, and hence, only self fertile inbreds could be carried over to advanced inbred generations. From the S_1 to the S_5 generation, the mean seed set was reduced from 15.2 to 8.5%. Inbreeding resulted in the development of male sterile lines and several variations in floral characters such as cleistogamy and various degrees of bisexuality. Inbreeding resulted in early flowering in many cases. Several inbred lines started flowering 40 days after planting while many did not flower. Among the yield components, the harvest index recorded the least inbreeding depression of 14.2% as inbreeding advanced from S_0 to S_5. Root yield recorded the highest inbreeding depression of 40.5%, followed by number of roots/ plant (38.2%) and total biomass (38.0%). On the other hand, there were exceptional inbred seedlings which recorded very high root yields of 5-6.5 kg/plant. Interestingly, inbreeding resulted in the segregation of tuberization pattern which ranged from no tuberous root formation (producing only fibrous roots) to a very high degree of tuber formation.

Inbreeding depression was not evident for the biochemical characters like dry matter and starch. The root starch content was higher among several lines of the fifth inbred generation. Inbreeding also resulted in the generation of lines with high starch content, and high carotene lines with dark yellow and orange flesh color. Both these characters showed transgressive variation among the inbreds. Thus, inbreeding in cassava was not deleterious *per se*, but was beneficial for the segregation and release of several desirable recessive alleles.

The two high yielding varieties released from CTCRI during 2000, i.e. Sree Rekha and Sree Prabha are the selections from the top cross of early generation inbreds with the

variety Sree Visakham. Both are high yielding table varieties suitable for both upland and lowland cultivation.

Interspecific Hybridization

Interspecific hybridization followed by back-cross breeding was carried out mainly to incorporate CMD resistance and to increase the protein content of roots. Two wild species, i.e., *M. glaziovii* and *M. caerulescens* were crossed for CMD resistance, and *M. tristis* was crossed for protein content enhancement in the roots. The interspecific hybrids of cassava with both *M. glaziovii* and *M. caerulescens* showed CMD resistance. Among the two, *M. glaziovii* is easy to work with, whereas *M. caerulescens* is sparsely flowering and hence difficult to cross, while the F_1 roots are also extremely long and of poor quality, which are characters that are difficult to improve even after repeated back crossing.

M. tristis is profusely flowering and the back crosses were more fruitful; total protein enhancement up to 4.6% has been accomplished. Six promising back-cross hybrids were identified; two having CMD resistance, three with high protein content in the roots and one with excellent cooking quality.

True Seed Program in Cassava

The multiplication rate of the traditional propagation of cassava by stem cuttings is only 10-15 times. Moreover, the use of cassava stems as planting material is bulky and inconvenient for storage and transportation, especially to distant areas. By adopting true seeds as the planting material the bulkiness is reduced and there is ease of storage and transport; only about 1.5 kg of true seeds is sufficient to plant one hectare of the crop, whereas a small truck load of stems would be required to plant the same area. By using true seeds the multiplication rate can be increased to about 20 fold of the normal stem propagation. Besides, the seeds have longer viability than the stems and CMD can be prevented from spreading, as the virus is not found to be seed transmitted.

The true seed program suffers from the drawback that the seedlings would be heterogeneous and the root yield and quality will not be uniform. This has been mitigated to a great extent by the selection of certain particular female parents which yield more or less uniform progeny with less variation in root yield and quality. The local variety Ambakadan is a profusely seed setting one, which also shows male-sterility. Ambakadan can be planted along with MNga 1 as male parent with CMD resistance to collect naturally cross pollinated seeds which are used in distant, non-traditional areas to establish a cassava crop. The seedlings are raised in a nursery and before transplantation, the tap root from each seedling is removed so that it stimulates the production of a large number of fibrous roots which became tuberous when the plant matures. By removing the tap root, the root yield of seedlings is substantially enhanced and the first clonal yield is comparable to that of the commercial varieties. The population is more or less homogeneous and largely free from CMD. At present, this program is highly suitable for introducing and establishing the crop in non-traditional areas, especially for industrial purposes. But it has to be further perfected for the table varieties, wherein absolutely uniform progeny with regard to superior root quality is required. It will be possible by selecting appropriate parents from the advanced inbred lines, among which suitable male-sterile clones are also available.

Tissue Culture and Somatic Embryogenesis

The institute has tissue culture programs for *in vitro* conservation of germplasm, rapid multiplication of virus free plants and also for somatic embryogenesis for the production of transgenic plants. The objective of *in vitro* conservation is to gradually convert the entire field gene bank into an *in vitro* gene bank to save land and labor. More than one third of the cassava germplasm accessions are now in the *in vitro* gene bank, maintained in the slow growth medium containing sorbitol, which can sustain the plantlets for 16 months in the same tube. In addition to the building up of an *in vitro* gene bank, rapid multiplication of cassava varieties by apical meristem culture is another activity for the rapid multiplication of virus-free planting material.

Work on the somatic embryogenesis of cassava is another recent program in CTCRI, in order to identify popular Indian cassava varieties having high embryogenic response and to develop a regeneration protocol for a transgenic program of cassava in India. Although earlier attempts on regeneration of cassava through somatic embryogenesis yielded limited results, recent studies have brought out significant results. Using young leaf lobes as explants, and MS medium with picloram (50 M), high embryogenic potential was observed in the industrial varieties H-165 and H-226, and in other table varieties such as Sree Prakash, Sree Visakham, Sree Prabha, Vellayani Hraswa, Malayan 4 and Ambakkadan, as well as in triploid lines. The protocol for the regeneration of plants from somatic embryos of different varieties was also standardized. Murashige & Skoog (MS) medium with sucrose (20%) and combinations of hormones, i.e., benzyl adenine (BA) 2µM and Thidiazuron (TDZ) 1µM were effective for shoot development, which varied among varieties. Among the varieties, H-226, the most popular industrial variety of cassava, recorded normal plantlet production. This is a breakthrough in the transgenic program as the earlier attempts on regeneration of this variety through somatic embryogenesis were not successful.

CONCLUSIONS

In India the productivity of cassava in the 1970s and early 80s was about 17 t/ha, which was increased to about 23 t/ha in the 90s and the present average productivity of 33.5 t/ha is the highest in the world. Across the country, cassava is cultivated either as a mono-crop or intercrop, in lowland or upland, under irrigated or rain-fed conditions and under different cropping systems. The development of high-yielding varieties, the standardization of agro-techniques and plant protection measures, and the technologies developed for value-added products from CTCRI have not only sustained the crop in the traditional areas, but has also spread the same to non-traditional areas. However, the traditional cassava growing area of Kerala is decreasing due to the changes in the consumption pattern of people, and changes in the cropping patterns, as farmers prefer to plant more economical crops. Hence, area expansion in the future is only possible by the expansion in the industrial areas. Apart from Tamil Nadu, the industrial areas have been steadily increasing in Andhra Pradesh, where the sago industry emerged as a cottage industry in the 1970s. At present, cassava is cultivated in about 25,000 ha and there are some 65 cassava-based industries functioning in Andhra Pradesh. The states of Maharashtra and Gujirat have also taken up cassava cultivation in several thousand ha, mainly for industrial purposes, and several processing industries have been set up in those states. In the north eastern states of Assam and Meghalaya, where cassava is primarily a food crop, cultivated in about 10,000

ha, production of sago is increasing. CTCRI has been instrumental in the spread of cassava as a food and industrial crop across the country, and the increased national productivity of the crop is due to the better varieties and better cultivation practices. The institute has been trying to develop still better varieties having CMD resistance, for table and industrial needs, as well as early-maturing varieties with higher harvest index and a longer shelf life of the roots.

INTEGRATED RESEARCH AND DEVELOPMENT, AND THE APPLICATION OF KEY TECHNOLOGIES OF BREEDING, CULTIVATION AND INDUSTRIALIZATION FOR CASSAVA IN CHINA

Li Kaimian, Jiang Shengjun and Ye Jiangqiu[1]

ABSTRACT

Recently, the total cassava planted area in China was about 440,000 ha, with a total annual production of about 9 million tonnes of fresh roots. Cassava processing and utilization have developed markedly in recent years, and the production of cassava-based products has increased from about 30 to 85%. The production of cassava has changed from being a scattered and backyard crop into one that is farmed intensively and grown mostly for industrial processing.

The recent increase in cassava yields can be attributed to the adoption of new technologies, especially that of improved varieties and good cultivation techniques. Cassava varietal improvement in China has focused on the following aspects: a) collection and introduction of cassava germplasm and establishment of a cassava germplasm bank for cross-breeding; b) establishing a national cassava trial network, forming an integrated breeding system of improved varieties, testing and demonstration, as well as extension; and c) multiplication and dissemination of improved varieties.

On the other hand, the development of cassava-based products and improved market channels, as well as changes in government policy also affected the development of cassava production in China.

INTRODUCTION

Cassava is the sixth most important grain crop in the world; in Chinese the crop is called "King of starch and underground grain storehouse". It is not only a basic food resource for about six hundred million people in tropical areas in the world, but also a major cash crop for underdeveloped countries and areas. In addition, it is a vital resource of raw material for starch processing as well as for that of bio-ethanol.

Processed cassava products are broadly employed in paper making, textiles, food, feedstuff, energy, medicine and other industries.

Presently, more than 90 countries in Africa, Asia and Latin America plant cassava. The total planting area in the world is about 18.7 million ha, producing 233 million tonnes of fresh cassava roots.

In 2007, the planting area of cassava in China was 440,000 ha, yielding 9,110,000 tonnes of fresh roots. This volume, however, was far from being enough to meet the domestic demand, thus requiring the importation of cassava products, which was equivalent to 15 million tonnes of fresh cassava roots.

The tropical and subtropical areas of China are characterized by a high proportion of poor people, limited farm land and lots of uncultivated waste land. Cassava used to be an important crop during periods of famine, but its advantages of high accumulation of starch and its capability of surviving during droughts and in infertile soils, has made it one of the most favored crops in the tropical agricultural development; it is also a raw material of great importance in industry. The development of the cassava industry will put land resources to rational cultivation and utilization, promote tropical agricultural advancement,

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and serve as a reliable means for farmers to increase their income and reduce poverty. Therefore, it is of great significance to make continuous efforts to develop the cassava industry. Over decades, party and government leaders of our country have always attached great importance to, and taken care of, the cassava industry.

The cassava project started in the 1970s. Previously, the cassava industry had not well developed due to a shortage of resources, poor quality cassava varieties, a low level of planting and backwardness of the processing techniques used. Against this background, with the support of the Chinese Ministry of Agriculture, Chinese Ministry of Science and Technology and other related organizations, the project was executed. The project took different provinces, areas and organizations 30 years of joint efforts to tackle many crucial problems, selecting and breeding new varieties, promoting better planting techniques and developing new processing procedures, new equipment and new products, all for the purpose of ensuring the rapid development of our country's cassava industry, and to meet the domestic requirements for the cassava industry and for other uses.

DESIGN OF THE CASSAVA PROJECT

The project was designed to make major breakthroughs in selecting and breeding better cassava varieties. By selecting and breeding new cassava varieties which typically give high yield and have high starch contents; by developing a set of highly productive and effective agronomic practices; and by integrating and innovating these techniques, the production of superior cassava varieties would be regionalized and yields would be increased.

Meanwhile, the research was market-oriented and an industrialization approach was adopted. Joint efforts were made to tackle crucial problems and various measures were taken to popularize and apply the achievements, so that superior cassava varieties and advanced agronomic techniques would be employed in the production of cassava, and the potential of cassava in supplying raw materials for processing would be strengthened. Leading enterprises were supported and new processing techniques, new equipment and new products were developed to upgrade the cassava industry in our country.

CASSAVA BREEDING AND CULTIVATION IN CHINA

The main objectives of cassava improvement are as follows:

High root yield/ high starch content
Early harvestability
Adaptation to unfavorable conditions
Resistance to CBB and brown leaf spot
Good plant type suitable for cultural practices and harvesting

Innovation 1: Introduction of cassava germplasm from abroad, establish the cassava germplasm bank, establish an evaluation system for characterizing the cassava germplasm

Germplasm resources of cassava were collected, multiplied and utilized creatively, and a national cassava germplasm bank and appraisal system of cassava germplasm resources were established.

More than 535 germplasm accessions of cassava were collected and kept in tissue culture, resulting in the establishment of our national *in vitro* cassava germplasm collection.

Criteria for describing cassava germplasm resources, specifications for data quality control and relative technology standards were worked out. A germplasm characterization system and resource database were constructed, and, in order to promote resource sharing, a resource sharing platform was set up.

A set of superior germplasm accessions were further evaluated, and more than five thousand intermediate breeding lines were produced, thus laying a solid foundation for the work of selecting and breeding cassava varieties.

Innovation 2: Cassava genetic improvement through breeding

A base for cassava crossbreeding was established and a standardized system of breeding and selecting cassava varieties was developed.

A system of cassava breeding was established by creatively making use of advanced breeding methods to produce a large number of F1 seedling populations, resulting in several breakthroughs in cassava varietal improvement.

Thirteen new cassava varieties, like South China No.5 (SC 5) and South China No.8 (SC 8) were developed through cross-breeding and recurrent selection. And a series of high-yielding varieties with high starch content and tolerance of adverse conditions in China were created **(Table 1)**.

Compared with the old varieties, these new varieties had 28% higher average fresh root yields, and 13% higher starch contents **(Table 2)**.

Table 1 Principal characteristics of the newly released cassava varieties in China.

Year of release	Variety	Pedigree	Yield (t/ha)	Remarks
2006	SC10		45	broadly adapted
2005	SC9		30	for food
2004	SC8		45	early harvestable
2004	SC7		45	high protein in leaves
2001	SC6		45	typhoon resistant
2000	SC5		60	broadly adapted
1994	SC8013		40	broadly adapted
1994	SC8002		40	broadly adapted
1988	SC124		45	broadly adapted

Innovation 3: Development of a rapid propagation system and improved cultural practices

A system of highly productive, effective and standardized agronomic practices for cassava was developed. The first rapid propagation system of cassava planting material through tissue culture was pioneered in our country, which increased the speed of stem propagation by 30-300%, and thus reduced the time for widespread dissemination of new varieties by three to five years.

Research was conducted on cassava's nutrient requirements and water use, as well as on reducing erosion when cassava is planted on slopes. Recommendations were formulated

on more effective fertilizer application and on soil and water conservation, which will ensure the maintenance of soil fertility and the sustainable high yields of cassava.

Various new technologies, including crop rotation and intercropping systems, were developed, as well as the use of plastic mulching and returning cassava stems and leaves to the soil; this increased profits by 10-30%.

Table 2. Comparison of root yields and starch contents between old and new varieties in China.

	Cassava root yield (t/ha)					Starch content (%)				
Variety	2003	2004	2005	Aver	(%)	2003	2004	2005	Aver	(%)
New	35.70	33.60	23.55	30.90	128	28.66	30.53	30.25	29.81	113
Old[1)]	25.95	24.75	21.60	24.15	100	25.14	26.50	27.70	26.45	100

[1)] Old variety is SC 205

Source: *Wuming county cassava experiments from 2003 to 2005 in Guangxi province.*

CASSAVA PROCESSING

Innovation 4: New procedures for cassava starch extraction and further processing to produce modified starch

New procedures for starch extraction from fresh cassava roots with high starch contents were developed, resulting in higher rates of starch extraction. This increased the starch conversion rate by 20-30%, and decreased energy consumption by more than 20%.

New machinery for cassava starch production was developed, resulting in savings of capital inputs by 50%, and energy consumption by 25%.

A number of modified cassava starch products were developed, some of which are considered as high-tech products, and are now widely used in the paper making, textile and petroleum industries.

CONCLUSIONS

Since 1982, the Chinese cassava research team has been working in close cooperation with CIAT, an international organization with the world mandate for cassava research, by sharing scientific and technological developments, thus enabling China to join an international network on cassava research.

In addition, China has developed a series of new processing techniques and new products, which have greatly improved the level of cassava technologies in China, as well as the economic benefits from cassava production and processing.

During the last two decades, the new cassava varieties have been widely adopted by farmers in Guangxi, Guangdong, Hainan and Yunnan provinces. The production of fresh cassava roots in China in 2008 was more than 9.0 million tonnes, which are mainly used for production of starch and alcohol. There are now more than 200 cassava processing factories in China, producing about 500,000 tonnes of starch (including modified starch) and 250,000 tonnes of alcohol.

In 2007 the total income from cassava production was about 3 billion RMB and that of cassava processing was about 7 billion RMB in China. As such, the total income of the cassava sector was more than 10 billion RMB in China.

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THIRTY TWO YEARS OF SOIL FERTILITY RESEARCH FOR CASSAVA IN THAILAND

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ABSTRACT

Research on soil fertility and fertilizers has been conducted for many years with the aim of developing new technologies for Thai cassava farmers. Earlier research on soil fertility showed that fertilization significantly increased yields and incomes, but the results were not entirely consistent. There are many soil types, varieties, climatic variations and farmers' management factors involved. There is a need for improving cassava yields at reduced cost and a better understanding of factors that contribute to overall fertilizer use efficiency. A large number of fertilizer trials in farmers' fields showed a high response to N and moderate responses to K and P. The yield responses to N were well correlated with soil organic matter content for both coarse-textured Quartzipsamment and Paleustult soil groups, while the response to K correlated with exchangeable K for Quartzipsamments only.

In 1975 and 1976, long-term fertility experiments using cassava were initiated in three locations in Thailand, i.e. at Rayong Field Crops Research Center in Huay Pong, Rayong; at Nakhon Ratchasima Field Crops Research Center in Si Khiw, Nakhon Ratchasima; and at Khon Kaen Field Crops Research Center in Khon Kaen. A Randomized Complete Block design was used with four replications. The treatments consisted of the application of different combinations of N, P and K, as well as municipal compost, either with or without incorporation of cassava stalks (stems and leaves) after each harvest. The results of 33 years of continuous cassava cropping in the same plots with the same treatments at Rayong and Nakhon Ratchasima, and 32 years at Khon Kaen, showed a clear response of cassava to annual fertilizer applications in all three locations. Without fertilizer application, cassava growth and yields sharply decreased, and the soil's fertility status also declined, especially in Khon Kaen. The lack of K application reduced the growth and yield of cassava more than the omission of either P or N, while the annual incorporation of cassava stalks resulted in a marked increase in growth and yield. The complete chemical fertilizer application of 100 kg N, 50 P_2O_5 and 100 K_2O/ha, combined with 12.5 t/ha of municipal compost or with 18.75 t/ha of incorporated cassava stalks, resulted in better growth and higher cassava root yields than the application of only chemical fertilizers. These treatments were able to maintain root yields of 20-40 t/ha in Khon Kaen, Rayong and Nakorn Ratchasima, and to maintain or improve the fertility status of soils. Based on these results, it can be concluded that long-term productivity of cassava can be successfully sustained with the application of adequate levels of N, P and K fertilizers, in combination with organic materials such as compost, or with the re-incorporation of crop residues into the soil.

INTRODUCTION

In Thailand, cassava has been cultivated continuously for more than 50 years. Originally cultivation started in the Southeast, but after 1970 it spread to the Northeastern, Western and Central part of the country (Boonjit, 1986).

The country is presently among the world's major producers of cassava roots, and is the biggest exporter of cassava products. About 70% of total cassava production is exported, mainly as chips, pellets and starch. The average fresh cassava root yield of the whole Kingdom in 2007 was 22.9 t/ha. The major cassava planted area is in the Northeast

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region, which accounts for 55% or approximately 0.66 million hectares, followed by 30% in the Central Plain region, and 15% in the North (OAE, 2008).

Most cassava in Thailand is grown on coarse-textured soils, with sandy clay loam and sandy loam textures and low fertility. These soils have rather unfavorable physical and chemical properties, having a very light texture, low levels of organic matter (OM), low content of available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and some micronutrients, and low-activity clay minerals. Moreover, due to their rather poor soil aggregate stability and their frequent occurrence in areas of undulating and rolling topography, soil loss due to erosion by heavy rain can be very severe, especially in the early growth stages of cassava when the canopy does not completely cover the soil (Tongglum *et al.*, 1990). Most cassava farmers grow cassava continuously on the same fields without soil erosion control measures and without adequate fertilizer applications that are specific to each location. This has caused the soil's productivity to steadily decline over the past several decades, and has led to an imbalance of plant nutrients in the soil, resulting in a decrease in cassava growth and yield, and environmental damage in the future. It has long been recognized that certain nutrient elements are essential for plant growth and normal development. Lack or excess of one or another of the essential elements in available form in the soil may lead to deficiency or toxicity symptoms, reduced growth, low yields and inferior quality of products.

To improve or maintain the soil's fertility under cassava cultivation is a most important objective to sustainable crop productivity, and requires the integration of various disciplines. This paper intends to provide an overview of the current status of soil fertility research in Thailand.

Overview of Earlier Research (1954-1980)

Many fertilizer experiments to determine the nutritional status of important soils in relation to cassava production, and the optimum amounts of fertilizer needed by the crop have been conducted in several cassava growing areas since 1954. Sittibusaya and Kuramarohita (1978) reviewed the existing literature, based on the information available from the Department of Agriculture Annual Reports during 1954-1978. This can be summarized as follows:

The results during the first period (1954-1967) indicate that application of N, P_2O_5 and K_2O at the rate of 50, 50 and 25 kg/ha could prove beneficial to the growers to obtain a good income. The effect of K application was consistently found to be not significant and only N played a dominant role in yield improvement, while P showed some beneficial effects in several locations. Results of field trials during the second period (1967-1970) on three soil series also confirmed those of the first period in that the most frequent yield responses were mainly caused by N addition, while response frequencies to P and K were much lower. The amounts of N, P_2O_5 and K_2O generally recommended for cassava were 40-96, 13-80 and 21-46 kg/ha, respectively. Fertilizer trials during the period (1972-1980) covered six soil series and produced similar results as obtained previously. The Warin soil produced the smallest yield response and the response increased in the order of Warin, Huai Pong, Korat, Yasothon, Sattahip and Pattaya soils. The magnitude of yield response was used as the criterium for measuring the fertility of soils.

Fertilizer experiments using high application rates of N, P_2O_5 and K_2O on exhausted soils were initiated in 1975 and the results showed that additions of 375 kg/ha

each of N, P_2O_5 and K_2O almost doubled the yield of Rayong 1 variety to 41 t/ha. Residual fertilizers also produced beneficial effects for more than three years, and the effect of N application for successive crops was found to be significant. The prolonged residual effects of N could be the result of nutrient cycling by leaf-drop or litter.

The application of secondary and minor elements did not increase root yields but increased the root starch contents.

Several methods of fertilizer application for cassava were also compared in one study, and it was found that various methods such as broadcasting, banding, side dressing, produced the same results. (Sittibusaya and Kuramarohita, 1978)

The nutrient removal by cassava was also investigated on many occasions. The uptake of total N and total K were similar, about 70 kg/ha for one cropping, while total P uptake was about half. Cassava is not a soil-depleting crop as it has been thought of because it removes plant nutrients from soils at a comparable rate as maize, and it removes much less K than sugarcane. The decline in yield thus could be attributed to the negligence of growers to fertilize the land and to the use of incorrect cultivation practices that caused severe soil erosion and nutrient loss.

It was found that during the past 30 years soil fertility had steadily declined as yield responses to fertilization increased from the first to the last periods of the trials. A steady decline in cassava yields in check plots in several trials conducted from 1955 to 1983 was observed; yields dropped from 30 t/ha to 15 t/ha on Sattahip soil in the Southeast, with a similar decline in Huai Pong soil in the East and in the Korat soil in the Northeast. A similar but even more drastic decline in soil fertility and cassava yield was also observed on Yasothon soils in the Northeast, as shown in **Figure 1.**

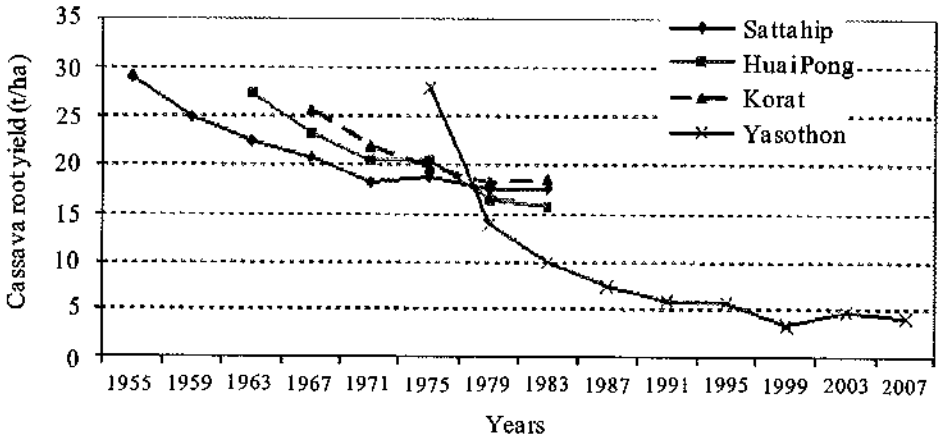

Figure.1. Yield trend of cassava grown in unfertilized plots of field experiments conducted from 1955 to 2007 on four soil series in Thailand.

Note: The trial on Yasothon soil was conducted in the same plots at Khon Kaen FCRC since 1976; the other three trials were conducted in farmers' fields, not every year in the same plots or fields..

Source: *Sittibusaya and Kuramarohita, 1978; Paisancharoen et al., 2008.*

The results of these fertilizer trials and experiments have been well documented and general fertilizer recommendations have been made. For the sake of simplicity, the fertility of cassava soils was divided into two classes: low and moderate. Optimal ranges of N, P_2O_5 and K_2O recommended for the "low" class were between 100 and 200 kg/ha each. The ranges for the "moderate" class were just half the quantities of those used in the "low" class. Side dressing or side-row banding at one month after planting is generally recommended as the most suitable method of application.

More Recent Soils Research on Cassava (1980-present)

Economic studies conducted in the early 1980s by the FAO Fertilizer Program on the yield response of cassava to fertilizers have clearly shown that the profitability of fertilizer use in Thailand was low due to the high price of fertilizers, while fresh cassava root prices were very low and uncertain. As a consequence, the quantity of fertilizers applied to many crops, including cassava, was very small. Greater use of mineral fertilizer is essential for the success of the government's policy of agricultural intensification. The current price of fertilizers in relation to those of crops does not favor this. At present much research focuses on site-specific recommendations of fertilizer use and proper soil management to improve the efficiency of fertilizers and to maintain desirable chemical, physical and biological soil conditions. The following information is now available:

1. Evidence from FAO fertilizer trials

During the period from 1982 to 1984 a large number of cassava fertilizer trials without replication were conducted on farmers' fields. The results were presented in the "FAO/Thailand Yield Increase Through the Use of Fertilizer and Related Inputs Technical Report" (FAO, 1985). In the report, emphasis was put on the recommendation of the profitable rates of fertilizers. It was shown that fertilizers can significantly increase yields and income. In all regions a high response to N and moderate responses to P and K were obtained. Although the data are insufficient to make specific area recommendations, general fertilizer recommendations could be made.

Ho and Sittibusaya (1984) reported that ranges of 50-100 kg/ha for N and K_2O but no phosphate are recommended for the Quartzipsamment soil group. Potassium recommendations can be defined further by soil testing as follows:

Exchangeable K (ppm)	**Recommended K_2O rate** (kg/ha)
< 30	100
31-50	30
> 50	0

For the Paleustult soil group, ranges of 80-100 kg N/ha, 0-30 kg P_2O_5/ha and 30-50 kg K_2O/ha are recommended. Nitrogen recommendations can be defined further by soil testing as follows:

Organic matter (%)	**Recommended N rate** (kg/ha)
< 0.51	100
0.51-0.92	50
> 0.92	0-25

In 1991 to 1994, the Soil Science Division of the Department of Agriculture (DOA) designed a study on the improvement of recommendations for chemical fertilizer use. The experiments were conducted with duplication at 25 sites in the Northeast. Sittibusaya (1996) analyzed the data and divided the soils into six groups according to soil test results; and made the following fertilizer recommendations for cassava grown on Oxic Paleustult soil:

Exchangeable K (ppm)	**Recommended K_2O rate** (kg/ha)
< 30 (low K)	100
> 50 (high K)	50
Organic matter (%)	**Recommended N rate (kg/ha)**
< 0.65 (low OM)	100
> 0.65 (high OM)	50
Available P (ppm)	**Recommended P_2O_5 rate (kg/ha)**
< 5 (low P)	50
> 5 (high P)	25

2. Green manures and mulching crops

In cassava areas with uncertain rainfall and low soil moisture reserves, mulching and the planting of green manures are perhaps the most important practices to conserve soil moisture, especially during dry periods. Leguminous crops are widely used as green manures for improving the productivity of the soil.

Paisancharoen *et al.* (1990) established a long-term experiment to study the effects of green manure incorporation on water storage and cassava yields in an Oxic Paleustult at the Khon Kaen Land Development Experiment Station in the Northeast. The five year results showed that water storage and cassava yields were higher by cowpea incorporation then the incorporation of pigeon pea or *Crotolaria*. Cowpea produced more biomass, had a higher nutrient content, especially of nitrogen, and cations such as potassium which are very important for cassava production in coarse- textured soil. In addition, this improved some physical properties of the soil, like bulk density (BD) and water hydraulic (Ks) conductivity, as shown in **Table 1**. Tongglum *et al.* (1990) also conducted a similar experiment on sandy soil at Rayong FCRC in the East for two years, and found that soil organic matter (OM) was maintained and cassava yields were higher by the incorporation of *Crotalaria* than by that of other legumes. However, the combination of cowpea green manure and chemical fertilizers increased fresh root yields on average 22% and 44% beyond that obtained with chemical fertilizer alone and the control treatment, respectively (Jantarak *et al.*, 2001).

Kokram *et al.* (1996a) conducted an experiment on Warin soil, an infertile sandy soil at Ubon Ratchathani FCRC, using verano (*Stylosanthes hamata*) as a living mulch in cassava during 1993-1995. They reported that a living ground cover of verano had a negative effect on the root yield of cassava, even though verano was cut back twice during the cassava growth cycle, due to the severe competition between the two crops.

Table 1. Effect of incorporation of three green manures on cassava fresh root yield (a), on the biomass of the green manures (b), on bulk density and water infiltration of the soil (c), and on the nutrients in those green manures (d) during five consecutive years (1985-1989) of Rayong 3 cassava cultivation on Yasothon (Oxic Paleustults, fine-loamy) soil in Khon Kaen province.

(a) Fresh root yield (t/ha) of Rayong 3, harvested at 10 months age.

Treatments	1985	1986	1987	1988	1989	Av. ±S.E.
Cowpea	10.2 [a]	13.3	16.2	19.1	14.6	14.7±1.5 [a]
Pigeon pea	5.4 [b]	12.9	14.2	13.3	14.2	12.0±1.7 [b]
Crotalaria	5.9 [b]	13.4	14.9	17.2	15.2	13.3±2.0 [b]
Control	4.4 [b]	14.0	14.1	12.4	14.0	11.8±1.9 [b]
CV(%)	23.2	29.7	23.9	11.54	32.7	10.7

(b) Amount of fresh biomass of green manure crops (t/ha) at 60 DAP.

Treatments[1/]	1985	1986	1987	1988	1989	Av. ±S.E.
Cowpea	17.9 [a]	21.2 [a]	10.8 [a]	25.8 [a]	14.6 [a]	18.1±2.6
Pigeon pea	1.7 [b]	10.9 [b]	2.7 [b]	5.2 [c]	4.8 [b]	5.1±1.6
Crotalaria	4.1 [b]	18.3 [a]	3.2 [b]	12.6 [b]	13.1 [a]	10.3±2.9
CV(%)	11.0	18.9	26.6	11.6	18.2	

(c) Amount of fresh biomass of green manure crops, at 60 DAP and the nutrients in the biomass in 1986.

Treatments	Fresh biomass (t/ha)	N	P_2O_5	K_2O	Ca	Mg
		(kg/ha)				
Cowpea	21.2	148.8	40.6	194.4	55.6	33.1
Pigeon pea	10.9	103.8	16.9	50.0	22.5	11.3
Crotalaria	18.3	114.4	21.3	56.9	41.9	14.4

(d) Effect of green manures on some physical properties of the soil after four years of intercropping with three green manure crops.

Treatments	Year	Soil bulk density (g/cc)		Water infiltration rate (cm/hr)	
		0-20 cm.	20-50 cm.	0-20 cm.	20-50 cm.
	1985 (initial)	1.66	1.84	1.5	2.3
Cowpea	1988 (4th yr)	1.49	1.54	6.4	3.2
Pigeon pea		1.50	1.62	5.5	1.6
Crotalaria		1.49	1.63	5.6	0.9
Control		1.53	1.60	4.5	1.9

Source: *Paisancharoen et al., 1990.*

3. Cropping systems

A study on the effect of cropping systems on soil productivity for cassava cultivation was conducted using either intercropping or crop rotation with leguminous crops. Crop rotation is not widely practiced in the area, primarily because of lack of crops other than cassava that consistently produce yields that give an economic return, compared with what can be obtained with cassava. Because of the importance of crop rotations on soil erosion and nutrient recycling, a long-term experiment to study soil improvement characteristics under alternate legume-cassava crop rotation systems was conducted on

three major soils in cassava growing areas from 1975 to 1984. Chaiwanakupt and Sittibusaya (1985) showed that rotating cassava with legumes is possible. Although the rotation system did not have much effect on soil properties, it increased farmer income, especially the cassava-groundnut system, as shown in **Table 2.**

Table 2. Average economic returns from fertilizer use in two cassava-legume rotations on Yasothon soil at Khon Kaen FCRC, and the effect on soil organic matter content.

Cropping system	Return[1]	Soil organic matter (%)		
	baht /ha/year	1976	1980	1983
Mono cassava		0.87		
-No fertilizer	8,044		0.71	0.62
-With fertilizer [2]	9,231		0.77	0.60
Crop rotation [3]		0.87		
-Cassava-Groundnut-Pigeon pea	10,756		0.75	0.68
-Cassava-Mungbean-Pigeon pea	5,212		0.75	0.63

[1] Return of cassava cropping systems (baht/ha/year)
[2] 50 kg/ha of each N, P_2O_5 and K_2O were applied annually
[3] Alternating cassava with groundnut or mungbean followed by pigeon pea in the same year
Source: *Chaiwanakupt and Sittibusaya, 1985.*

Paisancharoen *et al.* (1996) conducted a long-term cassava experiment for nine years (1987-1995) at the Khon Kaen Land Development Experiment Station using cowpea and sword bean (*Canavalia ensiformis*) as intercrops. Intercropping treatments were either without fertilizers or with chemical fertilizer application. During the first four years (1987-1990) the intercrops were planted at the same time as cassava; in that case, monocropping of cassava resulted in higher root yields than intercropping with cowpea or sword bean. During the following five year period (1991-1995) the intercrops were planted 2-3 weeks after cassava; in this case monocropping of cassava resulted in the lowest root yields. With fertilizer application the same relative cassava yield trends were observed, but the absolute yields were much higher than without the application of fertilizer. A similar experiment was conducted at Ubon Ratchathani FCRC by Kokram *et al.*(1996b). They reported that planting the intercropped cowpea 30 days after cassava tended to produce higher cassava root yields than planting 60 days after cassava or planting at the same time, respectively.

Wongwiwatchai *et al.* (2001) reported the results of a long-term experiment on various cropping systems of cassava, which has been conducted at Khon Kaen FCRC since 1980. There were three cropping systems, consisting of: 1) continuous cassava monocropping, 2) intercropping with groundnut (*Arachis hypogaea*) on the same planting date, and 3) a crop rotation of cassava alternated yearly with groundnut, followed by pigeon pea in the same year. The results indicate that the root yields obtained with the crop rotation tended to gradually increase over time, whereas in the other two systems cassava yields tended to decrease, especially in the mono-cropping system. But, when the planting of the intercropped groundnut was delayed to four weeks after that of cassava, this resulted in a cassava yield increase (Thippayarugs and Jabprakone, 2007), possibly due to the reduced competition from the groundnut during the early growth stages of cassava.

4. Organic materials and animal manures

Animal manures are used by farmers to improve the yield and quality of fruit and rice, but in cassava areas in Thailand they are seldom used. Incorporation of cattle and chicken manures significantly increased cassava root yields in sandy soils, especially in combination with chemical fertilizers (Chompoonukulrat *et al.,* 1996; Rammachat *et al.*,2001; and Kokram *et al.*,2002).

The effect of incorporation of residues of preceding crops (land use history) were also investigated in Satuk (Oxic Paleustults, fine-loamy) soil at the Khon Kaen Land Development Experiment Station during 2002 to 2004. A split plot design with three replications was used, consisting of two main plots of cassava and maize cropping systems. Subplots were: 1) check (without N fertilizer), 2) N-CF; i.e. chemical N fertilizer, 50 kg N/ha for cassava and 60 kg N/ha for maize, 3) N-CM; i.e. organic N, using cattle manure at the rate of 5,944 kg of dry manure/ha equivalent to 50 kg N/ha for cassava, and 4) N-RS; i.e. organic N, using rice straw at the rate of 9,519 kg of dry weight/ha equivalent to 50 kg N/ha. All treatments were applied with adequate phosphate and potash fertilizer at 50 kg P_2O_5 and K_2O/ha for cassava, respectively. The results showed that the rice straw treatment tended to produce a higher cassava root yield than other treatments, due to a 50% increase in N uptake over the use of chemical N fertilizer; in contrast, maize yields were highest with the use of chemical N fertilizer **(Table 3)**.

Table 3. Effect of the application of N from rice straw cattle manure or chemical fertilizer on the yield of dry cassava roots and maize grain at Khon Kaen Land Development Experiment Station, 2002-2003.

Crop (A)	N source[1/] (B)	Crop yield (ton dwt./ha)			Total of nitrogen uptake (kg/ha)			Response to N (%)[2/]
		1st year	2nd year	Aver.	1st year	2nd year	Aver.	
Cassava	Mean	18.7 [a]	13.2 [a]	15.9 [a]				
Maize	Mean	1.20 [b]	1.05 [b]	1.12 [b]				
Cassava	Without N	16.8 [c]	12.5 [b]	14.7 [b]	120.6	102.5	111.5	109
	50N-CM	22.5 [a]	12.8 [b]	17.6 [a]	182.5	125.7	154.1	150
	50N-RS	19.6 [b]	16.2 [a]	17.9 [a]	186.9	130.7	158.8	155
	50N-CF	16.0 [c]	11.3 [b]	13.6 [b]	117.5	87.7	102.6	100
Maize	Without N	0.94 [d]	0.49 [c]	0.72 [c]	30.6	13.2	21.9	51
	62.5N-CM	1.25 [d]	0.89 [c]	1.07 [c]	40.0 [ab]	27.6	33.8	79
	62.5N-RS	1.00 [d]	1.34 [c]	1.17 [c]	26.9 [b]	35.4	31.2	73
	62.5N-CF	1.60 [d]	1.46 [c]	1.53 [c]	48.8 [a]	37.2	43.0	100
	CV_a (%)	27.9	28.9	28.7	22.1	27.7	-	-
	CV_b (%)	24.5	15.7	22.2	12.2	16.6	-	-

Average of three replications. Mean separation by DMRT at 5% level.

[1/] N_{50}-CM and N_{50}-RS mean organic nitrogen fertilizer derived from cattle manure and rice straw at the same level of total N as chemical fertilizer (N_{50}-CF) at 50 and 62.5 kg N/ha/year for cassava and maize, respectively.

[2/]Response denotes N uptake in organic N treatment as % of the control (N_{50}-CF)

Source: *Paisancharoen et al., 2006.*

This may indicate that cassava can absorb directly organic N from protein-like compounds, similar to spinach, chingensai and sugarbeet (Okamoto *et al.*, 2000; Yamagata *et al.*, 1996).

5. Long-term fertility experiments

Experiments on the long-term fertilizer use of continuously grown cassava have been conducted on three soil series from 1975 to the present. One of the aims of this study was to monitor soil fertility changes under different combinations of N, P and K in chemical fertilizers, as well as the incorporation of municipal compost or cassava stalks in different cassava planting areas of Thailand. Sittibusaya *et al.* (1988), Tongglum *et al.* (1990) and Nakaviroj *et al.* (2008) reported that the application of NPK plus incorporation of cassava stalks (stems and leaves) or municipal compost maintained the root yields at a very high level for more than 30 years of continuous cassava cropping, as shown in **Table 4**.

Table 4. Long-term effects of various combinations of N, P and K and incorporation of compost and crop residues on the yield of cassava grown on Yasothon soil at Khon Kaen FCRC from 1976 to 2007.

Treatments[1)]	Root yield (t/ha)						
	1976	1985	1995	2005	2007	Total[2)]	Index
Control	28.2	6.6	7.0	2.5	5.6	217.4	100
N	26.6	7.9	7.1	2.7	5.5	248.1	114
NP	30.8	7.2	8.4	2.9	5.5	237.1	109
NK	30.8	17.1	23.9	24.5	28.2	693.2	319
NPK	29.6	19.1	25.6	32.0	32.0	795.2	366
NPK + municipal compost (CP)	29.0	18.1	40.5	42.1	48.6	1,003.2	461
NPK + stalk incorporation (CR)	25.6	20.2	26.3	34.3	43.2	980.7	451
Stalk incorporation (CR) only	27.3	13.7	10.9	18.4	20.9	452.9	208
Average	**28.5**	**13.7**	**18.7**	**19.9**	**23.7**	**578.5**	

[1)] NPK fertilizers were applied at 50 kg/ha each of N, P_2O_5 and/or K_2O, and *in situ* incorporation of stalks or compost from the beginning in 1976 to 2000. After that and until the present, the rate was 100-50-100 kg/ha of N-P_2O_5-K_2O and 18.75 t/ha of fresh weight of stalk incorporated. Municipal compost was always applied at 12.5 t/ha of fresh weight

[2)] Total cassava root yield over 32 years (t/ha)

Source: *Sittibusaya et al., 1988; Nakaviroj et al., 2008.*

The application of NPK, NPK plus 12.5 tonnes of compost/ha/year, or NPK plus stalk incorporation produced the highest yields after 30 years. But the application of NPK plus municipal compost tended to produce the highest yield, while the incorporation of cassava stalks alone increased yields about 108% over the control. However, the incorporation of only cassava stalks without NPK fertilizer treatment also drastically reduced root yields year after year, and yields were nearly at the same level as the control in the 24th year. But NPK plus cassava stalk incorporation tended to gradually increase root yields over those of the NPK alone treatment after many years. The change in root yield response to each treatment over the 30 crop year sequence on Yasothon soil series are shown in **Figure 2**. It shows that the decline in yield over time can be observed from the use of N alone, while the omission of K reduced cassava yields much more than the

omission of P; the application of NPK plus incorporation of stalks or compost increased cassava yields the most.

Figures 3 and **4** show similar data for the same experiment conducted at Banmai Samrong in Nakhon Ratchasima and at Rayong Field Crop Research Centers.

Soil test data obtained from the same experiment conducted in Khon Kaen on Yasothon (Fine-loamy, siliceous, isohyperthermic *Oxic Paleustults*), Si Khiw (Fine-loamy, mixed, isohyperthermic *Typic Rhodustalfs*), and Huaypong (Fine, kaolinitic, isohyperthermic *Typic Kandiudults*) soil showed that continuous monocropping of cassava without fertilizer application for 30 years caused the depletion of several major plant nutrients in the soil. (**Table 5**).

The average pH and the contents of organic matter, available P and exchangeable K decreased by 12, 51, 80 and 21 percent of the initial conditions respectively, in the 0-20 soil depth of the Yasothon soil. Similarly, organic matter, available P and exchangeable K were degraded in both the Si Khiw and Huai Pong soils. This indicates that the long-term productivity of the soil resource depends on the maintenance of desirable chemical, physical and biological conditions. The biological diversity was also studied by comparing the types and population of soil micro-organism after 25 years of continuous cassava on Yasothon soil. The combination of NPK and stalks incorporated had the highest total microbial biomass, such as bacteria, actinomyces and fungi, followed by NPK, NPK plus compost, and the control treatment, as shown in **Table 6**. The best soil health was found in those treatments of complete NPK fertilizer, especially the combination of chemical fertilizer and stalk incorporation. Results of soil analyses indicate that the annual application of municipal compost resulted in high levels of B, Cu, Fe, Mn and Zn (Howeler, 2001). This may have affected the microbial population.

The results of 33 years of continuous cassava cropping in the same plots with the same treatments at Rayong and Banmai Samrong (Nakhon Ratchasima), and 32 years at Khon Kaen, showed a clear response of cassava to annual fertilizer applications in all three locations. Without fertilizer application, cassava growth and yields sharply decreased, and the soil's fertility status also declined, especially in Khon Kaen. The lack of K application reduced the growth and yield of cassava more than the omission of either P or N, while the annual incorporation of cassava stalks resulted in a marked increase in growth and yield. The complete chemical fertilizer application of 100 kg N, 50 P_2O_5 and 100 K_2O/ha, combined with 12.5 t/ha of municipal compost or with 18.75 t/ha of incorporated cassava stalks, resulted in better growth and higher cassava root yields than the application of only chemical fertilizers. These treatments were able to maintain root yields of 20-40 t/ha in Khon Kaen, Rayong and Banmai Samrong (in Nakorn Ratchasima), and to maintain or improve the fertility status of the soils. Based on these results, it can be concluded that the long-term productivity of cassava can be successfully sustained with the application of adequate levels of N, P and K fertilizers, in combination with organic materials such as compost, or with the re-incorporation of cassava crop residues into the soil.

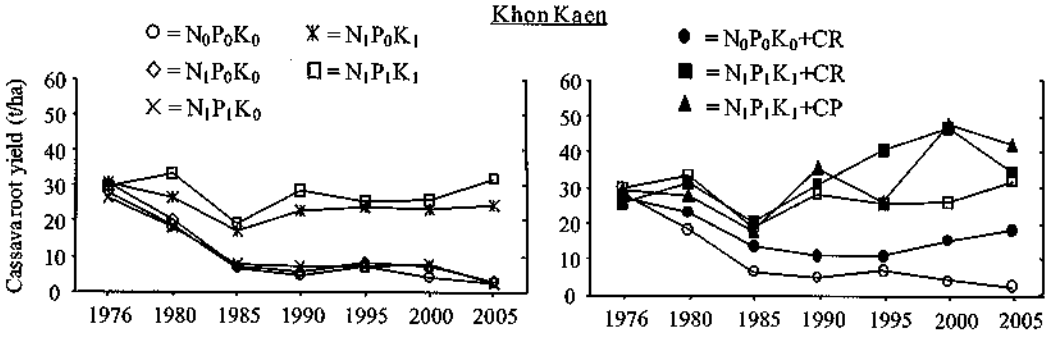

Figure 2.Effect of annual application of NPK fertilizers and compost (CP), and crop residue (CR) management on cassava root yields during 30 consecutive crops grown at Khon Kaen FCR.

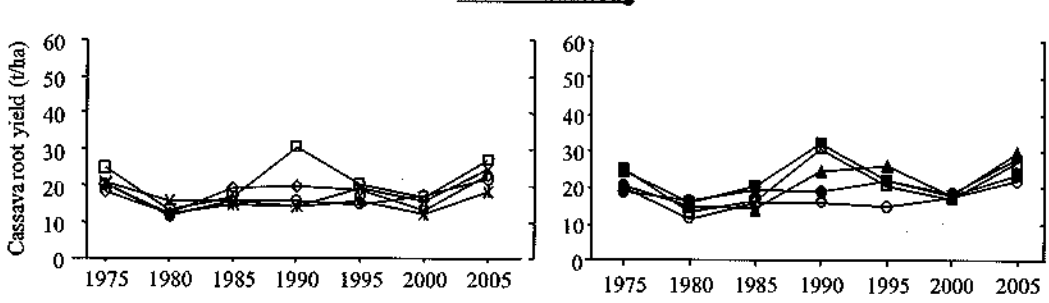

Figure 3.Effect of annual application of NPK fertilizers and compost (CP), and crop residue (CR) management on cassava root yields during 30 consecutive crops grown at Banmai Samrong FCRS in Nakhon Ratchasima province.

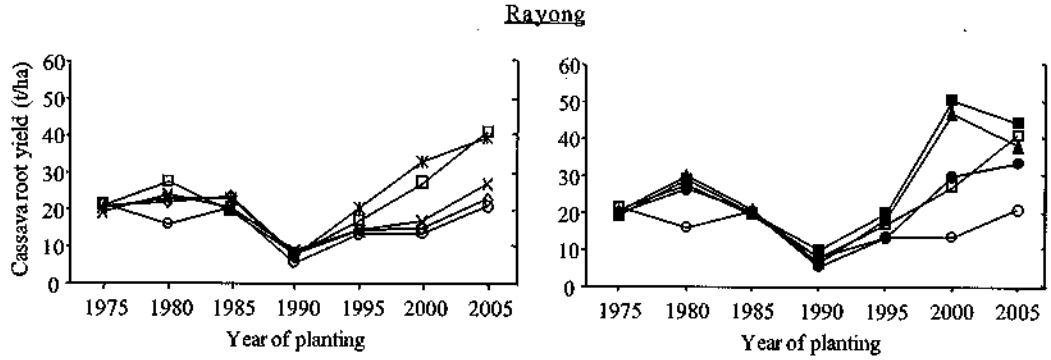

Figure 4.Effect of annual application of NPK fertilizers and compost (CP), and crop residue (CR) management on cassava root yields during 30 consecutive crops grown at Rayong FCRC.

Table 5. Changes in soil fertility status over 30 years of cassava monocropping without fertilization on three soils of the long-term fertilizer trial conducted on three soil series in Thailand from 1975 to 2005..

Soil test[1/]	Initial	10th year	20th year	30th years	% decrease[1)]
Yasothon soil (Khon Kaen FCRC)					
pH	5.2	4.6	4.6	4.6	12
Organic matter (%)	0.85	0.55	0.45	0.42	51
P-Bray 2 (mg/kg)	15	6	5	3	80
Exch. K (mg/kg)	19	17	17	15	21
Si Khiw soil (Banmai Samrong FCRS)					
pH	6.7	6.8	6.9	7.6	-13
Organic matter (%)	0.99	0.84	0.68	0.97	2
P-Bray 2 (mg/kg)	42	39	38	35	17
Exch. K (mg/kg)	198	109	129	78	61
Huai Pong soil (Rayong FCRC)					
pH	4.8	4.7	-	-	2
Organic matter (%)	1.90	1.14	-	-	40
P-Bray 2 (mg/kg)	28	15	-	-	39
Exch. K (mg/kg)	45	12	-	-	73

[1)] Percent change from the initial condition.
Source: *Nakaviroj et al., 2008.*

Table 6. Effect of chemical fertilizer and organic materials on the types and population of micro-organism in Yasothon soil after 25 consecutive years of cassava production at Khon Kaen FCRC in 2006.

Treatment	Microbial biomass (CFU/g soil)			
	Total	Bacteria	Actinomyces	Fungi
Control	$1.50x10^6$	$1.40x10^6$	$1.00x10^5$	$1.90x10^3$
NPK	$2.50x10^7$	$2.40x10^7$	$1.00x10^6$	$3.50x10^4$
NPK + municipal compost (CP)	$4.20x10^6$	$4.00x10^6$	$2.00x10^5$	$3.70x10^4$
NPK + stalk incorporation (CR)	$3.10x10^7$	$3.00x10^7$	$1.00x10^6$	$1.20x10^4$

Source: *Ligkhananon, 2006.*

6. Secondary and trace elements

Previous research had emphasized the application of N, P and K. More research on secondary and micronutrients were conducted to investigate the response of cassava to Mg, Fe, Zn and B by Watananonta *et al.* (2004).

Several experiments on the application of Mg, B, Fe, Cu and Zn were conducted in 2002/03 in Maha Sarakham and Ubon Ratchathani FCRC, and at the Thai Tapioca Development Institute (TTDI) in Nakhon Ratchasima province in 2001/02 to 2003/04. Two varieties, i.e. Rayong 72 and KU 50, were used as the test varieties in all experiments. The soils in Maha Sarakham and Ubon Ratchathani are both sandy loams, while the soil at

TTDI is a clay loam. The provinces have different patterns of annual rainfall, i.e. 1200-1400 mm at Maha Sarakham and >1400 mm/at Ubon Ratchathani. The soil fertility characteristics are shown in **Table 7.**

Table 7. Soil fertility characteristics at three locations in Thailand where micronutrient experiments have been conducted with cassava.

	pH	OM (%)	Avail. P (ppm)	Exch. K (ppm)	Exch. Ca (ppm)	Exch. Mg (ppm)	Avail. B (ppm)	Avail. Cu (ppm)	Avail. Fe (ppm)	Avail. Zn (ppm)
TTDI	6.9	2.0	25	285	4,082	110	0.93	0.06	0.75	0.50
M. Sarakh	6.5	0.3	35	43	230	17	0.50	0.41	7.3	1.55
U. Ratchat	5.7	0.4	104	51		23			7.0	2.78

From these data it is clear that the soil in TTDI is high in Ca, Mg and K, but very low in most micronutrients, while the soils in the northeastern provinces of Maha Sarakham and Ubon Ratchathani are very light-textured soils with low levels of OM and exchangeable bases, but with higher levels of micronutrients.

The results, shown in **Table 8**, indicate that in Maha Sarakham there were no significant responses to the application of Mg, B, Fe or Zn in terms of root yield or starch content. In Ubon Ratchathani there were no significant responses to Mg, B and Fe, but a marked response to Zn, while at TTDI in Nakhon Ratchasima there was also only a response to the application of Zn, but only in terms of root yields. The latter was confirmed by additional experiments on methods of Zn application in 2002/03 and 2003/04, which clearly showed a positive response to the application of Zn, either as a stake treatment, foliar application or applied to the soil **(Table 9)**. Treatments producing the highest net income included the foliar application with 4% zinc sulfate, the stake dip with 2% zinc sulfate, or the soil application of 10 kg Zn/ha.

In all experiments Rayong 72 tended to have higher fresh root yields but lower starch contents than KU 50, while Rayong 72 was also more susceptible to Zn deficiency than KU 50. In the case of calcareous soil, some cassava varieties show severe Fe deficiency symptoms, like Rayong 9 and Rayong 7, but CMR 35-22-196 and Rayong 5 seem to be more tolerant of low levels of Fe (Limsila *et al.,* 2008).

At present, the application of Mg, Zn, Fe and B fertilizers is not economically recommended to farmers for cassava production because the increase in root yields and starch contents was small in relation to the high cost of those fertilizers. In calcareous soils the application of Zn and/or Fe may be economically justified.

Table 8. Effect of the application of Mg, B, Zn, Fe and Cu on the average cassava yields and root starch contents of two varieties, Rayong 72 and KU 50, planted at TTDI in Nakhon Ratchasima, in Maha Sarakham FCRS and in Ubon Ratchathani FCRC in Thailand.

	Cassava root yield (t/ha)				Root starch content (%)			
Treatments	TTDI 2001/02	Maha Sara 2002/03	Ubon Ratch 2002/03	Aver	TTDI 2001/02	Maha Sara 2002/03	Ubon Ratch 2002/03	Aver
0 Mg		44.62	27.81	**36.22**		19.6	17.6	**18.6**
20 kg Mg/ha to soil		44.46	28.44	**36.45**		19.9	18.8	**19.3**
40 kg Mg/ha to soil		41.27	27.50	**34.38**		20.3	17.7	**19.0**
60 kg Mg/ha to soil		36.59	27.71	**32.15**		19.0	18.0	**18.5**
Average		**41.73**	**27.86**	**34.80**		**19.7**	**18.0**	**18.8**
0 B	26.96	37.49	30.21	**31.55**	24.9	20.1	18.8	**21.2**
1 kg B/ha to soil	23.60	39.75	34.17	**32.51**	21.3	19.2	19.0	**19.8**
2 kg B/ha to soil	28.21	33.91	26.77	**29.63**	24.6	19.0	17.3	**20.3**
0.5% Borax/ha stake dip	28.30	35.37	28.13	**30.60**	24.1	19.6	16.3	**20.0**
Average	**26.76**	**36.63**	**29.82**	**31.07**	**23.7**	**19.5**	**17.8**	**20.3**
0 Zn	25.43	40.94	24.38	**30.25**	27.0	18.9	18.1	**21.3**
5 kg Zn/ha to soil	28.21	45.05	29.58	**34.28**	27.2	19.4	17.6	**21.4**
10 kg Zn/ha to soil	27.76	43.94	34.59	**35.43**	27.1	19.4	18.1	**21.5**
2% ZnSO4 stake dip	28.54	40.14	25.94	**31.54**	25.8	18.1	19.8	**21.2**
Average	**27.48**	**42.52**	**28.62**	**32.87**	**26.8**	**18.9**	**18.4**	**21.4**
0 Fe	27.90	40.75	22.71	**30.45**	24.4	20.1	18.1	**20.9**
5 kg Fe/ha to soil	26.44	44.97	30.31	**33.90**	22.8	19.8	16.9	**19.8**
10 kg Fe/ha to soil	27.50	44.10	23.75	**31.78**	24.6	19.4	18.4	**20.8**
5% FeSO4 stake dip	26.04	37.87	24.06	**29.32**	24.9	19.1	18.4	**20.8**
Average	**26.97**	**41.92**	**25.21**	**31.36**	**24.2**	**19.6**	**17.9**	**20.6**
0 Cu	26.92				24.7			
2 kg Cu/ha to soil	26.94				23.6			
4 kg Cu/ha to soil	27.33				25.6			
0.5% CuSO4 stake dip	20.28				24.2			
Average	**25.36**				**24.5**			

Table 9. Effect of rates and methods of application of Zn on the cassava root yield and starch content of two varieties planted at TTDI in Huay Bong, Nakhon Ratchasima province of Thailand in 2002/03 and 2003/04.

	Root yield (t/ha)					Starch content (%)				
	2002/03		2003/04			2002/03		2003/04		
Treatments	Rayong 72	KU 50	Rayong 72	KU 50	Aver.	Rayong 72	KU 50	Rayong 72	KU 50	Aver.
Check, no Zn	13.60	16.90	16.66	14.94	**15.53**	22.0	23.2	20.0	23.3	**22.1**
Stake dip, 2% $ZnSO_4$	18.60	17.10	22.71	15.09	**18.38**	21.6	22.6	19.6	22.6	**21.6**
Stake dip, 4% $ZnSO_4$	13.30	17.20	19.02	14.04	**15.89**	21.1	21.4	19.8	23.3	**21.4**
Stake dip, 6% $ZnSO_4$	15.90	14.70	16.34	13.15	**15.02**	22.6	22.1	19.9	23.5	**22.0**
Stake dip, 8% $ZnSO_4$	15.80	14.00	19.15	13.74	**15.67**	21.5	21.4	19.8	22.9	**21.4**
Soil applic., 5 kg Zn/ha	15.40	16.60	19.68	17.67	**17.34**	20.3	22.8	19.6	23.7	**21.6**
Soil applic., 10 kg Zn/ha	16.40	19.60	22.22	16.81	**18.76**	22.0	22.4	20.3	24.3	**22.3**
Soil applic., 20 kg Zn/ha	16.60	18.90	21.79	16.03	**18.33**	21.6	23.0	20.0	24.1	**22.2**
Soil applic., 30 kg Zn/ha	19.30	20.20	21.56	16.11	**19.29**	22.0	21.9	19.2	22.4	**21.4**
Foliar applic., 1% $ZnSO_4$	13.50	14.60	14.40	13.66	**14.04**	19.6	21.1	17.9	22.5	**20.3**
Foliar applic., 2% $ZnSO_4$	17.00	14.60	18.81	12.23	**15.66**	21.9	22.5	19.4	23.3	**21.8**
Foliar applic., 3% $ZnSO_4$	18.30	17.10	18.20	12.73	**16.58**	21.4	21.9	18.7	21.1	**20.8**
Foliar applic., 4% $ZnSO_4$	22.80	19.40	19.98	17.30	**19.87**	21.0	21.7	19.7	23.5	**21.5**
Stake 2%+5 kg Zn+1% foliar	21.90	17.60	23.27	18.04	**20.20**	22.8	23.1	19.5	23.6	**22.3**
Stake 2%+5 kg Zn+2% foliar	19.00	16.30	21.75	13.77	**17.71**	22.3	21.5	20.6	23.3	**21.9**
Stake 2%+5 kg Zn+4% foliar	18.80	19.60	19.76	18.88	**19.26**	23.9	24.7	20.8	23.7	**23.3**
Average with Zn	**17.51**	**17.17**	**19.91**	**15.28**	**17.47**	**21.7**	**22.3**	**19.7**	**23.2**	**21.7**

FUTURE RESEARCH OUTLOOK

For future research needs, it seems justified to focus more on integrated soil fertility management rather than on individual factors. The reason for this is the fact that the investigations on the single effects of fertilizers on cassava growth and yield have already been done thoroughly during the past thirty years. In addition:

1. Improve the efficiency of fertilizer use. One possible direction is improving fertilizer use and plant nutrient uptake efficiency by genetic improvement of tolerance to abiotic stresses or enhanced N-fixation.
2. Study the water use efficiency (WUE) and water management for improved yields of cassava.
3. Study of technology packages of cassava variety and fertilizer recommendations based on site-specific conditions. Studies on the impacts of some integrated factors are needed in this regard.
4. Study on the validation of a crop model (DSSAT) and the analysis of the yield gap of cassava for good decision making and support systems for agro-technology transfer.

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SOIL FERTILITY MAINTENANCE AND EROSION CONTROL RESEARCH IN VIETNAM

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ABSTRACT

Recently, cassava in Vietnam has become a cash crop. As the price of cassava increased the area planted with cassava also increased rapidly. Although the government wants to limit the area for cassava production to about 300,000 ha, the actual area under cassava reached about 500,000 ha in 2007. Some areas intended for use as forestry were instead used for planting cassava. Oftentimes farmers grow cassava with little input and little knowledge. This has resulted in serious soil erosion and soil degradation.

Research on soil fertility maintenance and erosion control in Vietnam, with the support of CIAT and the Nippon Foundation of Japan, have been conducted for more than 18 years. The results of these experiments can be summarized as follows:

The two long-term NPK trials show that the response of cassava to NPK fertilizers is very clear. On the sandy loam soil at Thai Nguyen University in the north the response of two cassava varieties, KM 60 and Vinh Phu, to NPK application resulted in greater plant height and longer leaf life. Similarly, on the red Latosol soil of Hung Loc Agricultural Research Center in the south the response of the two cassava varieties, KM 60 and SM 937-26, resulted in greater plant height and a higher root starch content. In both sites the application of 80 kg N, 40 P_2O_5 and 80 K_2O/ha produced the highest yields and net income.

In the cassava intercropping-for-soil-improvement trial, the results of 15 years of continuous cropping indicate that soil fertility could not be maintained when cassava was intercropped with legumes, or by the application of prunings of *Leucaena leucocephala* and *Gliricidia sepium* when no chemical fertilizers were applied. Alley cropping and incorporation of prunings of the two latter leguminous tree species in combination with chemical fertilizer application was able to maintain soil fertility and produced the highest yields and net income.

In the cassava erosion control trial, the planting of cassava with contour hedgerows of vetiver grass or *Leucaena leucocephala* were most effective in reducing soil loss by erosion, but cassava intercropped with peanut or mungbean produced the highest net income.

INTRODUCTION

In the past cassava in Vietnam was an important crop, next to rice and maize. It provided food for people and feed for animals. Recently, the role of cassava in Vietnam has changed and it has become a cash crop. As the price of cassava increased, the area planted with cassava also increased rapidly. In the whole country there are now 62 factories and more than 4000 households processing cassava into starch; moreover, some factories are being built for making fuel-ethanol. Although the government wants to limit the area for cassava production to about 300,000 ha, the actual area under cassava reached about 500,000 ha in 2007. Some areas intended for use as forestry were used instead for planting cassava. Oftentimes farmers grow cassava with little input and limited knowledge. This has resulted in low cassava yields and low income for the farmers, but with serious soil erosion and soil degradation.

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Research on soil fertility maintenance and erosion control in Vietnam, with the support of CIAT and the Nippon Foundation of Japan, have been conducted for more than 18 years. The objectives of the research are:

- to increase cassava yields.
- to maintain soil fertility and reduce soil degradation.
- to increase the benefit for cassava farmers.

CASSAVA SOIL MANAGEMENT RESEARCH

1. Long-term NPK Experiments

Since 1990, two long-term NPK experiments have been conducted, one on the red latosol soil at Hung Loc Agricultural Research Center in Hung Thinh village, Thong Nhat district, Dong Nai province of South Vietnam, and one on a grey podzolic soil at Thai Nguyen University of Agriculture and Forestry in Thai Nguyen, North Vietnam. Both experiments have 12 treatments, consisting of various combinations of four levels of N, P, K, and with two cassava varieties in subplots. The early results of this research showed that in the red latosol soil at Hung Loc Agricultural Research Center the responses to fertilizer application of two cassava varieties was not clear during the first 4-5 years and even during the sixth year. But in the grey podzolic soil at Thai Nguyen University the responses to the application of K were highly significant even in the first year. In both sites the responses of cassava to the application of N, P and K became more pronounced over the years (Nguyen Huu Hy *et al.*, 1993; 1996; 2000; 2002). The results of the trials after 17 years at Thai Nguyen University and after 18 years at Hung Loc Center indicate that the responses of the two cassava varieties to fertilizer application were very clear, specially the response of cassava to K, followed by N and P. Among the 12 treatments, the application of 80 kg N, 40 kg P_2O_5 and 80 kg K_2O/ha generally produced the highest yields (**Tables 1** and **2**; **Figures 1** and **2**).

Analyzing soil samples in both sites, the results show that in the grey podzolic soil at Thai Nguyen University the two cassava varieties responded mainly to the application of K, as the exchangeable K-level of the soil was far below the critical level even at the start of the experiment (**Figure 3**). In the red latosol soil at Hung Loc Agricultural Research Center cassava also responded mainly to K once the soil K-level had decreased below the critical level in the 7th year of the experiment (**Figure 4**).

Table 3 shows the effect of the various NPK treatments on the fertility parameters of the soil before planting the 18th consecutive crop at Hung Loc Center. Continuous cassava cropping had increased soil acidity from pH 4.7 at the start of the experiment in 1990 to 4.1-4.3 in 2007; at the same time soil OM, Ca, Mg and K had markedly decreased while the Al-saturation had markedly increased, from 53% in 1990 to 70-80% in 2007. The soils are now very deficient in Ca, Mg and K and cassava may be suffering from Al-toxicity. Interestingly, the available P contents slightly increased during 17 years of cassava cropping even in the absence of P fertilizers, and they increased markedly with the annual application of 40 kg P_2O_5/ha. Application of 80 kg P_2O_5/ha not only further increased the P-level of the soil, but also the level of exchangeable Ca, which in turn decreased the Al-saturation to non-toxic levels. Thus, the response to increasing levels of P, may actually be a response to increasing levels of Ca and decreasing levels of Al-saturation.

Table 1. Effect of annual applications of various levels of N, P and K fertilizers on the root yield as well as the gross and net income obtained when two cassava varieties were grown at Thai Nguyen University of Agric. and Forestry in Thai Nguyen, Vietnam in 2006 (17th year).

Treatments	Cassava root yield (t/ha)			Gross income[1]	Fertilizer costs[2]	Production costs[2]	Net income
	Vinh Phu	KM 60	Av.	('000 dong/ha)			
1. $N_0P_0K_0$	3.73	5.17	**4.45**	2,358	0	3,380	-1,022
2. $N_0P_2K_2$	12.55	16.86	**14.70**	7,791	776	4,356	3,435
3. $N_1P_2K_2$	16.35	23.34	**19.84**	10,515	1,167	4,747	5,768
4. $N_2P_2K_2$	19.80	23.77	**21.78**	11,543	1,558	5,138	6,405
5. $N_3P_2K_2$	17.10	21.12	**19.11**	10,128	2,340	5,920	4,208
6. $N_2P_0K_2$	11.74	19.21	**15.48**	8,204	1,276	4,856	3,348
7. $N_2P_1K_2$	16.87	20.97	**18.92**	10,028	1,417	4,997	5,031
8. $N_2P_3K_2$	19.26	23.40	**21.33**	11,305	1,840	5,420	5,885
9. $N_2P_2K_0$	3.65	3.15	**3.40**	1,802	1,065	4,645	-2,843
10. $N_2P_2K_1$	19.23	18.05	**18.64**	9,879	1,311	4,891	4,988
11. $N_2P_2K_3$	20.06	22.16	**21.11**	11,188	2,051	5,631	5,557
12. $N_3P_3K_3$	22.40	23.28	**22.84**	12,105	3,116	6,696	5,409

[1] Prices: cassava dong 530/kg fresh roots (harvest by middleman)

[2] Costs:

urea (45% N)	4,400/kg
SSP (17% P_2O_5)	1,200/kg
KCl (60% K_2O)	3,700/kg
land preparation	500,000/ha
planting (12 mdays/ha)	480,000/ha
weeding (60 mdays/ha)	2,400,000/ha
fertilizer application (5 mdays/ha)	200,000/ha
labor	40,000/manday

2. Cassava Intercropping for Soil Improvement

An intercropping experiment for soil improvement has been conducted at Hung Loc Agricultural Research Center for 16 consecutive years by using various leguminous species intercropped with cassava to study their long-term effect on cassava yields and net income, as well as on soil fertility. The experiment was designed with eight treatments. In five treatments cassava was intercropped with various grain legumes or green manures and in two treatments each four rows of cassava were alternated by a hedgerow of leguminous tree species; the top growth of these was cut off and mulched on the soil at least once a year before replanting of cassava. Starting in the 11th crop cycle, plots were split into two subplots, without and with the application of 80-40-80 of N-P_2O_5-K_2O/ha. The objective of the research was to determine the effect of intercropping on soil fertility and cassava root yield, while also controlling weeds and reducing soil degradation.

The results of the 16th cycle shown in **Table 4**, indicate that the cassava root yields in some of the intercropping and alley cropping treatments were higher than those of cassava grown in monoculture; among the eight treatments the two treatments of cassava planted as an alley crop with hedgerows of *Leucaena leucocephala* and *Gliricidia sepium* resulted in the highest cassava root yields and economic benefits, both with fertilizer and without fertilizers applied. Fertilizer application greatly increased the income in all

intercropping treatments. Planting cassava in monoculture or intercropped with cowpea as a green manure generally produced the lowest yields and net income, especially when no fertilizers were applied.

Table 2. Effect of annual applications of various levels of N, P and K fertilizers on the root yield and starch content as well as the gross and net income obtained when two cassava varieties were grown at Hung Loc Agric. Research Center in Dongnai, Vietnam in 2007. (18th year)

	Root yield (t/ha)		Starch content (%)		Av. root yield	Av. starch content	Gross	Fertilizer	Production	Net
Treatments[1]	KM 60	SM 937-26	KM 60	SM 937-26	(t/ha)	(t/ha)	income[2]	costs[3]	costs[3]	income
							('000 dong/ha)			
1. $N_0P_0K_0$	6.44	9.90	22.2	24.6	**8.17**	**23.4**	9,559	0	4,800	4,759
2. $N_0P_2K_2$	15.08	16.17	24.8	26.5	**15.62**	**25.6**	18,275	1,027	6,127	12,148
3. $N_1P_2K_2$	19.61	21.24	23.9	25.6	**20.42**	**24.8**	23,891	1,505	6,605	17,286
4. $N_2P_2K_2$	24.58	31.31	23.4	25.6	**27.94**	**24.5**	32,690	1,983	7,083	25,607
5. $N_3P_2K_2$	26.13	31.10	24.8	25.7	**28.62**	**25.2**	33,485	2,940	8,040	25,445
6. $N_2P_0K_2$	12.79	21.61	23.3	23.7	**17.20**	**23.5**	20,124	1,583	6,683	13,441
7. $N_2P_1K_2$	23.82	25.78	23.4	24.6	**24.80**	**24.0**	29,016	1,783	6,883	22,133
8. $N_2P_3K_2$	28.59	32.12	24.5	25.8	**30.36**	**25.2**	35,521	2,383	7,483	28,038
9. $N_2P_2K_0$	6.67	10.98	22.4	24.0	**8.82**	**23.2**	10,319	1,356	6,456	3,863
10. $N_2P_2K_1$	21.14	23.99	23.8	25.3	**22.56**	**24.6**	26,395	1,669	6,769	19,626
11. $N_2P_2K_3$	25.03	28.21	25.2	26.7	**26.62**	**26.0**	31,145	2,609	7,709	23,436
12. $N_3P_3K_3$	31.68	34.29	24.8	25.6	**32.98**	**25.2**	38,587	3,966	9,066	29,521

[1] N_0 = 0N; P_0 = 0P; K_0 = 0K
N_1 = 40 kg N/ha; P_1 = 20 kg P_2O_5/ha; K_1 = 40 kg K_2O/ha
N_2 = 80 kg N/ha; P_2 = 40 kg P_2O_5/ha; K_2 = 80 kg K_2O/ha
N_3 = 160 kg N/ha; P_3 = 80 kg P_2O_5/ha; K_3 = 160 kg K_2O/ha

[2] Prices: cassava VND 1,170/kg

[3] Costs:
urea (46% N) 5,500/kg
SSP (17% P_2O_5) 1,700/kg
KCl (60% K_2O) 4,700/kg
land preparation 900,000/ha
planting material 1,000,000/ha
planting 700,000/ha
weeding 2,200,000/ha
fertilizer application 300,000/ha
labor 45,000/manday

3. Erosion Control in Cassava

In South Vietnam, cassava is generally grown by farmers on sloping land with poor crop management practices. Thus, the soils used for cassava production are often characterized by severe soil erosion, soil degradation and of low productive capacity.

An intercropping experiment to reduce soil erosion has been conducted on a 12% slope at Hung Loc Agricultural Research Center since 1996. Several cropping patterns were established using either intercropped grain legumes or leguminous tree or vetiver grass hedgerows planted on contour lines. The results of this experiment in the 11th consecutive year are shown in **Table 5**. Among the six treatments the planting of hedgerows of vetiver grass was the most effective in reducing erosion, followed by hedgerows of *Leucaena leucocphala* and *Gliricidium sepium*, the prunings of which were mulched between cassava rows. The highest cassava root yields, gross and net income, however, were obtained by intercropping with peanut; the latter treatment was also fairly effective in decreasing erosion.

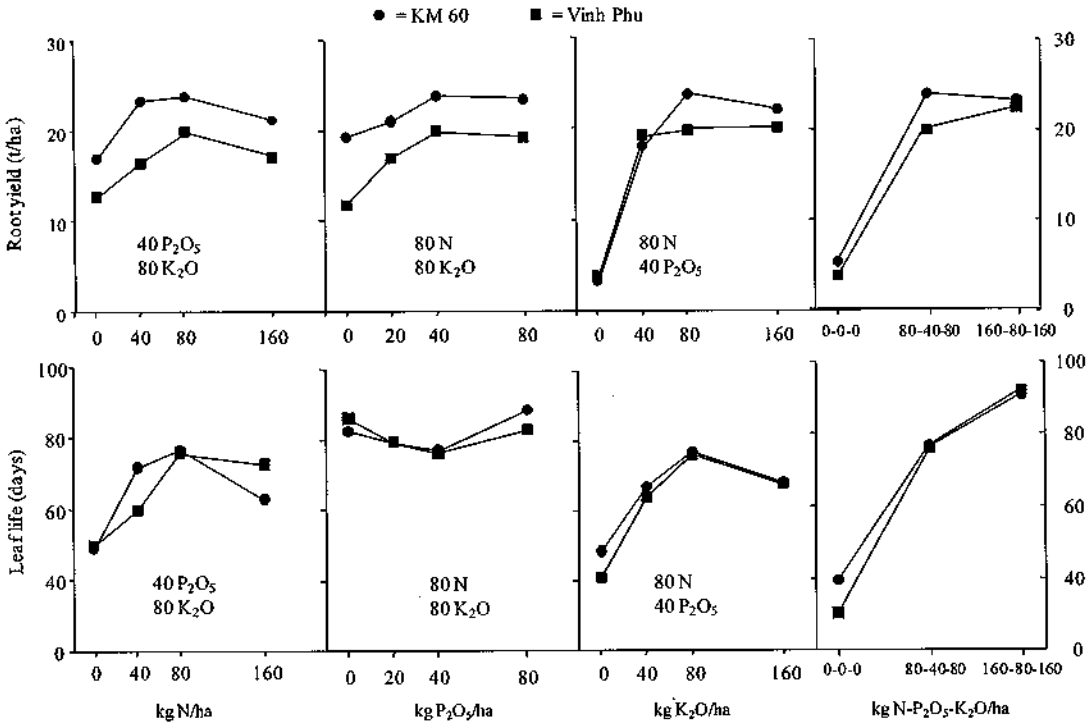

Figure 1. Effect of annual applications of various levels of N, P and K on the root yield at 10 MAP and the leaf life at 3 MAP of two cassava varieties grown at Thai Nguyen University in Thai Nguyen, north Vietnam in 2006 (17 th year).

The long-term effect of the three hedgerow treatments on relative cassava yields and dry soil loss due to erosion, shown in **Figure 5**, indicate that all three hedgerows became increasingly effective over time, with vetiver grass consistently being the most effective after the 2nd year of its establishment, reducing dry soil losses to only 20-30% of that of the check treatment of monoculture cassava without hedgerows. The vetiver grass treatment also tended to increase cassava yields by 10-15%.

Analyses of soil samples taken before planting the 11th cropping cycle in 2007 (**Table 6**), indicate that the hedgerows of vetiver grass had little effect on soil fertility, while the two leguminous hedgerow species, *Leucaena leucocephala* and *Gliricidia sepium*, were most effective in increasing soil fertility through the increase in soil OM, P, Ca, Mg and K. Intercropping with mungbean also improved soil fertility, while peanuts had only a minor effect.

FUTURE DIRECTION

Based on the results obtained from past research, cassava agronomy research in South Vietnam will focus in the future on the following research topics:

-Maintenance of soil fertility by intercropping and fertilizer application, and erosion control in cassava areas with sloping land in various parts of South Vietnam.

-Using FPR and PRD methods to develop practical agronomic practices and enhance the widespread adoption of these practices by farmers.

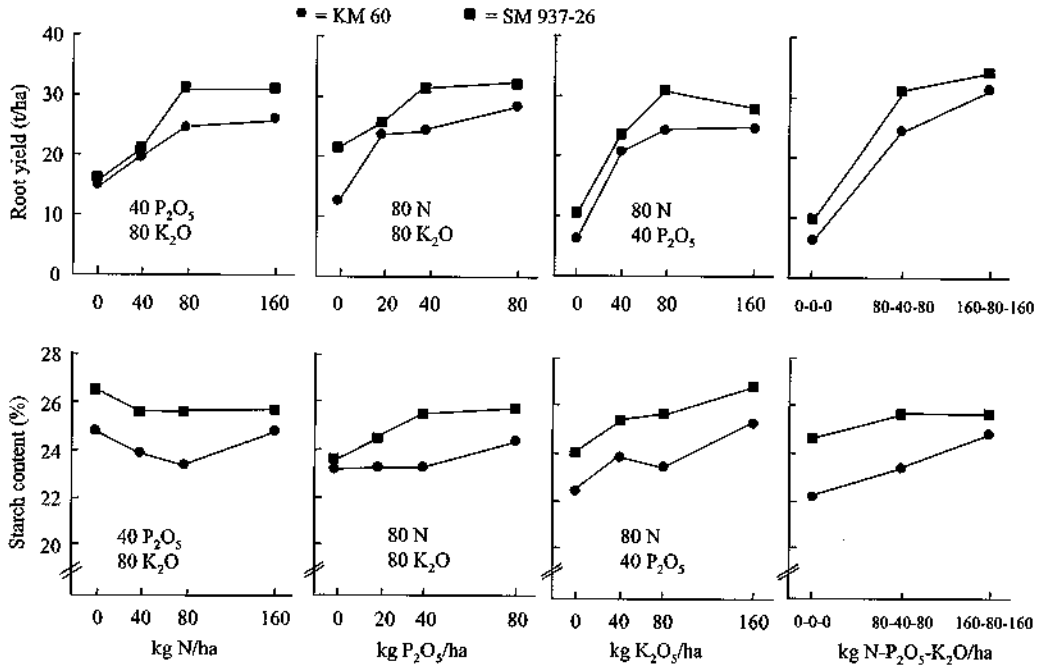

Figure 2. Effect of annual applications of various levels of N, P and K on the root yield and starch content of two cassava varieties grown at Hung Loc Agricultural Research Center, in Thong Nhat, Dong Nai, Vietnam in 2007/08 (18th year).

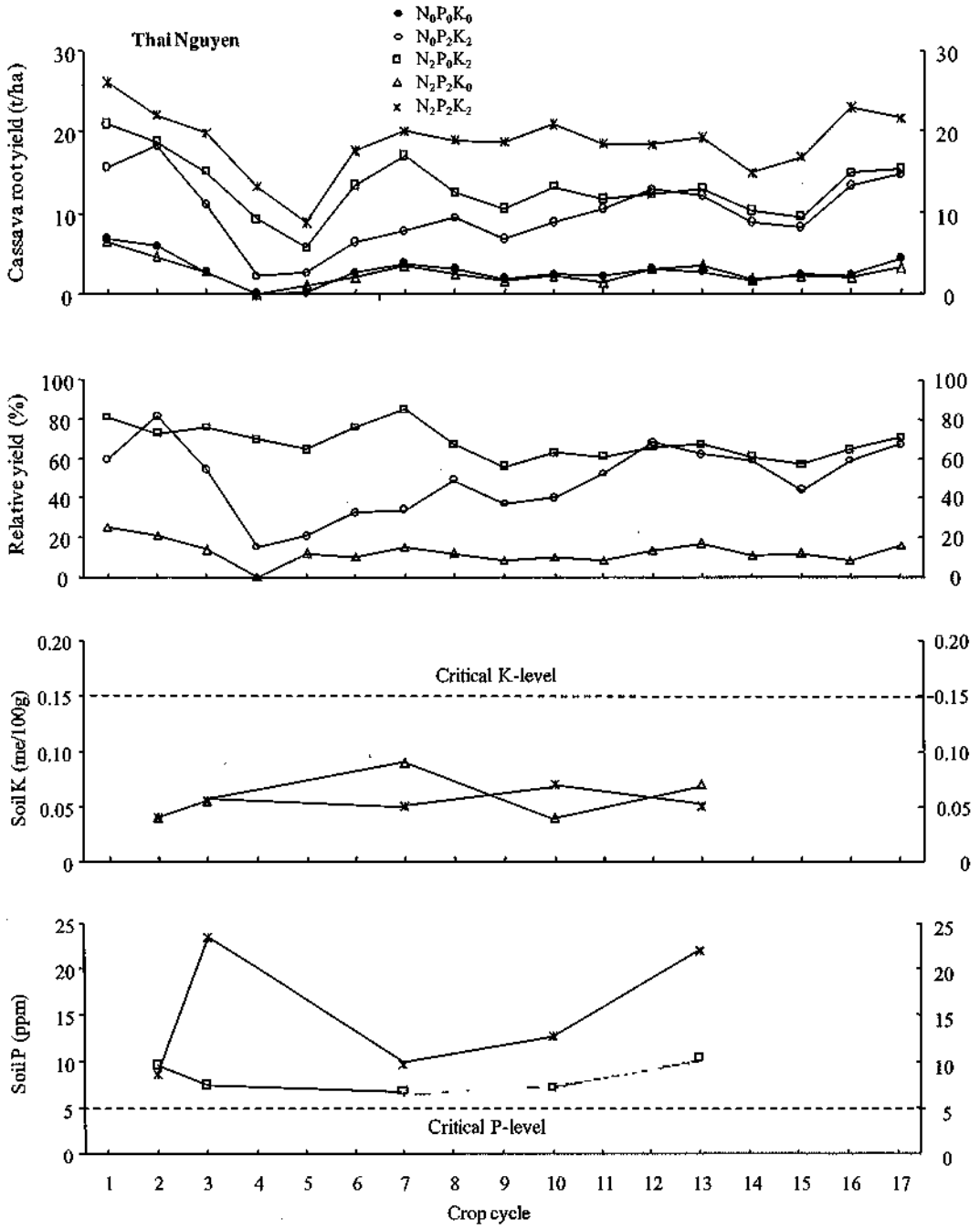

Figure 3. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during seventeen years of continuous cropping in of Thai Nguyen University, of Agriculture and Forestry, Thai Nguyen, Vietnam.

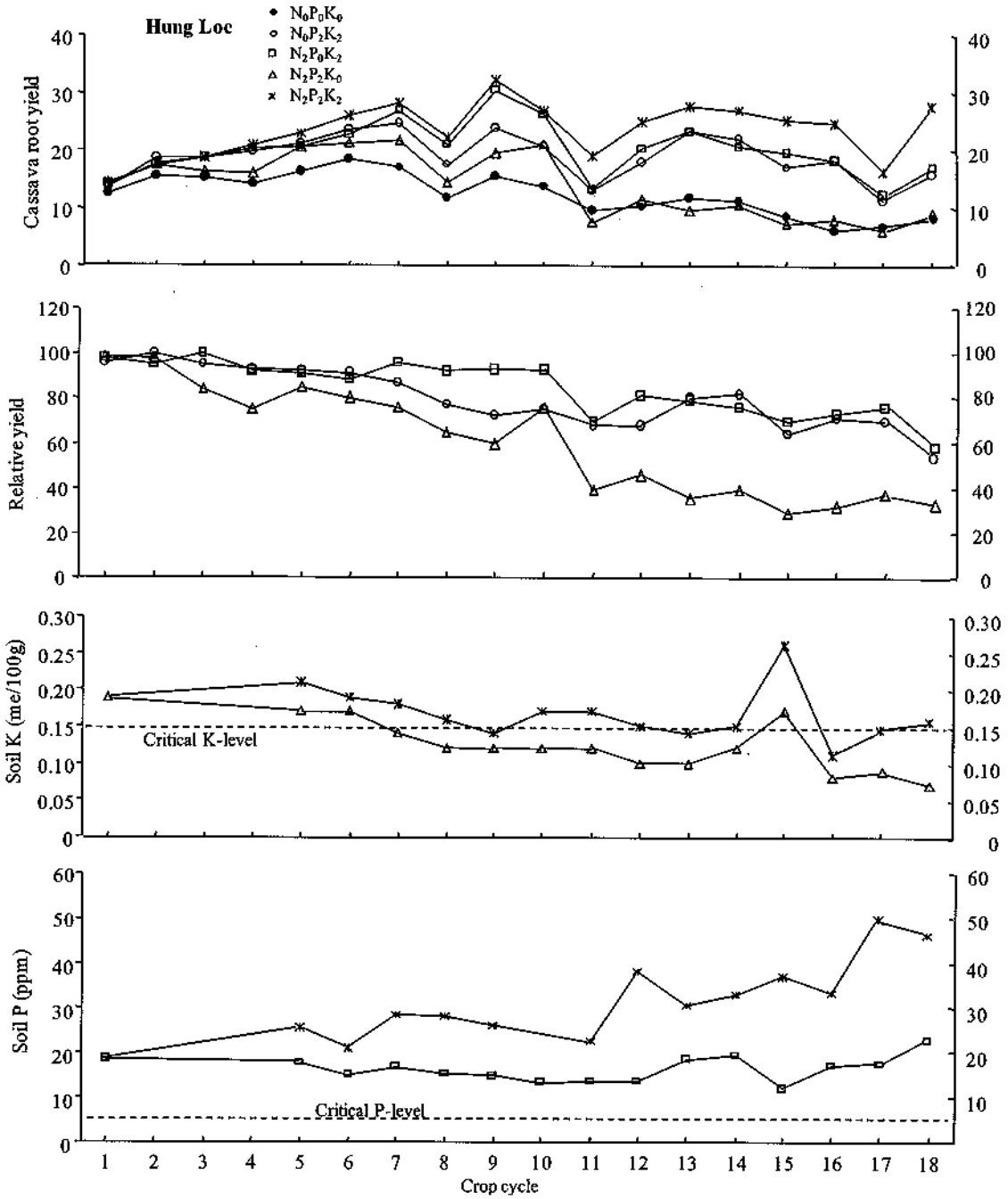

Figure 4. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during eighteen years of continuous cropping at Hung Log Agric. Research Center in Dong Nai, South Vietnam.

Table 3. Effect of annual applications of various levels of N, P and K fertilizers on soil fertility characteristics after 17 years of continuous cassava cultivation at Hung Loc Agric. Research Center in Dongnai, Vietnam in 2007. (before 18th year planting)

		(%)	(ppm)	(me/100g)				(%)	(ppm					(%)			
Treatments[1)]	pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	sand	silt	clay	texture
1. $N_0P_0K_0$	4.06	2.40	26.74	3.07	0.55	0.15	0.09	80	0.54	2.03	86.6	0.'	17.	2.9	17.!	79.2	clay
2. $N_0P_2K_2$	4.20	2.45	45.26	3.02	0.58	0.10	0.14	79									
3. $N_1P_2K_2$	4.19	2.30	44.30	3.12	0.57	0.11	0.11	80									
4. $N_2P_2K_2$	4.26	2.29	47.00	3.07	0.79	0.13	0.15	74									
5. $N_3P_2K_2$	4.11	2.34	35.85	3.12	0.61	0.09	0.15	79									
6. $N_2P_0K_2$	4.19	2.34	23.10	2.91	0.53	0.13	0.17	78									
7. $N_2P_1K_2$	4.16	2.53	27.88	2.96	0.62	0.11	0.14	77									
8. $N_2P_3K_2$	4.31	2.43	92.65	2.76	1.20	0.13	0.13	65									
9. $N_2P_2K_0$	4.14	2.33	46.52	3.28	0.51	0.10	0.07	83									
10. $N_2P_2K_1$	4.28	2.23	47.73	3.17	0.46	0.06	0.09	84									
11. $N_2P_2K_3$	4.32	2.47	53.07	2.70	0.79	0.11	0.28	70									
12. $N_3P_3K_3$	4.33	2.56	81.84	2.55	1.16	0.13	0.22	63	0.70	1.68	88.4	0.'	18.	4.4	21.'	74.0	clay

[1)] N_0 = 0N P_0 = 0P K_0 = 0K

N_1 = 40 kg N/ha P_1 = 20 kg P_2O_5/ha K_1 = 40 kg K_2O/ha

N_2 = 80 kg N/ha P_2 = 40 kg P_2O_5/ha K_2 = 80 kg K_2O/ha

N_3 = 160 kg N/ha P_3 = 80 kg P_2O_5/ha K_3 = 160 kg K_2O/ha

Table 4. Effect of planting intercrops, green manures and alley crops, with or without fertilizers, on cassava and intercrop yields, as well as the gross and net income obtained when cassava, KM 60, was grown for the 16th consecutive year at Hung Loc Agric. Research Center in Dong Nai, Vietnam in 2007/08.

Treatments[1]	Root yield (t/ha)		Starch content (%)		Gross income[2] (000 d/ha)		Product. costs[3] (000 d/ha)		Net income (000 d/ha)	
	+fert	-fert	+fert	-fert	+fert	-fert	+fert	-fert	+fert	-fert
1. C monoculture	17.44	4.81	23.28	21.28	20,405	5,628	6,008	3,800	14,397	1,828
2. C+pigeon pea GM	15.62	6.75	23.60	21.70	18,275	7,898	8,108	5,900	10,167	1,998
3. C+*Mucuna* GM	17.82	8.56	24.45	22.35	20,849	10,015	8,108	5,900	12,741	4,115
4. C+peanut IC[4]	20.41	8.62	25.35	24.08	24,824	10,085	8,108	5,900	16,716	4,185
5. C+cowpea IC	19.44	7.44	24.92	22.65	22,745	8,705	8,108	5,900	14,637	2,805
6. C+*Crotalaria* GM	18.75	8.50	24.95	21.72	21,938	9,945	8,108	5,900	13,830	4,045
7. C+*Leucaena* AC	20.68	13.39	25.52	24.40	24,196	15,666	7,708	5,500	16,488	10,166
8. C+*Gliricidia* AC	19.30	16.75	26.32	24.95	22,581	19,597	7,708	5,500	14,873	14,097
Average	**18.68**	**9.35**	**24.80**	**22.89**	**21,977**	**10,942**	**7,745**	**5,538**	**14,231**	**5,404**

[1] C = cassava, GM = green manure, IC = intercrop, AC = alley crop

[2] Prices: cassava dong 1,170/kg fresh roots
peanut 8,000/kg dry pods

[3] Costs:
land preparation	900,000/ha
cassava planting	700,000/ha
weeding	2,200,000/ha
fertilizers (80:40:80 kg/ha)	1,983,000/ha
- urea (46% N)	5,500/kg
- SSP (17% P_2O_5)	1,700/kg
- KCl (60% K_2O)	4,700/kg
intercrop planting	500,000/ha
cost of labor	45,000/manday
fertilizer application (5 mdays/ha)	225,000/ha
intercrop harvest and cutting	1,200,000/ha
seed of intercrops or GM	400,000/ha

[4] peanut yield +fertilizers 118 kg dry peanut pods/ha; -fertilizers 0 peanut yield

Table 5. Effect of cropping systems and the planting of contour hedgerows on the yield of cassava and intercrops, on dry soil loss by erosion, and on gross and net income during the 11th consecutive year of cropping on 12% slope at Hung Loc Agric. Research Center in Thong Nhat district, Dong Nai, Vietnam in 2007/08.

Treatments[1)]	Dry soil loss (t/ha)	Root yield (t/ha)	Starch content (t/ha)	Hedgerow yield (%)	Gross income[2)]	Product cost[3)] ('000d/ha)	Net income
1. C monoculture, no hedgerows	33.56	27.06	27.90	-	31,660	6,008	25,652
2. C+mungbean IC	28.84	32.60	28.03	2.19	38,142	8,108	30,034
3. C+peanut IC[4)]	22.46	34.58	29.43	3.76	41,595	8,108	33,487
4. C+vetiver hedgerows	10.03	30.45	28.73	10.10	35,626	7,008	28,618
5. C+*Leucaena* AC	16.50	30.09	30.00	10.21	35,205	7,008	28,197
6. C+*Gliricidia* AC	18.11	29.58	28.18	8.45	34,609	7,008	27,601

[1)] C = cassava; IC = intercrop; AC = alley crop

[2)] Prices: cassava dong 1,170/kg fresh roots
peanut 8,000/kg dry pods

[3)] Costs:

land preparation	900,000/ha
planting cassava	700,000/ha
planting intercrops	500,000/ha
seed intercrops	400,000/ha
weeding	2,200,000/ha
harvest or cutting of intercrops	1,200,000/ha
fertilizers (90:40:80 kg/ha)	1,983,000/ha
fertilizer application	225,000/ha

[4)] peanut yield: 142 kg dry pods/ha = dong 1,136,000

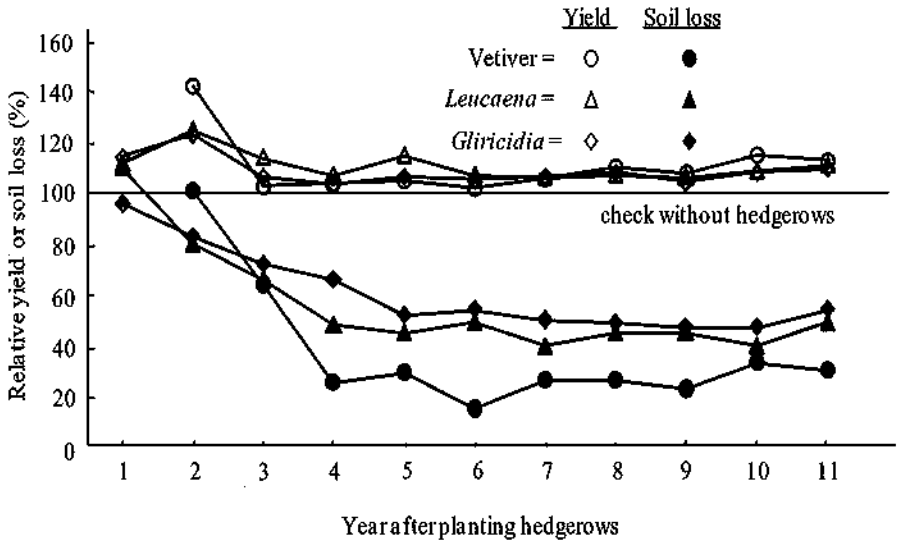

Figure 5. Trend in relative yield and relative soil loss by erosion when cassava was planted with contour hedgerows of vetiver grass, Leucaena leucocephala or Gliricidia sepium, in comparison with the check without hedgerows during ten consecutive years in Hung Loc Agric. Research Center in South Vietnam from 1997/98 to 2008/09.

Table 6. Effect of cropping systems and the planting of contour hedgerows on soil fertility characteristics after 10 years of continuous cassava cultivation on 12% slope at Hung Loc Agric. Research Center in Dongnai, Vietnam in 2007/08. (before 11th year planting)

Treatments[1)]	pH	(%) OM	(ppm) P	(me/100g) Al	Ca	Mg	K	(%) Al	(ppm) B	Zn	Mn	Cu	Fe	(%) sand	silt	clay	texture
1. C monoculture, no hedg.	4.71	3.14	26.06	1.77	1.87	0.50	0.15	41	0.72	2.77	15	0.89	20.7	7.2	22.2	70.6	clay
2. C+mungbean intercrop	4.50	3.22	35.37	2.34	1.49	0.31	0.22	54									
3. C+peanut intercrop	4.60	3.16	30.63	2.18	1.40	0.38	0.17	53									
4. C+vetiver hedgerows	4.70	3.34	27.51	1.98	1.89	0.47	0.15	44									
5. C+*Leucaena* hedgerows	4.72	3.49	36.27	1.72	2.28	0.54	0.17	37									
6. C+*Gliricidia* hedgerows	4.63	3.34	33.49	1.77	2.18	0.53	0.18	38	0.89	2.83	13	0.86	20.8	5.7	18.4	75.9	clay

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Vietnam Agricultural Statistics. 2007.

SOIL FERTILITY RESEARCH FOR CASSAVA IN INDIA

G. Byju[1], M. Nedunchezhiyan[2] and G. Ramnandam[3]

ABSTRACT

In India, cassava is grown in an area of 0.24 million ha, of which about 85% is in the three southern states of Kerala, Tamil Nadu and Andhra Pradesh. In Kerala, cassava is grown mainly for human consumption in the form of different cooked items, whereas in Tamil Nadu and Andhra Pradesh it is cultivated for the industrial production of sago, starch and other products. The present average productivity of cassava in India is 32.9 t/ha, which is the highest in the world.

Scientific management of the soil resources is one of the most important reasons for this. The present blanket recommendation of N, P_2O_5 and K_2O for cassava in India is 100:50:100 kg/ha. Research conducted in CTCRI during the past 45 years has developed different soil management technologies that address various soil related constraints to cassava production. The major constraints are deficiency of nutrients, soil physical constraints, soil loss due to erosion, long-term productivity of cassava, deficiency of iron in Vertisols, imbalance in the application of NPK, and root rot due to poor drainage in Vertisols.

In India, cassava is grown under different agroclimatic and edaphic conditions, which necessitate the development of site-specific nutrient management (SSNM). In Tamil Nadu, Andhra Pradesh and Maharashtra, where the farmers aim at very high yields, the SSNM technology has been developed and field-tested in a number of validation trials. Besides this, a farmer-friendly leaf color chart (LCC) has also been standardized to aid farmers in deciding the time of N application, which maximizes the N-use efficiency. Studies on the use of biofertilizers and biocontrol agents have indicated increased yield as well as improved soil quality in areas where these microbial cultures are used. It was also observed that the chemical fertilizer application rate can be reduced to 50 per cent if we apply these biofertilizers.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial shrub native to tropical America. It is a short-lived erect perennial shrub, with lobed leaves and lanceolate-obvate leaflets. It yields an energy of 250,000 cal/ha/day compared to maize (200,000), rice (176,000), sorghum (114,000) or wheat (110,000) (Okigbo, 1980). The high yield of calorie per hectare, adaptability to very poor soil conditions, relative resistance to diseases, and flexibility of harvesting time are the major advantages of this starchy crop compared to many other crops. It is the most important tuberous root crop and fourth most important source of food calories in the tropics and is a staple for more than 800 million people (Cock, 1985; Nasser *et al.*, 2007). An estimated 700 million people obtain more than 500 cal /day from cassava and more than 500 million people consume more than 100 cal/day in the form of cassava throughout the tropics. In Kerala state, India, cassava is consumed as a secondary staple along with the staple, rice, and many rural poor consume it as the staple in different forms of preparations. Approximately 300,000 tonnes of sago and starch are manufactured from cassava tuberous roots by nearly 1,100 factories in Tamil Nadu and 50 factories in Andhra Pradesh states in India. Sago is consumed as a breakfast food, or is used for the preparation of wafers. It is also an ingredient in *payasam* (a sweet semi-solid food preparation served during auspicious occasions like weddings, festivals etc). West Bengal,

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Maharashtra, Gujarat, Rajasthan and Madhya Pradesh are the largest consumers of sago in India. Although cassava-based products were exported by India to European countries from 1958 to 1964, these exports stopped subsequently when internal demand increased. In 1996, India exported 31,000 tonnes of cassava products earning 141.30 million Indian rupee (INR) of foreign exchange.

The crop was introduced from Brazil into India by the Portuguese during the 17th century (Edison *et al.*, 2006). The popularization of the crop in the state of Kerala was attributed to the famous King of erstwhile Travancore state (a part of Kerala state), Sri Visakham Thirunal by introducing popular varieties from Malaya and other places. During the Second World War (1939-1945), it was cassava that saved the people of this region from famine when the importation of rice from Myanmar was stopped (Edison, 2001). Since its introduction, the crop has been relished by the people of Kerala state and has attained the status of a secondary staple. Though cassava cultivation has a history in India of more than 300 years, it spread from Kerala to the adjacent states of Tamil Nadu and Andhra Pradesh only about 60 years ago. In these latter two states, it is grown on comparatively bigger farms, mostly for the industrial production of starch, sago and other products. In Tamil Nadu cassava cultivation began in 1943, while in Andhra Pradesh it started in 1965, especially in East Godavari district. Out of the total area of 260,000 ha under cassava in India, about 85% (220,000 ha) is in these three southern states. In this region, 72% is under high yielding varieties such as H-165 and H-226, 26% is under local varieties and 2% under an old improved variety, M-4 (Srinivas *et al.*, 2006). Introduction and popularization of the new high yielding varieties, irrigation and soil fertility management practices have helped in increasing the productivity of cassava from 14.79 t/ha in 1971 to 32.87 t/ha in 2007 **(Figure 1).**

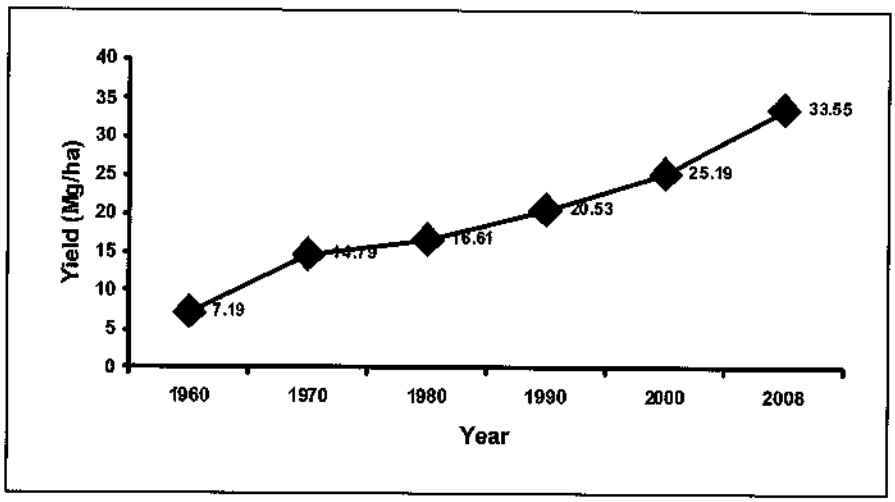

Figure 1. Trend in productivity of cassava in India over the past 47 years.

Climate and Soil

An ideal environment for cassava is an annual rainfall of more than 1000 mm, annual temperatures higher than 18^{0}C and a mean solar radiation level higher than 16

MJ/m^2 (Ekanayake *et al.*, 1998). Cassava is cultivated mostly in the tropical and subtropical latitude between 30^0 N and S of the equator and elevations up to 2300 m above sea level (Cock, 1983). The cassava plant is very sensitive to frost and cannot be grown successfully where the temperature is below 15^0C (Cock, 1984). In areas with marked seasonal temperature changes, cassava is grown only when the annual mean temperature is greater than 20^0C. The minimum, optimum and maximum temperature for sprouting are 12-17, 28-30 and 36-40^0C, respectively (Keating and Evenson, 1979). Cassava is grown in areas with as little as 750 mm rainfall per year, since the crop has an extremely efficient pattern of water use. Reduced leaf area and stomatal closure markedly reduce crop growth rates during periods of stress (Conor *et al.*, 1981). In India, cassava is grown in areas with a wide range of climatic conditions. It is grown in areas with rainfall as high as 3000 mm (Kerala) to as low as 600 mm (Tamil Nadu), and at elevations from below sea level to 2200 m above mean sea level. In Idukki district of Kerala and the Kolli hills of Tamil Nadu, which are located at altitudes of 2200 and 1200 m above sea level, respectively, cassava performs well. It has been gaining importance as an industrial crop in the western, eastern and northeastern states of India and grows well in a wide range of soils and climates (Nedunchezhiyan and Mohanty, 2005; Nedunchezhiyan *et al.*, 2008).

Cassava requires a soil which allows for the development of an adequate rooting volume for the bulking of tuberous roots and for early harvesting. Cassava is renowned as the species that will still produce a harvestable yield (5-6 t/ha) in tropical soils of low fertility where other crops will fail (Cock and Howeler, 1978). Edwards *et al.* (1977) concluded from solution culture experiments with cassava, maize, soybean and sunflower that cassava was able to tolerate low Ca, N and K in the root environment better than any of the other species tested. The optimal soil requirements for cassava cultivation are summarized in **Table 1** (Byju, 2006).

Ravi and Ravindran (2006) studied the effect of drought on the growth and flowering in cassava. They observed that high air temperature (>30^0C) and low relative humidity reduced flower and fruit production in cassava. It is also observed that soil moisture is the critical factor which influences flower and fruit production in cassava..

Soils on which cassava is grown in India

In India, cassava is cultivated in a wide range of agroclimatic and soil environments. In Kerala state, where the crop was introduced into India more than 300 years ago, it is cultivated mostly in laterite soils (Ultisols) (Byju and Thomas Varghese, 1999a; 2001a,b). In Tamil Nadu state, where it is cultivated mainly for industrial uses, cassava is grown in black soils (Vertisols) and red soils (Alfisols). In Andhra Pradesh state, where it is also cultivated mainly for industrial uses, cassava is grown in sandy loam and coastal alluvial soils (Inceptisols). **Tables 2, 3** and **4** summarize the soil physico-chemical characteristics of the major soil orders where cassava is cultivated in India (Sheeja, 1994; Byju and Varghese, 1998; 1999b; Byju, 2000; Susan John and Venugopal, 2004; Byju *et al.*, in press a,b). The critical levels of available P and exchangeable K in cassava growing soils of Kerala were estimated to be 8.23 and 45.5 µg/g (Susan John *et al.*, 2004). The impact of cassava cultivation on soil physico-chemical characteristics, on laterization process and on soil acidity parameters was studied by Byju and Varghese (2001, 2002).

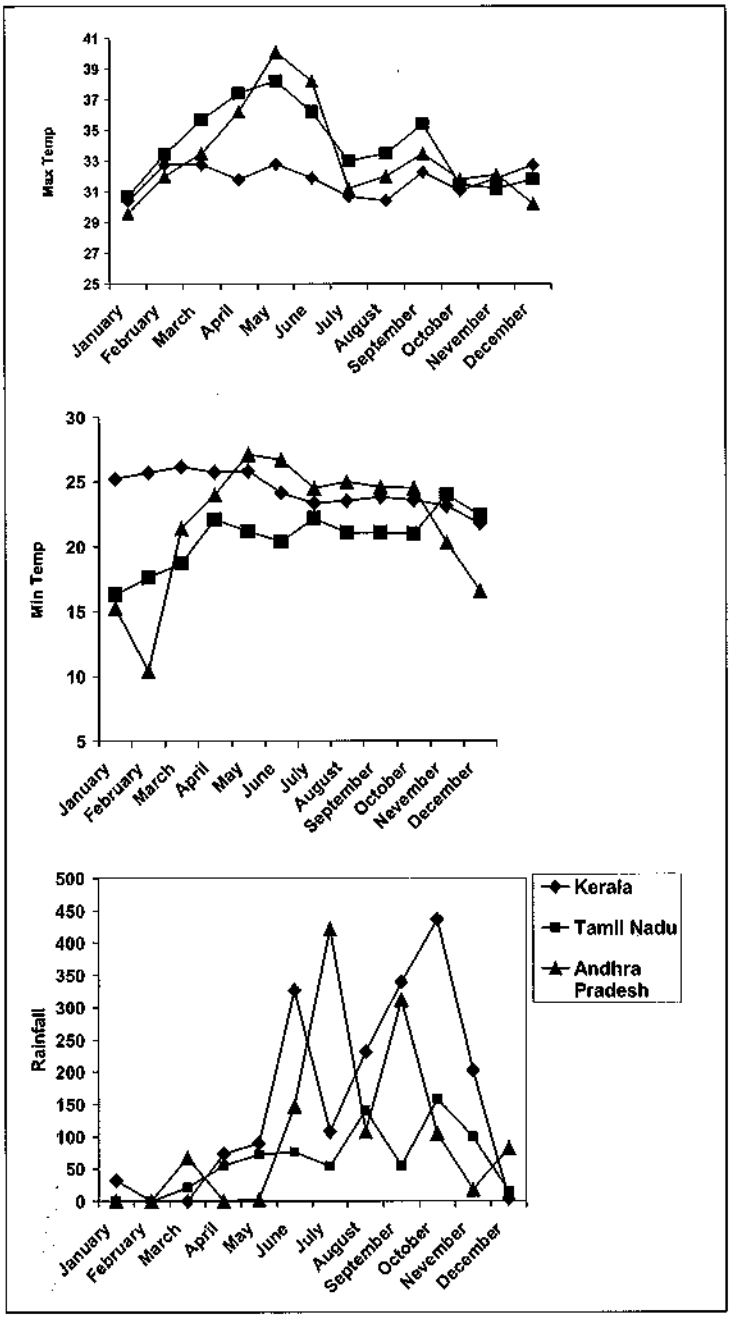

Figure 2. Average annual variation in temperature and rainfall in the three major cassava growing states in India.

Table 1. Indicative optimal soil requirements for cassava.

Parameter	Unit	Value
pH		5.5-7.0
Rooting depth	cm	90
Soil slope	%	< 3.0
Electrical conductivity	dS/m	0.7
Exchangeable Sodium Percent	%	< 5
Texture		Loam, sandy loam
Infiltration	cm/hour	1-2
Available Water Capacity	mm m	120-150
Hydraulic conductivity	cm/hour	3-5

***Source:** Byju, 2006.*

Nutrient Requirements of Cassava

Cassava responds well to application of manures and fertilizers. A study by Mohankumar *et al.*, (1976) reported a fresh root yield of 27.1 t/ha when cassava was grown with the application of manures and fertilizers, compared to 15.8 t/ha obtained in the control treatment where no manures and fertilizers were applied. It was also estimated that for producing one tonne of cassava roots, the crop removed 6.45 kg N, 1.23 kg P and 8.5 kg K, whereas rice removed 6.6 kg N, 1.3 kg P and 8.62 kg K (Mohankumar and Nair, 1996). This clearly indicates that per unit production of dry matter, both these starch yielding crops removed similar quantities of N, P and K. Detailed reviews of work done on nutrient management of cassava in India have been written by different workers (Mohankumar *et al.*, 1998.; James George *et al.*, 2001). The amount of N, P and K removed by cassava are summarized in **Table 6**. Application of optimum levels of nutrients through a systematic approach has been suggested by Susan John *et al.* (2007b). Sorption studies have also been conducted to optimize the nutritional status of a typic Kandiustult of Kerala (Susan John and Venugopal, 2005). In a study on nutrient use efficiency and balance sheet of nutrients under maximum yield research (MYR) in cassava, Susan John and Venugopal (2006a) observed the highest use efficiency of N, P_2O_5 and K_2O at 100:300:300 kg/ha along with farm-yard manure (FYM) at 12.5 t/ha.

Recommended rates of fertilizers for targeted yields of cassava in laterite soils of Kerala were developed by Swadija and Sreedharan (1998) and for soils of Tamil Nadu by Selvakumari *et al.* (2001). Further, a soil test-based fertilizer recommendation for cassava cultivation in Kerala and for Kanyakumari district of Tamil Nadu have been developed based on a rapid appraisal of the nutrient status of these soils (Susan John, 2007).

Resource management for short duration cassava varieties grown after paddy in lowlands of Kerala have been studied (CTCRI, 2008). Five short duration cassava varieties, Vellayani Hraswa, Kalpaka, Sree Jaya, Sree Vijaya and a promising triploid 2-18, were evaluated for growth, yield and biomass production. The short duration cassava cultivars, Sree Vijaya, Sree Jaya, Vellayani Hraswa and Kalpaka are promising for cultivation after rice for food purpose, and the early bulking triploids, i.e. 2-18 and 4-2, are ideal for industrial uses owing to their high root dry biomass production. Nutrient management for short-duration cassava, based on soil test data for organic carbon, available P and K status, was the most appropriate (root yield of 24.18 t/ha).

Table 2. Physico-chemical properties of an Ultisols where cassava is cultivated in Kerala.

Depth (cm)	pH	OC (%)	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Sand	Silt	Clay
			(kg/ha)			cmol(+)/kg		(mg/kg)					(%)		
0-28	5.05	1.96	182.24	29.34	103.34	0.41	0.07	6.55	34.12	10.18	1.25	1.17	64.81	5.59	29.60
28-63	5.00	1.47	58.34	11.38	52.39	0.29	0.05	3.21	23.18	5.52	0.65	0.87	58.30	7.51	34.20
63-87	5.20	0.52	42.14	6.59	34.11	0.21	0.03	2.34	13.45	3.21	0.32	0.52	50.72	8.54	40.75
97-200	4.95	0.33	38.81	4.32	22.87	0.17	0.02	0.96	8.91	1.08	0.27	0.19	57.04	7.47	35.50

Table 3. Physico-chemical properties of two soil orders where cassava is cultivated in Tamil Nadu.

Depth (cm)	pH	OC (%)	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
			(kg/ha)			(cmol(+)/kg)		(mg/kg)					
Vertisols													
0-20	7.8	0.72	109.2	30.66	500.0	9.88	2.76	17.0	1.40	3.9	4.61	3.17	0.83
20-40	8.1	0.34	87.36	10.51	198.0	10.00	2.75	5.0	0.64	1.4	0.73	2.93	0.61
40-60	8.3	0.34	80.08	10.51	176.0	9.63	2.74	5.0	0.57	1.0	0.82	2.19	0.52
60-80	8.3	0.36	50.96	7.01	144.0	9.75	2.66	5.5	0.52	1.2	0.67	1.34	0.41
80-100	8.5	0.39	43.68	10.51	76.0	7.63	2.20	3.1	1.47	0.3	0.52	0.77	0.20
100-120	8.5	0.28	43.68	7.01	84.0	7.63	2.34	1.8	0.89	0.8	0.80	0.81	0.13
Alfisols													
0-20	7.02	0.36	133.74	34.64	184.93	1.02	0.95	12.2	22.65	2.8	0.95	1.03	0.30
20-40	7.13	0.15	75.28	21.62	82.15	0.73	0.63	6.3	12.15	0.9	0.32	0.69	0.15
40-60	7.15	0.15	68.71	14.15	65.68	0.51	0.51	2.5	10.63	0.5	0.30	0.51	0.13
60-80	7.16	0.11	47.13	9.68	35.12	0.32	0.42	1.6	8.15	0.4	0.25	0.42	0.08
80-100	7.11	0.09	34.15	8.53	28.83	0.25	0.33	0.9	5.33	0.3	0.21	0.38	0.05
100-120	7.13	0.06	30.68	5.15	21.61	0.22	0.28	0.6	3.15	0.3	0.18	0.35	0.04

Table 4. Physico-chemical properties of an Inceptisols where cassava is cultivated in Andhra Pradesh.

Depth (cm)	pH	OC (%)	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Sand	Silt	Clay
			(kg/ha)			cmol(+)/kg		(mg/kg)						(%)		
0-20	6.8	0.18	98.64	46.43	104.87	0.23	0.21	6.25	2.75	1.23	1.06	2.38	0.28	94.2	3.9	1.9
20-50	6.9	0.09	41.25	10.34	30.45	0.17	0.14	4.12	1.31	1.03	0.59	1.04	0.15	95.3	2.2	2.5
50-100	7.0	0.05	37.53	6.75	16.75	0.11	0.10	2.18	1.15	0.82	0.21	0.58	0.07	94.6	2.7	2.7
100-150	7.0	0.03	35.64	4.83	10.49	0.06	0.05	1.27	1.06	0.51	0.15	0.30	0.04	95.2	2.6	2.2

Table 5. Physico-chemical characteristics of soils where cassava is cultivated in India.

Parameter	Unit	Kerala		Tamil Nadu				Andhra Pradesh	
		Ultisols		Vertisols		Alfisols		Inceptisols	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
pH		4.1-5.8	5.0	7.2-8.5	8.0	5.7-8.5	6.8	4.90-6.20	5.5
Organic C	%	0.31-2.70	1.08	0.48-1.11	0.70	0.16-0.71	0.38	0.15-0.53	0.35
Available N	kg/ha	165.20-300.15	174.23	87.36-189.30	123.80	107.25-268.13	168.70	94.52-128.89	106.55
„ P	kg/ha	15.61-39.62	28.94	16.64-92.70	41.35	1.57-82.77	19.82	16.78-74.98	54.60
Exchangeable K	kg/ha	60.4-174.2	98.3	60.5-1050.0	439.3	78.4-705.0	298.1	82.6-96.7	86.2
„ Ca	cmol/kg	0.22-0.63	0.39	3.13-13.43	8.44	2.63-11.50	5.70	0.15-0.48	0.31
„ Mg	cmol/kg	0.02-0.08	0.06	1.38-3.50	2.42	0.14-1.13	0.78	0.02-0.05	0.03
Available S	mg/kg	3.47-9.55	6.51	-	-	-	-	-	-
„ Fe	mg/kg	5.98-82.90	19.43	1.82-33.40	9.84	0.60-3.83	1.80	0.69-2.57	1.89
„ Mn	mg/kg	2.48-84.76	19.90	1.09-20.43	6.85	0.50-5.60	1.50	0.41-1.75	0.93
„ Zn	mg/kg	0.26-1.96	0.78	0.37-2.71	0.83	0.50-4.60	1.10	0.88-2.43	1.65
„ Cu	mg/kg	0.24-10.20	1.24	0.95-4.53	2.68	1.69-4.66	2.80	0.59-1.29	0.86
„ B	mg/kg	0.02-0.40	0.27	0.61-0.95	0.82	0.16-0.29	0.22	0.26-0.35	0.31
CEC	cmol/kg	1.39-7.70	3.04	-	-	-	-	-	-
Bulk density	Mg/m^3	1.30-1.60	1.40	1.18-1.27	1.23	1.03-1.22	1.18	1.24-1.39	1.34
Sand	%	32.10-65.80	53.70	24.75-38.50	33.69	22.61-36.48	31.21	90.50-95.90	93.80
Silt	%	3.10-8.40	5.20	21.30-32.30	28.09	23.65-33.31	29.27	1.70-4.10	3.70
Clay	%	26.30-62.50	42.00	29.25-54.00	38.96	28.72-47.61	39.53	1.50-3.00	2.50

Table 6. Removal of N, P and K by cassava roots.

Fresh root yield (t/ha)	Nutrient removed (kg/ha)			Reference
	N	P	K	
30.0	180.0	22.0	160.0	CTCRI, 1983
49.6	187.6	33.6	233.3	Mohankumar and Nair, 1996

1. Long term effect of application of manures and fertilizers

The Central Tuber Crops Research Institute (CTCRI) in India has been conducting long-term experiments to study the influence of manures and fertilizers on soil fertility as well as on the tuberous root yield of cassava for the past 32 years, since 1977 (Pillai *et al.*, 1985; Kabeerathumma and Mohankumar, 1990a; Kabeerathumma *et al.*, 1990; 1993; Susan John *et al.*, 2003; 2005). The long-term experiments have been conducted in three different phases (1977-1990, 1990-2003 and 2004-present) by modifying the treatments based on results of the previous phase.

The results of the first phase of the experiment, that spans for a period of 13 years, from 1977-1990, showed that continuous application of FYM at 12.5 t/ha and N, P and K at 100:100:100 kg/ha (as $N\text{-}P_2O_5\text{-}K_2O$) produced a mean root yield of 29.0 t/ha for the cassava variety Sree Vishakham (H-1687), whereas in the control treatment where no manure and fertilizers were applied, the mean root yield was only 1.03 t/ha.

A second phase of the long-term experiment was conducted during 1990-2003 with another set of treatments. The experiment again showed the significance of balanced fertilization in improving the organic carbon and available nutrient contents. The results also indicated that Mg and Zn deficiencies are likely to develop if we continuously grow cassava in Ultisols, and it is recommended to apply Mg and Zn at 20 and 12.5 kg/ha, respectively. The use of magnesium sulfate and zinc sulfate are recommended for these situations. The starch content of cassava roots was also found to be significantly increased when we adopt balanced NPK and Zn application. Continuous cropping of cassava with only chemical fertilizers decreased the levels of Ca, Mg, Zn and Cu in the soil, and lowered the soil pH. The results clearly indicate the need for organic manure application along with addition of chemical fertilizers. The long-term experiments also showed that the rate of application of FYM can be reduced to 50% (6.25 t/ha) by incorporating the residues of the previous cassava crop and by practicing green manuring *in situ* with cowpea as suggested earlier by different workers (Sasidhar and Sadanandan, 1976; Prabhakar and Nair, 1987; Mohankumar and Nair, 1990; Nayar *et al.*, 1993). The nutrient availability in relation to soil microbial biomass was also studied by Susan John *et al.* (1996).

The third phase of the long term experiment was started during 2004 and the results so far indicate that application of FYM at 12.5 t/ha and N, P and K at 125:50:125 kg/ha (as $N\text{-}P_2O_5\text{-}K_2O$) produced significantly higher root yields (18.53 t/ha) compared to other treatments.

2. Lime, organic manure and N, P and K

Amending an acid soil by the application of lime is a common practice for reducing acidity and increasing the nutrients' availability. Liming increased the root yield as well as increased the starch content and decreased the HCN content (Nair and Varghese, 1970).

Another study was also conducted at CTCRI, (Mohankumar and Nair, 1985) with different rates of lime, from 0 to 2000 kg CaO/ha in addition to the recommended dose of N, P_2O_5 and K_2O (100:100:100 kg/ha). The root yield was increased by 35.6% by the application of 2000 kg CaO/ha compared to the control. It also improved the quality of the tuberous roots by increasing the starch content and by reducing the HCN content. In contrast to the earlier studies, Susan John and Venugopal (2006b) reported a negative response of lime on growth and yield of cassava, which indicates that cassava may not require the application of lime even if grown in acid soils.

Cassava is extremely tolerant of low pH and high levels of exchangeable Al, while it has a low external requirement for P because of an effective mycorrhizal association. From earlier studies on different cassava clones grown with different levels of organic manures and inorganic fertilizers, it was recommended to apply 12.5 t/ha of FYM and 100:100:100 kg/ha N, P_2O_5 and K_2O (Mandal *et al.,* 1973). A similar recommendation was made by Pillai *et al.* (1985). But, later studies by Kabeerathumma and Ravindran (1996) showed that the rate of P application can be reduced to 50%, thus changing the NPK recommendation to 100:50:100 kg/ha. Based on these and other related studies, Nair *et al.* (2004) now recommend to apply 100:50:100 kg/ha N, P_2O_5 and K_2O for high-yielding cassava varieties and 50:25:50 kg/ha for M-4 and local cultivars. Half the dose of N and K, and the entire amount of P should be broadcast at the time of final land preparation and the remaining amount of N and K is applied 45-60 days after planting in short bands around each plant.

Vinod and Nair (1992) conducted a study to find out the effect of slow release nitrogen fertilizers on cassava. The N sources were urea, urea super-granules, neem cake-coated urea and rubber-coated urea, each applied at 50, 75, 100, 125 and 150 kg N/ha. Application of urea super granules and neem cake-coated urea resulted in significantly higher root yields and better quality characters. On-farm experiments conducted at five locations in Tamil Nadu showed a 27% yield increase due to the application of neem cake-coated urea compared to application of urea (TNAU, 2002).

The effect of different sources of N, P and K on yield and quality of cassava roots has been studied in detail. Different sources and levels of N have been studied by Vijayan and Aiyer (1969), Mandal *et al.* (1971) and Nair and Sadanandan (1985). Muthuswamy and Chiranjivi Rao (1988) found that the leaf N concentration at the 5th month after planting (MAP) was maximum and was positively correlated with the root yield of cassava. Different sources (Mussoorie rock phosphate and single superphosphate) and levels of P have been studied by Vijayan and Aiyer (1969), Nair and Rajendran (1973), Kabeerathumma and Mohankumar (1990b), Susan John *et al.* (1997) and Nair *et al.* (1988). Since potassium is the most important major nutrient affecting root yields, a lot of studies were conducted in India on the K nutrition of cassava (Mohankumar *et al.,* 1971; Rajendran *et al.,* 1976; Pushpadas and Aiyer, 1976; Ashokan and Sreedharan, 1977; Pillai and George, 1978; Nair *et al.,* 1980; Nair and Aiyer, 1985; Nair and Sadanandan, 1985; Nair and Aiyer, 1986; Mohankumar *et al.,* 1991).

The root CEC of different cultivars was studied by Nair *et al.* (1981), who observed that the root CEC of cassava ranged from 20.0-42.5 cmol/kg and the best correlation with yield was obtained at 2 months after planting.

In a study on the response of cassava to application of NaCl, Nair *et al.* (1980) found no additional advantage by the application of NaCl to cassava, either in increasing

the yield or improving the quality of roots. Another study conducted in Kerala Agricultural University, India showed that 50% of the K requirement of cassava can be substituted by Na through the application of common salt, without any deleterious influence on cassava yield (Sudharmayi Devi, 1995). Studies on substitution of common salt for KCl were also conducted by Susan John *et al.* (2007a).

3. Calcium, magnesium and sulfur

The beneficial influence of application of the secondary nutrients, namely Ca, Mg and S has been studied by many workers (Pushpadas and Aiyer, 1976; Korah *et al.,* 1989; Mohankumar and Nair, 1983; 1985). Application of S at 50 kg/ha in an Ultisols resulted in a significantly higher root yield and starch content and a lower HCN content. Sulfur addition also increased the total protein and methionine contents. Continuous cultivation of cassava in Ultisols may also result in the development of Mg deficiency, and in such situations it is recommended to apply Mg at 20 kg/ha as $MgSO_4$ (Susan John *et al.,* 2005).

4. Micronutrients

Cassava may respond significantly to the application of some micronutrients. Cassava responded to soil application of Zn, B and Mo at 12.5, 10.0 and 1.0 kg/ha, respectively, applied as zinc sulfate, borax and ammonium molybdate (Nair and Mohankumar, 1980). In Kerala state, where cassava is cultivated mostly in laterite soils (Ultisols), Zn and B deficiency have been reported in some fields (Sheeja, 1994). A very strong positive correlation between N and K fertilization and micronutrient uptake was observed by Muthuswamy and Chiranjivi Rao (1986). Between the two cassava varieties studied, namely H-165 (high yielding) and Burma (local), higher requirements of Fe, Mn, Zn and Cu were observed for the high yielding variety than the local cultivar.

A detailed survey with sample collection and analysis have been conducted by Byju *et al.* (in press a, b, c). in cassava growing regions of Tamil Nadu and Andhra Pradesh. In the black soils of Tamil Nadu, Fe deficiency is found to be a very serious problem limiting cassava production. Besides Fe deficiency, Zn and Mn deficiencies have also been reported from some of the farmers' fields where they have grown cassava continuously for more than 3-4 years. **Table 7** presents the mean soil chemical characteristics of those areas that were free of iron chlorosis, and those partially and totally affected by iron chlorosis. The mean values of Ca and Fe contents in the leaf blade of cassava grown in areas free of iron chlorosis, and those in areas partially and totally affected by iron chlorosis are given in **Table 8.** A study by Mani and Duraisami (2002) showed that foliar application of 1% $FeSO_4.7H_2O$ and 0.5% $ZnSO_4.7H_2O$ at 30 and 45 days after planting reduced iron chlorosis in cassava. Byju *et al.* (2006) developed a micronutrient product for cassava based on the nutritional requirements of cassava, as well as by considering the average soil fertility status in major cassava growing areas. The results are very promising and more detailed studies in farmers' field are planned before its development as a commercial product. In Andhra Pradesh, Fe, B and Mn were found to be limiting micronutrients that resulted in a yield plateau in major cassava growing areas. A compilation of the symptoms of major nutritional deficiencies and their corrective measures has been published by CTCRI, India, as a technical bulletin (Susan John *et al.,* 2006).

Table 7. Mean values of soil chemical characteristics of areas without and of those areas affected by iron chlorosis.

Location	pH	Organic C (%)	N	P	K	Fe (µg/g)	Ca (cmol/kg)
---	---	---	---	---(kg/ha)---			
Normal	7.70	0.72	109.20	30.66	500.00	8.76	7.88
Partially affected	7.75	0.66	117.61	29.39	453.68	4.37	12.49
Totally affected	7.90	0.67	94.47	28.31	421.37	1.10	15.67

Table 8. Mean values of iron and calcium contents in cassava leaf blades and petioles of YFEL of plants at 3 month stage as affected or not affected by Fe or Ca deficiency.

Location	Iron (µg/g)		Calcium (%)	
	Leaf blade	Petiole	Leaf blade	Petiole
Normal	189.67	78.63	0.82	0.34
Partially affected	113.67	62.74	1.74	0.82
Totally affected	104.21	48.45	1.95	0.91

5. Low-input soil fertility management

In India, efforts were made to identify cassava genotypes adapted to sub-optimal soil conditions, to utilize locally available organic wastes as soil amendments, to exploit indigenous nutrient carriers and biofertilizers. The rate of application of FYM could be reduced to 50% (6.25 t/ha) by incorporating the residues of the previous cassava crop and by practicing green manuring *in situ* with cowpea, as suggested by different workers (Sasidhar and Sadanandan, 1976; Prabhakar and Nair, 1987; Mohankumar and Nair, 1990; Nayar *et al.,* 2007). Based on a series of experiments conducted at CTCRI, a low-input soil fertility management practice has been developed with the following four components (Nayar *et al.,* 1993; 2007).

a. Three cassava genotypes i.e. Sree Prabha, Mankuzhanthan and M-4, were identified for their adaptation to low-input management
b. Green manuring *in situ* with cowpea has both agronomic and economic advantages
c. Mussoorie rock phosphate can be used in place of single superphosphate
d. Application of coir pith compost and press mud is cheap and is a very effective substitute to FYM, and has no adverse effects on the soil's available N, P and K status.

Gopimony *et al.* (2001) studied the nutrient dynamics of Bhindi (ladies finger) and cassava production under organic farming, and observed that it is not possible to sustain high yields of cassava by organic practices alone over the years.

6. Biofertilizers and biocontrol agents

The response of cassava to biofertilizers was studied by Suja *et al.* (2005); they reported that the rate of application of N and P fertilizers can be reduced to half when integrated with the use of *Azospirillum* and *phosphobacterium*. FYM and K still need to be applied at the recommended rates. Vesicular-arbuscular mycorrhizal (VAM) fungi are present in nearly all natural soils; they infect the roots of cassava. In this symbiotic

association the fungus utilizes carbohydrates produced by the plant, while the plant benefits from the increased uptake of P and some other nutrients (Zn and Cu) through the external hyphae extending from the root surface into the soil. Detailed studies on the effect of VAM fungi on cassava nutrition were conducted in CTCRI (Potty, 1978; 1985; 1990). Sivaprasad *et al.* (1989) observed cultivar differences to VAM inoculation.

In Tamil Nadu, where cassava is grown as an irrigated crop in Vertisols, root rot caused by *Phytophthora palmivora* is found to be a very serious problem resulting in yield reductions of up to 80-85%. On-farm research was conducted during 2007-2010 in Tamil Nadu to study the effect of three biofertilizers (N fixer, P solubilizing bacteria and VAM fungi) and two biocontrol agents (*Trichoderma* and *Pseudomonas*) on the incidence of root rot under two levels of NPK fertilizers (Byju *et al.*, 2008; Byju *et al.*, 2010c). Application of *Trichoderma* together with *Azospirillum* or VAM fungi resulted in significantly higher root yields. The N and K uptake at recommended and at 50% of recommended levels of applied NPK were at par (not significantly different). Application of all cultures to the soil significantly increased the N uptake which was at par with the *Azospirillum* application. The P uptake was significantly increased by the use of VAM and phosphate solubilizing bacteria (PSB). The activity of the soil enzyme urease was significantly higher in plots treated with the recommended rates of NPK as compared to 50% of the recommended level. The urease acivity was also increased significantly by the application of *Azospirillum*. Application of all cultures to the soil resulted in significantly higher dehydrogenase activity, which was at par with the application of *Trichoderma* along with VAM fungi. Application of all cultures to the soil also resulted in significantly higher β-glucosidase activity, followed by application of PSB and VAM, which were at par. The microbial biomass C was significantly higher when all cultures were applied to the soil, which was at par with application of *Trichoderma* along with VAM.

7. Subsoiling for control of root rots

A survey conducted in Tamil Nadu during 2002-2003 indicate that root rot caused by *Phytophthora palmivora* is a very serious problem in irrigated Vertisols. In order to develop a management technology, an on-farm experiment was conducted during 2002-2006 with different tillage treatments (normal and deep tillage), method of land preparation (flat and ridge methods), application of sulfur, neem cake and *Trichoderma,* along with the farmer's practice as control. The study revealed that deep plowing (subsoiling), followed by the ridge-and-furrow method of planting and with the application of neem cake and *Trichoderma viride* resulted in a significant reduction in root rot incidence and in the highest root yields (Nair *et al.*, 2004). A very successful management practice has been developed, based on this study, for the control of root rots of cassava, which had been a major problem faced by cassava farmers in Tamil Nadu (Byju et al. 2010c). The six components of the management practice developed are as follows:

a. Deep plowing with a chisel plow.
b. Plant on top of ridges
c. Broadcast and incorporate neem cake at the rate of 250 kg/ha at the time of final land preparation.
d. Apply *Trichoderma viride* at 1 kg/ha, mixed with 100 kg dry cow dung at the time of planting.
e. Strict field sanitation by removing and burning infected roots after harvest.

f. Practice crop rotation with pulses, turmeric or sugarcane.

8. Integrated nutrient management (INM)

Geetha *et al.* (2001 conducted experiments to determine the best integrated nutrient management (INM) practice for cassava in laterite soils. The results indicate that chemical fertilizer application can be reduced to half when combined with biofertilizers. The effect of INM on the growth, dry matter production and root yield of cassava was reported by Ramanandam *et al.* (2008). There were 13 different treatments involving different combinations of full, ¾ and ½ dose of recommended NPK with organic manures (FYM and vermicompost) and *in situ* green manuring with cowpea and biofertilizer (*Azospirillum*) (**Table 9**). The results indicate that the application of ¾ of recommended NPK, combined with vermicompost and *Azospirillum* resulted in growth and yield parameters on par with the application of the recommended NPK, combined with vermicompost and *Azospirillum*.

James George and Susan John (2008) reported the results of the integrated application of organic sources of fertilizers for sustainable cassava production. Different sources of organic manures like coir pith compost, vermicompost, processed urban waste, farm-yard manure and VAM fungi were applied along with inorganic fertilizers. Organic manures like farm-yard manure at 7.34 t/ha, processed urban waste at 3.67 t/ha, vermicompost at 2.29 t/ha, combined with 50% of the recommended chemical fertilizers (50:25:50 kg/ha) resulted in significantly higher root yields and these treatments were on par with the yield obtained when the recommended package of practices (100:50:100 kg/ha) was followed.

9. Site-specific nutrient management

The present average yield of cassava in India is 32.9 t/ha, but is still far below the potential yield of 100 t/ha produced occasionally under experimental conditions. Crop management of cassava over the past four decades in India was driven by the increasing use of external inputs and blanket recommendations for fertilizer use over wide areas (Mohankumar, 2000). Another problem is that estimates of nutrient requirements of cassava is mostly derived from field experiments conducted at a relatively small number of research stations in India in the last decades. Although these experiments supply valuable information for a particular site, results can only partly be extrapolated to estimate nutrient requirements in farmers' fields because of the much broader range of soil, climatic, agronomic and socio-economic conditions at the farm level (Witt *et al.*, 1999). Hence, future gain in productivity and input-use-efficiency will require soil and crop management technologies that are more knowledge-intensive and tailored to the specific characteristics of individual farms and fields. The production of cassava in India has increased markedly with the introduction of crop production technologies based on the development of fertilizer-responsive high-yielding cultivars. The removal of nutrients with the harvested roots per unit area of cultivated land has also increased considerably (James George *et al.*, 2001). The literature shows that future gains in productivity and input-use-efficiency will be possible only by managing the large variability existing in soil nutrient supply, nutrient use efficiency and crop response to nutrients among different farms.

Table 9. Effect of integrated nutrient management practice on root yield of cassava

Treatment	Root yield (t/ha)	
	2002-03	2003-04
Recommended N, P_2O_5, K_2O	12.98	16.34
Recommended N, P_2O_5, K_2O + FYM	14.99	22.25
Recommended N, P_2O5, K_2O + FYM + Azospirillum	19.21	24.83
2/3Recommended N, P_2O_5, K_2O + FYM + Azospirillum	18.10	23.84
1/2Recommended N, P_2O_5, K_2O + FYM + Azospirillum	14.36	21.04
Recommended N, P_2O_5, K_2O + Vermicompost	18.89	24.04
Recommended N, P_2O_5, K_2O + Vermicompost + Azospirillum	21.21	26.58
2/3Recommended N, P_2O_5, K_2O + Vermicompost + Azospirillum	20.80	25.89
1/2Recommended N, P_2O_5, K_2O + Vermicompost + Azospirillum	17.68	23.05
Recommended N, P_2O_5, K_2O + Green manure	13.86	20.57
Recommended N, P_2O_5, K_2O + Green manure + Azospirillum	16.82	22.93
2/3Recommended N, P_2O_5, K_2O + Green manure + Azospirillum	15.00	22.74
1/2Recommended N, P_2O_5, K_2O + Green manure + Azospirillum	13.48	19.13

***Source**: Ramanandam et al. (2008).*

There are considerable uncertainties about N, P and K requirements of cassava because the internal nutrient efficiencies (IE) (kg root/kg plant nutrient) vary greatly depending on nutrient supply, crop management practices and climatic conditions. Estimates of total nutrient removal per tonne of root ranges from 3.40 to 7.15 kg N, 0.75 to 1.67 kg P and 4.47 to 9.95 kg K (Asher *et al.,* 1980; Howeler, 1981; Howeler, 1991; James George *et al.,* 2001; and Byju *et al.,* 2006). One of the critical constraints to productivity of cassava cultivation in India is low 'apparent' recovery efficiency of applied nutrients (Nayar *et al.,* 1985; James George *et al.,* 2001; Byju *et al.,* 2006). The recovery efficiency of applied nutrients can be improved by adjusting the splitting and application timing, and placement of fertilizer nutrients. In contrast, less attention has been given to manipulate the utilization of the indigenous nutrient supply, i.e. the amount of nutrient taken up by the crop from the unfertilized soil. Recovery efficiency of applied nutrients can be improved if information on indigenous nutrient supply is available to match nutrient supplies from soil and fertilizer with the crop's requirements. A simple method for predicting indigenous nutrient supply would simplify the development of appropriate management strategies to increase nutrient recovery efficiency.

Apparent nutrient recovery efficiency, particularly that of N, varies widely in cassava (Cenpukdee and Fukai, 1991). Though it depends on soil, climate, water management, and crop cultivar, plus splitting and timing of fertilizer application, the level

of fertilizer application also plays a dominant role. Therefore, establishing a relationship between recovery of N, P and K with the levels of application is of practical importance.

The QUEFTS (Quantitative Evaluation of Fertility of Tropical Soils) model, originally developed by Janssen and Guiking (1990), and first applied in Kenya and Surinam, and further evaluated by, among others, Smaling and Janssen (1993) for maize, and by Witt *et al.* (1999) for rice, considers interactions of N, P and K. The model is applicable to cassava once the basic relationships between tuberous root yield and nutrient uptake of the crop are established.

With this concept in mind, a study was conducted by CTCRI in 15 farmers' fields during 2003-2008 in Tamil Nadu and Andhra Pradesh, to quantity the variation in soil nutrient supply in cassava fields within typical cassava areas of India, where cassava is cultivated on a commercial scale, and to develop a new approach for site-specific nutrient management (SSNM) using the modified QUEFTS model (Byju *et al.,* 2006).

In order to adapt and test the QUEFTS model for cassava, we modified steps 3 and 4 of the model dealing with the relationship between root yield and nutrient accumulation in total plant dry matter by:

(a) selecting suitable data that fulfill the boundary conditions of the model;
(b) defining borderlines that describe the maximum and minimum accumulation of N, P and K, and assessing their sensitivity to different criteria of data selection;
(c) assessing whether intercepts that describe the minimum nutrient uptake required to produce any measurable root yield were needed;
(d) simulating curves of optimum uptake requirements of N, P and K at different Y_{max} (YN, YP, YK);
(e) assessing whether the same borderline models are suitable for all high-yielding cassava varieties of different growth duration, and whether these borderline models can be used for different climatic seasons, i.e. sites and seasons with different Y_{max};and
(f) comparing model-simulated optimal IEs of N, P and K in farmers' fields.

A Microsoft Excel spreadsheet version of QUEFTS was used in combination with a solver module to work out field-specific fertilizer recommendations for each farm at the beginning of each season.

Based on the results of the study, fertilizer calculation charts have been prepared to determine field specific NPK requirements for cassava based on yield in N/P/K nutrient omission plots (Byju et al., 2009; Byju et al., 2010 a. b). This simple farmer-friendly tool has resulted in significant increases in root yields by improving the nutrient uptake and nutrient use efficiencies. Large-scale on-farm experiments to validate the results and to integrate all the findings into a nutrient decision support system (NuDSS) are in progress.

10. Leaf color chart and chlorophyl meter-based dynamic N management

The present nitrogen fertilizer recommendation for cassava is the application of 100 kg N/ha in two split doses. Cassava is sensitive to over-fertilization, particularly N, and also, there is large-scale field-to-field variability of N in soils where cassava is cultivated in India and this definitely restricts the efficient use of nitrogen fertilizer when broad-based blanket recommendations are used (Byju *et al.,* 2008). To achieve and sustain high cassava yields, it is very vital to develop farmer-friendly technologies that can improve N-use efficiency and reduce N losses to a considerable extent. A leaf color chart (LCC) and

chlorophyl meter (SPAD-502) are two such very effective tools used in many other crops such as rice, maize and potato.

Two field experiments were conducted at the Central Tuber Crops Research Institute, Kerala, India during 2005-2008. The first experiment was intended to find the critical leaf and critical values of LCC and chlorophyll meter (SPAD-502), while the second experiment was conducted to validate the technology by comparing the results with the present recommendations (Byju and Haripriya Anand, 2009 a, b).

Significant and positive correlations were observed between leaf N content, SPAD values and LCC in leaf 1 (r^2 = 0.85 and r^2 = 0.95) at 30 days after planting, while the correlation between SPAD and leaf N for leaf 2 and 3 were poor. LCC readings of leaf 2 also produced a significant and positive correlation between leaf N content and LCC readings (r^2 = 0.87), while a poor correlation was observed using leaf 3. It was also found that the correlations were lower at 60 and 90 days. When the data of leaf 1 were combined across cultivars, nitrogen fertilizer rates and the first two growth stages (30 and 60 DAP), the regression between LCC scores and leaf nitrogen concentration was: LCC = 0.358 (leaf N) + 0.78 (r^2= 0.81) (equation 1)

The correlation between LCC score, SPAD value and total chlorophyl content of leaf 1 was positive and significant (P<0.01) for both cassava cultivars. The relationship was stronger in leaf 1 than in leaf 2 and 3. The correlations of chlorophyl a and b with the LCC score were not found to be significant (P>0.01) (Haripriya Anand and Byju, 2008a).

The LCC score of leaf 1 at 30 DAP accounted for 85% and at 60 DAP for 81% of the variation in the root yields of cassava. The SPAD values of leaf 1 at 30 DAP accounted for 83% and at 60 DAP for 81% of the variation in root yields of cassava. The relationship between LCC score or SPAD and root yield was better than with leaf nitrogen concentration (r^2 = 0.79 and 0.64, respectively, at 30 and 60 DAP), and chlorophyl (*a+b*) (r^2 = 0.80 and 0.65, respectively, at 30 and 60 DAP). The results indicate that any disorders in nitrogen nutrition can be detected at an early plant age by the leaf color chart or chlorophyl meter. Since the correlation was significantly higher with SPAD value or LCC score than with chlorophyl contents, these two tools can very effectively be used in predicting root yields of cassava, and can be used for more precise N management (Haripriya Anand and Byju, 2008a, 2008b, 2009; Byju and Haripriya Anand, 2009, 2010).

The LCC score had a very significant (P<0.01) and positive linear relationship with the SPAD value of leaf 1 at 30 and 60 days after planting. For leaf 1, the LCC scores had an equal or stronger relationship with SPAD values than with the leaf N concentration. The correlations were not significant (P>0.01) for leaf 2 and 3 at all three growth stages. When the data of leaf 1 were combined across cultivars, N fertilizer rates and the first two growth stages (30 and 60 DAP), the regression between LCC scores and SPAD values was:

SPAD = 10.981 (LCC) – 3.51 (r^2 = 0.82)

(equation 2)

Published critical values for cassava leaf tissue N (concentration that results in 10 percent reduction in yield) at 1-2 months after planting range from 5.2 to 5.3%. There was much less variability between the growth stages at 30 and 60 DAP in the yield vs LCC or SPAD function than in the yield vs leaf N function. Since the correlations were always significantly higher in the youngest fully-expanded (YFEL) blades compared to leaf 2 and 3, YFEL was identified as the critical leaf for the estimation of LCC and SPAD values.

Threshold values were calculated from equations 1 and 2 and obtained as 2.65 for LCC and 25 for SPAD values.

Higher root yields were obtained with real time nitrogen management (RTNM) without basal as compared to RTNM with basal and the present recommendation. A similar trend was also observed in nutrient (NPK) uptake values. Agronomic efficiency factors for N, AE_N, RE_N and PE_N for RTNM treatments were also higher. It was suggested that the RTNM-based treatment using LCC or SPAD is better compared to the present recommendation.

11. Soil erosion and conservation

Cassava is generally considered as an erosion enhancing crop due to its slow initial growth, its weak tolerance of weed competition and considerable soil movement during harvest. In Kerala state and in the hilly areas of Tamil Nadu state, cassava is cultivated on sloping terrain, while in other areas of Tamil Nadu and in Andhra Pradesh, it is grown mostly on flat land with very little slope. Studies on soil loss due to erosion in laterite soils under cassava were conducted by CTCRI in Kerala. Studies on soil erosion in a cassava-based agroforestry system (Ghosh *et al.*, 1989) indicate that both runoff and soil loss were effectively reduced when cassava was grown on staggered mounds along with *Eucalyptus* and *Leucaena*, compared to the respective sole crops. This was due to the better canopy coverage on the soil surface which protects the soil from erosion. The benefit of the staggered mound method of planting was again reported by Kabeerathumma *et al.* (1996).

In Kadambur hills of Tamil Nadu, studies conducted by Ramesh (2008) indicate that cassava is generally grown in fields with slopes ranging from 3 to >14%, and in all areas the continuous cultivation of cassava for many years has resulted in considerable soil loss. Continuous monocropping of cassava under rainfed conditions without the adoption of any soil fertility management and erosion control measures resulted in sheet and gully erosion in many places. At higher elevations (above 1000 masl), soil erosion is considered a major problem by the farmers. Developing suitable site- and location-specific soil conservation and fertility control measures that are within the social and economic reach of farmers is the solution for the above problems, and CTCRI has been conducting studies to develop such practices.

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CASSAVA AGRONOMY RESEARCH IN CHINA

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ABSTRACT

According to previous research, fertilizer applied in the ratio $N:P_2O_5:K_2O = 2:1:2$ is generally the optimum for continuous cropping of cassava, not only in China but also in other Asian countries. Based on the results of our long-term fertilizer trial conducted at CATAS in Hainan, China, the $N:P_2O_5:K_2O$ ratio of 2:1:2 was the optimum formula for cassava production during the first eight years of cropping, but a ratio of 4:1:4 (100:25:100 kg/ha) was the optimum during subsequent years. Based on these results and those of other fertilizer trials, we have now adopted this new fertilizer formula for continuous cassava production. P fertilizer application can always be kept low, but the N and K ratio need to gradually increase year by year, even up to the level of $N: P_2O_5: K_2O = 4:1:4$. For continuous cropping of cassava, we recommend that the importance of nutrient are $N > K_2O > P_2O_5$, and suggest that the $N:P_2O_5:K_2O$ ratio is 1-2:1:1-2 in the first four years 2-3:1:2-3 from the 5^{th}-8^{th} year, and 3-4:1:3-4 after the 9^{th} year.

In addition, Ca, Mg, S, B, Zn and Cu fertilizer could be needed in some regions according to local soil conditions. In some regions, it is recommended to apply potassium-magnesium sulfate (PMS), calcium-magnesium phosphate and bio-organic fertilizers to supply micronutrients. Early application of fertilizers was most effective in obtaining higher fresh root yields and starch contents.

According to experiences in Wuming county of Guangxi province, which is nicknamed "cassava county" because of their highest yield, largest harvested area and production in China, with the adoption of recommended agronomic techniques, cassava production and soil fertility can be sustained in continuous cropping if a balanced fertilization is used that will replace those nutrients removed from the soil during cassava cultivation.

Intercropping with peanut and other crops in cassava fields could increase or even double total net income as compared to monocropping of cassava; this will also improve the soil's fertility through the return of intercrop residues. Furthermore, improved water management during the very early stages of growth greatly increased the fresh root yield by 67.4%, the root number per plant 30.0%, plant height 30.7% and stem diameter 14.3%. It also slightly increased the starch content of fresh roots and increased net income by US$ 485/ha after taking off the cost of water. Plant growth regulators can also promote germination and root expansion, increasing fresh root yields and starch accumulation. The use of homobarssinolide was best for increasing yield and Ethrel was best for increasing the starch content. Research on erosion control, chemical weed control, mechanization and rapid propagation are also briefly described.

Future research will also focus on basic mechanisms of physiology and ecology to produce high starch yields and high starch contents, intercropping, water management, mechanization and resistance to drought, typhoon and cold conditions. The goal will be to spread some improved technologies which not only increase fresh root yields and starch contents, but also can tolerate various adverse conditions in newly developed areas. This will be helpful in promoting the further industrialization of cassava in China.

INTRODUCTION

Cassava was introduced in China in 1820, and has since been widely adopted in southern China. Initially, cassava was for human food and animal feed, but the crop has

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gradually changed into an industrial raw material for production of starch and alcohol. It is now considered the best energy crop in tropical areas of the country, according to Chinese government experts.

The earliest cassava agronomy research was conducted at the Agriculture Experiment Station in Guangdong province during 1914-1919, but more systematic agronomy research started in the 1950s. During the 1980s, the Chinese Academy of Tropical Agricultural Sciences (CATAS) and the Guangxi Subtropical Crops Research Institute (GSCRI) have cooperated with CIAT, conducting mainly research on NPK fertilization and erosion control in Hainan, Guangxi, Guangdong and Yunnan provinces. More recently, a Farmer Participatory Research (FPR) project to enhance the adoption by farmers of improved agronomic practices was carried out in major cassava areas from 1994 to 2003 (Huang Jie *et al.*, 2000a; 2003; Li Jun *et al.*, 2000).

This paper focuses on cassava agronomy research in China during the past ten years; results are reported mainly based on various Chinese papers in order to avoid repeating the results reported in the Proceedings of previous Asian Regional Workshops.

FERTILIZATION

1. Long-term NPK Trial

1.1. Trials conducted from 1992 to 2003

CATAS has conducted, in collaboration with CIAT, a long-term NPK trial that compares various combinations of four levels of N, P and K as well as "burned soil". The trial has 16 fertilizer treatments in main plots and two different varieties in subplots, and has been conducted since 1992 at CATAS in Danzhou city, Hainan province (**Table 1**) (Huang Jie *et al.*, 2004a).

Table 1. Rates of application of N, P, K and burned soil in a long-term NPK trial conducted since 1992 in CATAS, Hainan China.

Fertilizer	Application levels (kg/ha)			
	0	1	2	3
N	0	50	100	200
P (P_2O_5)	0	25	50	100
K (K_2O)	0	50	100	200
B (burned soil)	0	1500	3000	6000

The correlation analysis between six agronomic characters **(Table 2)** indicate that the fresh root yield was very significantly and positively correlated with plant height, diameter

of stem, and root number per plant, but was negatively correlated with harvest index. Starch content was significantly and positively correlated with harvest index. Starch content was negatively correlated with fresh root yield. The most suitable NPK formula needs to be adopted to improve both fresh root yield and starch content, or to obtain higher fresh root yields but with a slightly lower starch content.

Table 2. Correlation analysis between five agronomic characters in the long-term NPK trial conducted from 1992 to 2002 in CATAS, Hainan, China.

Item	Stem diameter	Root/plant	Harvest index	Fresh root yield	Starch content
Plant height	0.989**	0.880**	-0.698*	0.916**	-0.365
Stem diameter		0.875**	-0.668**	0.935**	-0.358
No. roots/plant			-0.460	0.872**	-0.316
Harvest index				-0.423*	0.656*
Fresh root yield					-0.385

According to the average results of the first 11 years (**Table 3**), the application of higher rates of fertilizer resulted in higher fresh root yields, while without fertilizer (CK) the fresh root yield decreased rapidly during continuous cropping. Application of burned soil did not increase significantly fresh root yield nor the root starch content. Higher NK levels ($N_{2\text{-}3}K_{2\text{-}3}$) resulted in higher fresh root yields and net income, while the lower NK level ($N_{0\text{-}1}K_{0\text{-}1}$) produced lower fresh root yields and net income. However, the highest net income was obtained with the application of a moderate NPK level ($N_2P_1K_2$). High rates of P ($P_{2\text{-}3}$) did not increase fresh root yields. Lower NPK levels ($N_{1\text{-}2}P_{1\text{-}2}K_{1\text{-}2}$) resulted in higher root starch contents, while zero K (K_0) combined with the intermediate levels of N and P (N_2 and P_2) resulted in low yields and lower starch contents. Considering the most relevant data, the intermediate level of $N_2P_1K_2$ is the most recommended in terms of net income, fresh root yield, starch yield and starch content.

1.2. Comparison of results in 1992-1993 with those of 2002-2003

In order to determine the change in the optimum NPK ratio in different years, we compared the fresh root yield and starch content between the first two years (1992-1993) with those of the last two years (2002-2003). When different N levels were applied (**Figure 1**), N_1 was enough to obtain a high fresh root yield in the first two years, but N_2 was needed to harvest a higher fresh yield in the last two years; in both cases the highest N level (N_3) reduced the starch content except for N_1 during the last years; N_2 is the most recommended level for continuous cropping.

Table 3. Average yield parameters and net income in the long-term NPK trial conducted from 1992 to 2002 in CATAS.

Treatment	Root yield (t/ha)	Starch content (%)	Starch yield (t/ha)	Net income US$/ha	Rank	Increase in net income
12. $N_3P_3K_3B_0$	22.4aA	30.1cdBC	6.74	490.0	5	268.4
7. $N_2P_1K_2B_0$	22.3aA	31.8aA	7.09	576.4	1	354.8
5. $N_3P_2K_2B_0$	21.8AB	29.8cdC	6.50	471.3	8	249.7
8. $N_2P_3K_2B_0$	21.3aAB	31.3abAB	6.67	500.4	3	278.8
11. $N_2P_2K_3B_0$	21.2aAB	31.2abAB	6.61	496.9	4	275.3
4. $N_2P_2K_2B_0$	20.7abABC	30.7bcABC	6.35	512.1	2	290.5
10. $N_2P_2K_1B_0$	18.8bcBCD	31.2abAB	5.87	469.0	9	247.4
6. $N_2P_0K_2B_0$	18.7bcBCD	31.5abA	5.89	480.0	6	258.4
3. $N_1P_2K_2B_0$	17.9cCD	31.9aA	5.71	461.9	10	240.3
14. $N_1P_1K_1B_1$	17.7cCD	31.9aA	5.65	421.1	11	199.5
16. $N_1P_1K_1B_3$	17.6cD	31.3abAB	5.51	219.9	16	-1.7
15. $N_1P_1K_1B_2$	17.6cD	32.0aA	5.63	349.9	12	128.3
13. $N_1P_1K_1B_0$	17.3cD	31.9aA	5.52	472.4	7	250.8
9. $N_2P_2K_0B_0$	14.0dE	29.4DC	4.12	335.0	13	113.4
2. $N_0P_2K_2B_0$	12.3dE	31.7abA	3.90	323.8	14	102.2
1. $N_0P_0K_0B_0$	7.1eF	31.7aA	2.25	221.6	15	0

Note: Average results of 12 years using different varieties. Net income = total income – fertilizer cost; all prices of fertilizers and fresh roots were according to the local market, same as below.
Values followed by the same letters in lower case are not significantly different at the 1% level, while those followed by the same capital letters are not different at the 5% level.

When different P levels were applied **(Figure 2)**, there was no significant effect except that P_1 was obviously increasing fresh root yields in the last two years, so P_1 is the most recommended level for continuous cropping.

When different K levels were applied **(Figure 3)**, the higher K level increased the fresh root yield, but K_2 was not significantly different from K_1 during the first two years, but K_2 obviously increased the fresh root yield in the last two years more than in the first two years; K_1 also improved the starch content. It is clear that K_3 didn't produce a good effect in terms of fresh yield and starch content, so K_2 is the most recommended level for continuous cropping.

When comparing different levels of the combined application of NPK **(Figure 4)**, the highest NPK level increased fresh root yields except for $N_3P_3K_3$ in the last two years. Higher NPK levels reduced the starch content except $N_1P_1K_1$ in the last two years. So,

$N_2P_2K_2$ is the most recommended level for continuous cropping. The analysis of different N, P and K ratios indicate that the ratio $N:P_2O_5:K_2O$ ($N_2P_1K_2$ treatment)=4:1:4 was the best ratio after the 10th continuous cropping cycle.

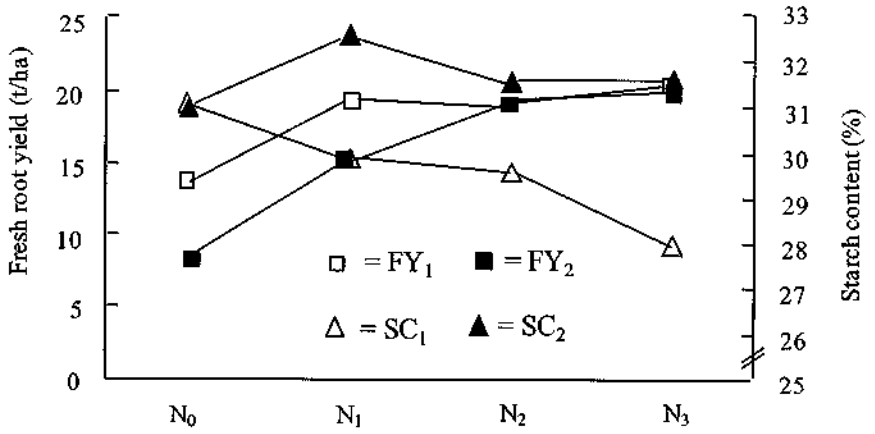

Figure 1. Effect of different levels of application of N.

Note: FY1 is the average fresh root yield in the first two years, FY2 is the average fresh root yield in the last two years; SC1 is the average root starch content in the first two years, SC2 is the average root starch content in the last two years; same for **Figures 2** to **4** below.

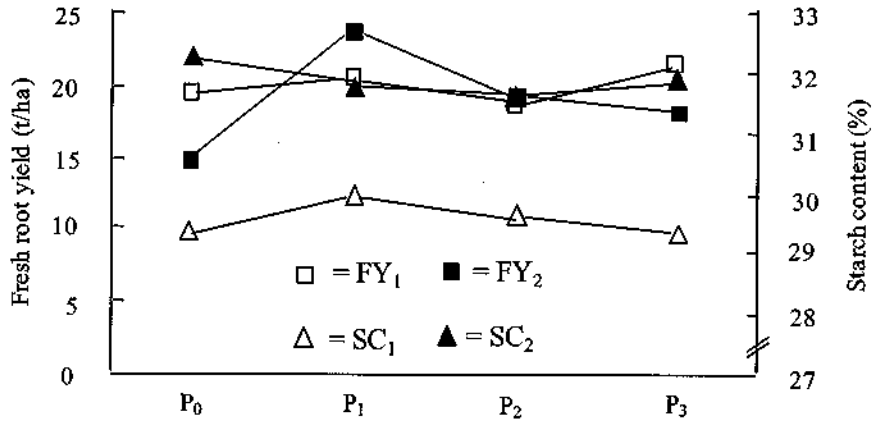

Figure 2. Effect of different levels of application of P.

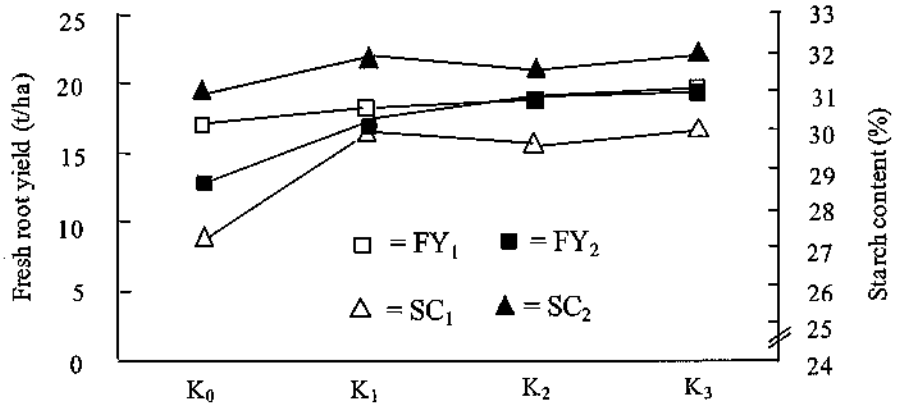

Figure 3. Effect of different levels of application of K.

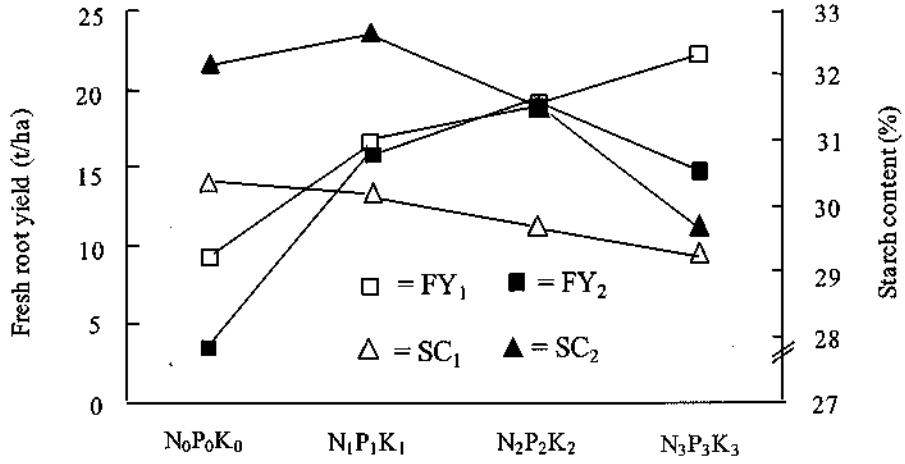

Figure 4. Effect of different levels of application of NPK.

1.3. The effect of rainfall and typhoon in the long-term NPK trial

Table 4 shows the effect of rainfall and typhoon on the average fresh root yield, starch content and starch yield in the long-term NPK trial. The results indicate that a strong typhoon accompanied by heavy rainfall markedly reduced the fresh root yields and starch contents, particularly in 1996; two subsequent strong typhoons led to serious lodging, very low fresh root yields and starch contents. When the typhoon years were excluded from the analysis the results indicate that lower rainfall led to lower fresh root yields but higher starch contents. On the other hand, higher fresh root yields but lower starch

contents were obtained with more than 2000 mm/year rainfall but no strong typhoons. Overall, fresh root yields were positively and significantly correlated (r=0.674*) with rainfall, and starch contents were negatively correlated with rainfall. It should be noted that the most suitable fertilizer rate needs to be considered carefully in some coastal areas because higher fertilizer rates may produce higher yields but could also produce very low yields and starch contents if a strong typhoon affects the area.

Table 4. Effect of rainfall and typhoons on the average fresh root yield, starch content and starch yield in the long-term NPK trial conducted at CATAS from 1992 to 2003.

Year	Rainfall (mm/year)	Typhoon (grade no.)	Fresh root yield (t/ha)	Starch content (%)	Starch yield (%)
1997	2168		35.3aA	29.8eF	10.52
1999	2484		23.8bA	32.1bBC	7.64
1994	2057		20.8cC	31.3cCDE	6.51
1992	1188	9 and 11	19.0dD		
1998	1396		17.8eDE	32.6bB	5.80
1993	1724		16.8efEF	28.4fG	4.77
2002	1750		16.5fEF	31.4cCD	5.18
1995	1376		16.0fFG	38.8aA	6.21
2003	1565		14.7gGH	32.4bB	4.76
2000	2302	9	14.2gH	30.5dEF	4.33
1996	2379	10 and 11	10.9hI	25.4gH	2.77
2001	2367	10	10.7hI	30.9cdDE	3.31

Note: Data shown are the average values for different varieties in 16 treatments. Typhoons mainly occur from June to September when cassava is already tall. The table only lists those typhoons grade 8 and above because there is little lodging at grades below 8.

1.4. Soil analysis of the long-term NPK trial in 1993 and 2002

Table 5 shows the results of soil analyses at the start of the trial in 1992 and the effect of treatments in 2002 after 11 years of continuous cropping. In all treatments, soil pH increased but was still in the medium range; organic matter had decreased except with the application of burned soil. $P_{2\text{-}3}$ resulted in a marked increase in the soil P level to high or very high levels; $P_{0\text{-}1}$ caused a decrease but these levels were still in the medium P range. Although K_3 or B_3 increased the soil-K level slightly, those levels were still low. Only treatment $N_0P_2K_2B_0$ improved the soil-K level enough to enter the medium range because little K was removed when no N was applied. The application of burned soil could maintain the soil-K level. The soil Ca and Mg levels remained low in all treatments. Thus, when cassava is grown continuously there is little effect on soil pH, but we need to

think carefully how to maintain fertility through the application of at least N_2, K_2, P_1 fertilizers and 15t/ha of burned soil or FYM every year, while, applying some Ca and Mg fertilizer to supply these nutrients in some years.

Table 5. Soil analysis data of the long-term fertilizer trial in 1992 and in 2002.

Treatment	pH	OM (%)	P (ppm)	K (me/100g)	Ca (me/100g)	Mg (me/100g)
NPK trial[1)]	**4.6**	**2.3**	28.7	0.12	0.65	0.11
1. $N_0P_0K_0B_0$	**5.3**	0.75	**8.8**	0.09	0.44	0.08
2. $N_0P_2K_2B_0$	**5.4**	0.83	50.7	**0.16**	0.58	0.10
3. $N_1P_2K_2B_0$	**5.3**	0.83	20.3	0.13	0.59	0.08
4. $N_2P_2K_2B_0$	**5.4**	0.88	36.5	0.10	0.70	0.15
5. $N_3P_2K_2B_0$	**5.4**	0.88	51.8	0.08	0.64	0.07
6. $N_2P_0K_2B_0$	**5.2**	0.80	**5.8**	0.12	0.38	0.07
7. $N_2P_1K_2B_0$	**5.3**	0.91	**17.7**	0.10	0.51	0.07
8. $N_2P_3K_2B_0$	**5.3**	1.10	97.5	0.09	0.67	0.08
9. $N_2P_2K_0B_0$	**5.4**	0.91	85.2	0.08	0.66	0.15
10. $N_2P_2K_1B_0$	**5.3**	0.75	25.6	0.08	0.43	0.06
11. $N_2P_2K_3B_0$	**5.3**	0.88	32.6	0.14	0.60	0.07
12. $N_3P_3K_3B_0$	**5.3**	0.88	48.0	0.13	0.74	0.14
13. $N_1P_1K_1B_0$	**5.3**	0.83	30.3	0.10	0.50	0.07
14. $N_1P_1K_1B_1$	**5.2**	**2.42**	**8.9**	0.11	0.49	0.10
15. $N_1P_1K_1B_2$	**5.4**	**2.67**	22.4	0.12	0.55	0.11
16. $N_1P_1K_1B_3$	**5.4**	**2.91**	38.4	0.13	0.74	0.18

Note: Soil samples taken in each treatment were analyzed by CIAT.
Data shown in bold face are considered medium, underlined are high or very high, others are low or very low according to the nutritional requirements of cassava (Howeler, 2002)

[1)] Soil samples of the trial site before the first planting in 1992; all others are from 2002

From the above analysis and previous research in China (Huang Jie *et al.*, 2000b; Li Jun *et al.*, 2000; Qi Zhiping *et al.*, 1999; Zhang Weite *et al.*, 1996), we may conclude that the $N:P_2O_5:K_2O$ ratio of 2:1:2 is the optimum ratio for cassava production during the first few years of continuous cropping; this is the most suitable recommendation not only in China but also in other Asian countries (Howeler, 2002). However, we found that the $N:P_2O_5:K_2O$ ratio of 4:1:4 (100:25:100 kg/ha) is the optimum after the 10^{th} year of continuous cropping. When adopting the NPK ratio for long-term continuous cassava production, the P application rate can always be kept low, but the N and K ratio need to gradually increase year after year, even up to $N:P_2O_5:K_2O$ = 4:1:4. For Chinese conditions,

we suggest that the optimum $N:P_2O_5:K_2O$ ratio is 1-2:1:1-2 in the first four years, 2-3:1:2-3 in the 5th-8th year and 3-4:1:3-4 after the 9th year.

2. NPK Ratio Experiment

Based on the long-term NPK trial, an NPK ratio trial was conducted at CATAS in Danzhou, Hainan in 2004 and 2005. The experiment had 12 treatments, with three replications, and a complete randomized design; plot size was 16 m^2, the plant spacing 1.0 x 0.8 m, the variety SC 5, harvested at 11 or 12 months after planting.

The results, shown in **Table 6**, indicate that the higher NK ratios (treatments 9-12) or higher N ratio (treatments 6, 7 and 9) greatly increased fresh root yields but decreased the starch contents, while the higher K ratio (treatments 3 and 4) reduced the fresh root yield slightly. The lower NK ratio (treatments 8 and 9) or higher K ratio (treatments 3-5) increased the starch content. Starch yield and net income depended mainly on the fresh root yields and were little affected by the starch content. As such, the treatment $N:P_2O_5:K_2O$ = 3-5:1:2-5 resulted in higher fresh root yields, starch yields and net income, but the ratios $N:P_2O_5:K_2O$ = 3-4:1:2-3 would be the best ratio when considering the utilizable efficiency and profit ratio from the use of fertilizers. A moderate rate of NPK fertilizer would ensure a stable root yield and avoid excessive top growth and lodging in case of heavy rain or typhoons.

3. K, Mg and S Fertilizer Trial in Guangxi

A fertilizer trial was conducted on a low K, Mg and S soil in Laibin county of Guangxi province. The experiment had three treatments and four replications in a completely randomized design; each plot had 36 plants, with a spacing of 1.0 x 0.9 m; the variety was Nanzhi 188. The results **(Table 7)** indicate that the application of potassium-magnesium sulfate (PMS) increased the fresh root yield more than that of potassium chloride (KCl) when the same amount of NPK fertilizers were applied. It means that Mg and S fertilizer could increase cassava yields (Wei Jiaxing *et al.*, 1998).

A similar fertilizer trial was conducted on another low K, Mg and S soil in Laibin county. The experiment had five treatments in 1991, four treatments in 1992, and four replications in both years; a complete randomized design, a plot size of 33.3 m^2, variety Nanzhi 188, harvested at seven months after planting. The results **(Table 8)** indicate that application of K and Mg had an important effect on increasing fresh root yields, especially K which more than doubled the yield in 1992 when there was a three month drought period; it means that K fertilizer might have helped to resist drought conditions (Tan Hongwei *et al.*, 1994).

Table 6. Average economic cassava yields and income from the application of different NPK ratios in CATAS, Hainan in 2004 and 2005.

Treatments	N-P_2O_5-K_2O (kg/ha)	NPK ratio	Fresh yield (t/ha)	Starch content (%)	Starch yield (t/ha)	Increase in net income (US$/ha)	Rank
1	0-0-0	0:0:0	14.1dC	26.9aA	3.8bB	0	12
2	60-30-30	2:1:1	20.2abcdABC	26.4aA	5.3abAB	171.0	8
3	60-30-90	2:1:3	19.5abcABC	27.1aA	5.3abAB	118.6	9
4	60-30-120	2:1:4	19.3bcdABC	27.8aA	5.4abAB	99.8	11
5	30-30-60	1:1:2	21.3abcABC	28.3aA	6.0aAB	212.1	7
6	90-30-60	3:1:2	24.8abcAB	26.6aA	6.6aA	315.6	3
7	120-30-60	4:1:2	24.6abcAB	25.3aA	6.2aA	297.0	4
8	30-30-30	1:1:1	18.3cdBC	27.7aA	5.1abAB	111.4	10
9	60-30-60	2:1:2	22.4abcABC	27.9aA	6.2aA	239.1	6
10	90-30-90	3:1:3	25.7abAB	25.6aA	6.6aA	334.6	2
11	120-30-120	4:1:4	24.4abcAB	24.9aA	6.1aA	259.1	5
12	150-30-150	5:1:5	27.3aA	25.5aA	7.0aA	340.0	1

Note: In the NPK ratio trial level 1 equals 30 kg/ha of N, P_2O_5 or K_2O. Net income = income from increased yield– fertilizer cost.

Table 7. Effect of the application of potassium-magnesium sulfate (PMS) on cassava yields in Laibin county of Guangxi province.

Treatments	Fertilizer(kg/ha)	Fresh root yield (t/ha)	% of check
NP (CK)	150 N, 67.5 P_2O_5.	25.4	100
NP + KCl	150 N, 67.5 P_2O_5, 135 K_2O.	31.4	124
NP + PMS	150 N, 67.5 P_2O_5, 135 K_2O, 67.5 Mg, 135 S	34.0	134

Source: *Wi Jiaxing et al., 1998.*

4. Micro-nutrient Fertilizer Trial in Hainan

According to the soil analysis and the nutritional requirements of cassava (Howeler, 2002), the soil Ca, Mg, B, Zn and Cu levels were low or very low in the long-term NPK trial conducted at CATAS; and Cu, Mg and Zn levels tended to be low in many Farmer Participatory Research (FPR) trials in Kongba village of Baisha county of Hainan province **(Table 9)**. For this reason, a Ca, Mg, B, Zn and Cu fertilizer trial was conducted at

CATAS in Danzhou city, as well as in a Farmer Participatory Research trial in Baisha county in 2004. However, application of micro-nutrients didn't have a good effect on increasing root yields. The lack of a response may be due to the fact that the land of the FPR trial was fertile, the use of an inadequate application method, or the variety SC5 has a great capacity to absorb soil micro-nutrients, since SC5 produced higher fresh root yields than other varieties on poor soil. Whatever the reason, we are conducting the micro-nutrient trial again in 2008.

Table 8. Effect of application of K and Mg fertilizers on cassava fresh root yields in Laibin county of Guangxi province in 1991 and 1992.

1991		1992	
Treatments	Fresh root yield (t/ha)	Treatments	Fresh root yield (t/ha)
NP	16.1	NP	8.4
NPK_1	20.9	NPMg	9.5
NPK_1Mg	23.7	NPK_1	17.6
NPK_2	23.7	NPK_1Mg	18.7
NPK_2Mg	27.8		

Note: N is 121 kg N/ha, P is 54 kg P_2O_5/ha, K_1 is 75 kg K_2O/ha, K_2 is 150 kg K_2O/ha, Mg is 40.5 kg MgO/ha. K fertilizer is potassium sulfate.

Source: *Tan Hongwei at al., 1994.*

Table 9. Soil analyses results of Ca, Mg and micronutrients in several cassava trials conducted in Hainan province between 1992 and 2006.

Sample	Samples	Ca (me/100g)	Mg (me/100g)	B (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)	pH
NPK trial in 1992	4 reps	0.65	0.11	0.30	0.52	**20.0**	**0.32**	**18.0**	**4.6**
$N_0P_0K_0$ in 1997	4 reps	0.45	0.15	0.13	0.35	**12.1**	0.15	**19.7**	**4.7**
$N_0P_0K_0$ in 2006	4 reps	0.35	0.09	0.26	0.63	**16.1**	0.11	**15.2**	**4.6**
$N_3P_3K_3$ in 1995	4 reps	0.66	0.10	0.23	0.58	**14.5**	0.18	**15.6**	4.4
$N_3P_3K_3$ in 2002	4 reps	0.74	0.14	**0.50**	0.71	**13.0**	0.12	**13.7**	**5.3**
FPR trial in 1995	6 sites	**1.44**	**0.72**	**0.33**	**1.51**	**52.5**	**0.24**	**15.7**	**4.6**
FPR trial in 1999	7 sites	**1.01**	0.35	**0.62**	**1.14**	**45.8**	**0.26**	**24.6**	**4.8**

Note: Soil samples were analyzed by CIAT. Date in bold face are considered medium; others are low or very low.

The soil analysis results **(Table 9)** indicate that the micro-nutrient levels in the soil decreased or increased by continuous cropping whether fertilizers were applied or not; the reason for this is not clear but may be due to the effect of different fertilizers on soil pH which in turn affects the availability of micro-nutrients in the soil.

5. Bio-organic Fertilizer Trial

Bio-organic fertilizers were applied as basic fertilizers in a trial conducted in Nanning city, Guangxi province in 2004 and 2005. The experiment had five treatments and three replications, a completely randomized design; plot size was 33 m^2, plant spacing was 1.0 x 0.7 m, variety is Fuxuan 01. The results, shown in **Table 10**, indicate that application of bio-organic fertilizers significantly increased the fresh root yield and starch content (Luo Xinglu *et al.*, 2008). Some biological nutrition may be helpful to resolve soil nutritional problems and promote cassava growth.

Table 10. Average economic effect of applying bio-organic fertilizers in Nanning city, Guangxi, in 2004 and 2005.

Bio-organic fertilizer (kg/ha)	$N+P_2O_5+K_2O$ (kg/ha)	Fresh root yield (t/ha)	Starch content (%)	Fertilizer cost (US$/ha)	Net income (US$/ha)	Increase in net income (US$/ha)
0	0	28.6 eE	32.3	0	1,430	0
450	≥27	31.0 dD	32.7	99	1,451	21
600	≥36	45.0 bB	33.2	132	2,118	688
750	≥45	50.0 aA	33.5	165	2,335	905
900	≥54	35.3 cC	31.8	198	1,567	137

Note: Average results of two years. Bio-organic fertilizer has organic matter ≥25%; $N+P_2O_5+K_2O$ ≥6%; amount of living effective bacteria ≥ 20 million/g. Bio-organic fertilizer is 220 US$/t, fresh root was 50 US$/t. Net income = total income – fertilizer cost.

6. Time-of-Fertilizer-Application Trial

A time-of-fertilizer application trial was conducted in Nanning city, Guangxi province in 1997 and 1998. The experiment had four treatments and three replications, and a completely randomized design; each plot had 53 plants, spaced at 0.9 x 0.7 m; the variety was GR891, harvested at 9 months after planting. The results **(Table 11)** indicate that the application of most fertilizers at about one month after planting (MAP) was most effective in increasing fresh root yields and starch contents, while delaying the application to 3-4 MAP reduced the fertilizer response (Luo Xinglu *et al.*, 2000).

Table 11. Effect of different times of fertilizer aplication on cassava yield and root starch content in Nanning city, Guangxi, in 1997 and 1998.

Treatment (% of total fertilizer)	Fresh root yield (t/ha)	Starch content (%)
50% Basic, 25% early, 25% late	33.2bB	32.9
25% Basic, 50% early, 25% late	42.4aA	31.9
25% Basic, 25% early, 50% late	30.2cC	28.2
No fertilizer (CK)	15.4dD	30.6

Note: Date are average values for two years. The total fertilizer was 225 kg N/ha, 90 kg P_2O_5/ha and 300 kg K_2O/ha in each year. Basic fertilizer is applied at time of planting, the early fertilizer when plant height is about 40 cm at about 2 months after planting, and the late application is at 4 months after planting.

Source: *Luo Xinglu et al., 2000.*

7. Variety Plant Density x Fertilizer Trial

A trial on variety, plant density and fertilizer was conducted in Wuming county of Guangxi province in 2000. The experiment had four varieties, four plant densities, four N levels and four K levels, with three replications and an orthogonal design. The results showed that the factors of most importance for obtaining high yields were: variety > plant density > N fertilizer > K fertilizer, and among varieties SC5>SC205>GR911>Nanzhi188. Finally, the recommendation for SC5 is 16,500 plants/ha, 150 kg N/ha and 360 kg K_2O/ha (Tao Hanhong *et al.*, 2001).

8. Maintenance of Soil Fertility

A total of 76 representative soil samples (0-20cm) were collected in seven surveyed towns with the greatest cassava acreage in Wuming county in 2006. Compared to the second soil survey which was conducted all over China in 1983, the results **(Table 12)** indicate that soil pH had decreased to about 5.0; organic matter, available phosphorus and potassium had generally increased compared with those in 1983; alkali-hydrolysis nitrogen was a little lower than before, while the available phosphorus and potassium levels in some regions were very high according to the nutritional requirements of cassava. In four of the seven surveyed towns, the organic matter and alkali-hydrolysis nitrogen had increased 38-204% and 30-68%, respectively (Wei Zhiyuan *et al.*, 2007).

Wuming is nicknamed "cassava county" as it has the largest harvested area, highest average fresh root yield and production, and the most cassava processing factories in China. Local farmers have gradually developed good agricultural practices to maintain soil fertility, including high rates of application of chemical fertilizers and FYM; they also return the cassava stems and branches to the soil every year. Of course, we had to emphasize the importance of a balanced fertilization based on the above information; in many cases

farmers applied excessive levels of fertilizers, resulting in low economic benefit. Certainly, the experience in Wuming county can refute a common myth that cassava extracts more nutrients than other crops and seriously decreases soil fertility. It is clear that soil fertility can be maintained in continuous cassava cropping as long as we pay attention to use a balanced fertilization which returns back to the soil those nutrients that had been removed in the crop harvests and by erosion.

Table 12. Soil analysis of major cassava fields in 1983 and in 2006 in Wuming county of Guangxi province.

Item	Index	1983 (% survey samples)	2006 (% survey samples)
pH	>7.5	11.3	0
	6.5-7.5	47.2	1.3
	<6.5	41.5	98.7
Organic matter (%)	>3.0	22.1	19.0
	2.0-3.0	31.7	60.5
	<2.0	46.2	14.5
Alkali-hydrolysis N (mg/kg)	>150	8.4	0
	120-150	14.4	10.5
	<120	77.2	89.5
Available P (mg/kg)	>10	7.3	100
	5-10	15.7	0
	<5	77.0	0
Available K (mg/kg)	>100	22.8	93.4
	50-100	32.7	6.6
	<50	44.5	0

Note: The soil samples in 2006 were taken nearby the sample sites in 1983.
Source: *Wei Zhiyuan et al., 2007.*

9. Summary of Fertilization Trials

The results of the cassava fertilizer research conducted in China can be summarized as follows: the most important nutrients are $N>K_2O>P_2O_5$, and the most suitable ratio of $N:P_2O_5:K_2O$ =2-4:1:2-4, which is the recommended ratio for continuous planting of cassava. The optimum rate of fertilization per year for medium fertility soils is about 50-100 kg/ha N and K_2O, and 25-50 kg/ha P_2O_5. In addition, Ca, Mg, S, B, Zn and Cu fertilizers can be necessary in some regions according to the local soil analysis. It is suggested to apply potassium-magnesium sulfate (PMS), calcium-magnesium phosphate and bio-organic fertilizer in some years. Most fertilizers should be applied as basic fertilizer or as an early application during the first 1-2 month after planting as long as there is adequate soil moisture.

INTERCROPPING

1. Cassava Intercropping with Peanut

A cassava intercropping trial with peanut was conducted in Nanning city, Guangxi province in 1996 and 1997. The experiment had five treatments and three replications; cassava plant spacing was 1 x 0.8 m, the peanut spacing was 0.2 x 0.15 m, plot size was 40 m^2, varieties SC124 and GR891 (Luo Xinglu, 1998). The results show that intercropping 3-4 rows of peanuts between cassava rows increased peanut yields and income without affecting cassava root yields. Intercropping 3-4 peanut rows increased net income more than 100% compared to that of cassava monoculture **(Table 13)**. Intercropping cassava with peanut also greatly improved soil fertility because of the incorporation of peanut vine residues in the soil **(Table 14)**.

2. Cassava Intercropping with Maize

A demonstration intercropping trial was conducted in Luoding city, Guangdong province in 1998 (Wang Xiaoming *et al.*, 1999), using local varieties of cassava and maize. The results **(Table 15)** showed that cassava intercropping with maize increased total net income. Increasing the maize plant density up to 52,500 maize plants/ha resulted in higher maize yields and did not seriously affect cassava yields.

Table 13. Effect of number of peanut rows intercropped between cassava rows on cassava and peanut yields as well as net income in a cassava intercropping trial conducted in Nanning city, Guangxi in 1996 and 1997. Data are average of two varieties.

Intercropping ratio (cassava row:peanut row)	Cassava fresh roots yield (t/ha)	Peanut dry pod yield (t/ha)	Net income (US$/ha)	Benefit/ cost ratio
cassava monoculture (CK)	28.6	0	712.6	1.24
1 cassava, 1 peanut row	28.9	0.66	1054.0	1.59
1 cassava, 2 peanut rows	28.8	1.25	1329.7	1.77
1 cassava, 3 peanut rows	28.9	1.56	1487.6	1.89
1 cassava, 4 peanut rows	27.8	1.68	1452.8	1.71

Note: Date are average values for two years. Peanut was planted four days after planting cassava. Peanut yield includes the shell. Net income = total income – total costs. Benefit-cost ratio is total income divided by total costs.

Source: *Luo Xinglu, 1998.*

Table 14. Effect of cassava intercropping with peanut on soil fertility parameters in 1997. Data are average of two varieties.

Intercropping ratio (cassava row: peanut row)	OM (%)	N (%)	P (%)	K (%)	Available -N (mg/kg)	Available-P (mg/kg)	Available-K (mg/kg)
cassava monoculture (CK)	1.48	0.13	0.07	0.87	86	64	68
1 cassava, 1 peanut row	1.86	0.15	0.08	0.92	92	72	78
1 cassava, 2 peanut rows	1.93	0.17	0.09	0.96	98	76	81
1 cassava, 3 peanut rows	1.97	0.19	0.10	1.10	102	83	84
1 cassava, 4 peanut rows	2.08	0.19	0.12	1.13	106	83	88

Source: *Luo Xinglu, 1998.*

Table 15. Economic yield and income of cassava intercropping with maize in Luoding city, Guangdong, in 1998.

Maize density (plants/ha)	Fresh root yield (t/ha)	Dry maize yield (t/ha)	Net income (US$/ha)
30,000	19.7	4.6	288.8
37,500	19.9	5.5	466.9
45,000	20.2	6.4	635.6
52,500	18.7	7.0	656.3

Note: Cassava is 15,000 plants/ha, planted at 1 meter row spacing. Cassava and maize were planted on the same day. Net income = total income – total costs.

Source: *Wang Xiaoming et al., 1999.*

3. Intercropping Techniques

Intercropping cassava with watermelon, soybean, red bean etc. in the spring season has become popular in South China (Huang Jie, 2007a). These crops are cold resistant and have a short growth cycle, so they can be planted before planting cassava, especially when both crops are planted on plastic film cover. Cassava is planted one month or slightly more after the intercrops in the northern part of Guangxi and Guangdong provinces, while in Yunnan and Fujian province, the intercrops are planted at the same time as cassava, same as the southern part of Guangxi and Guangdong provinces. This system increases both the economic yield and income from the intercrop and seldom reduces cassava yields. For instance, the income from the water melon was higher than that of cassava when the water melon price was high in Guangxi province in some years. In that case intercropping could double the total income as compared to cassava monoculture.

In addition, planting cassava among young rubber trees, fruit trees, sisal etc. was also successfully developed and popularized in South China (Huang Jie, 2007a). This practice increased cassava income and also benefited the growth of the long-term crop through intensive management, including the return of cassava residues to the soil. At the same time, the income from cassava covers some of the costs during the early growth of the trees.

EROSION CONTROL

Soil erosion is one of the main constraints to increase cassava yields and production in China. So, a lot of international cooperative research on soil conservation in cassava fields has been conducted since 1989 between China and CIAT; this was later financially supported by the Nippon Foundation of Japan from 1994 to 2003. The experiments indicate that zero-tillage, chemical weed control, contour ridging, early planting and fertilization, closer planting and adequate fertilization, intercropping, the use of plastic film cover, vegetative hedgerows etc. are very effective, both for reducing erosion and increasing yields (Huang Jie *et al.*, 2000a, 2003 and 2004b; Li Jun *et al.*, 2000; Tian Yinong *et al.*, 1993; Zhang Weite *et al.*, 1996)

FPR trials on soil erosion control in cassava fields in 1997-2001 showed that vetiver grass hedgerows were the most effective in reducing soil erosion (dry soil loss decreased by 68.3%) and increasing cassava yields (cassava yields increased by 2.7%) as compared to the check plot.. Soil analysis in Da Bulin village, Baisha county, Hainan province **(Table 16)** showed that between two vetiver grass hedgerows, the surface soil in the upper part of the cassava strip was washed out leaving mainly sand and small stones. On the contrary, in the bottom of the strip between two hedgerows the soil remained loose, moist and had accumulated as high as 50 cm, while the soil fertility was higher than in the middle and upper part (Huang Jie *et al.*, 2004).

Table 16. Change in soil fertility characteristics between 1999 and 2003 after planting vetiver grass hedgerows in 1999 in Da Bulin village, Baisha county, Hainan.

Year	Sample site	Sand content (%)	Water content (%)	pH	OM (%)	Total-N (%)	Available-P (mg/kg)	Available-K (mg/kg)
1999	Mixed	-	-	4.9	2.82	0.17	2.9	38.0
2003	Upper	38.3	13.1	3.9	2.83	0.13	3.3	29.2
	Middle	16.3	15.3	3.9	2.78	0.13	2.9	29.2
	Bottom	14.3	16.0	3.8	3.34	0.16	3.8	41.7

Note: Soil samples were taken at 0-20 cm depth and at 5 points within a 1 m strip at the bottom, 4 m in the middle and 7 m in the upper part between contour hedgerows of vetiver grass.

***Source:** Huang Jie et al., 2004.*

WATER MANAGEMENT

CATAS conducted a water management trial by pouring 0.5 kg water/plant (6,250 kg water/ha) at one month after planting cassava in March, 2004 when we had six months of drought. The results **(Table 17)** indicate that water application in the early growth stage greatly increased fresh root yield, the root number per plant, plant height and the diameter of stems; it also increased the root starch content slightly. This application of water increased net income 485 US$/ha, including the cost of the water (Huang Jie, 2005a). Currently, some new cassava planting areas are being developed in some drought-prone sandy coastal areas in Hainan and Guangxi provinces by using irrigation (Huang Jie, 2005a).

Table 17. Effect of applying water to young cassava plants on yield parameters in Danzhou city, Hainan, in 2004.

Treatment	Fresh yield (t/ha)	Starch content (%)	Roots /plant	Harvest index	Plant height (cm)	Stem diameter (cm)
No water	18.1	32.1	7.0	0.64	155.7	2.1
With water	30.3	32.9	9.1	0.61	203.5	2.4

Note: two treatments, five replications, plant spacing is 1.0 x 0.8 m, 50 plants per plot, randomized design.

PLANT GROWTH REGULATORS

A trial on the use of plant growth regulators was conducted in Nanning city, Guangxi, in 1999 and 2000 (Luo Xinglu, 2002). The experiment had five treatments, and three replications; the plot size was 40 m^2, plant spacing 0.9 x 0.7 m, variety SC124, harvested at nine months after planting. The results indicate that plant growth regulators promoted germination, root growth, and the accumulation of starch, which increased fresh root yield. Homobarssinolide was most effective in increasing yield and Ethrel was best for increasing the root starch content **(Table 18)**.

Solutions of four concentrations of paclobutrazol (3 reps, variety Nanzhi188) were sprayed on cassava leaves at different growth stages in Guiping city, Guangxi province. The results showed that paclobutrazol could dwarf the plants and turn the leaves darker green, thereby enhancing the photosynthesis of leaves, nutrient accumulation and root expansion, resulting in an increase in cassava yield and starch content. Most effective was the use of 500 mg/l and 1000 mg/l of 15% paclobutrazol solution sprayed at the early growth stage and during root expansion, respectively; this significantly increased root yield by 26.7% over that of the check (32.9 t/ha) and very significantly increased the starch content 22.4% over the check (31.3%) (Li Yingwen *et al.*, 2008).

Table 18. Effect of plant growth regulators on cassava (SC 124) yield and starch content in 1999 and 2000 in Nanning.

Plant growth regulators	Germination after planting (days)	Roots /plant	Fresh yield (t/ha)	Starch content (%)
Homobrassinolide	8	9.8	61.8aA	29.5
Multi-effect-agent	9	9.6	61.1aA	29.3
Ethrel	11	8.5	55.0bB	31.4
Multi-effect-triazole	11	8.3	54.1bB	30.8
Pure water (CK)	12	7.8	50.7cB	28.6

Note: First, soaking the cassava stems in a diluted solution for 24 hours before planting; second, the solution was sprayed three times at 1, 2 and 3 months after planting. One part of Homobrassinolide was added to 3000 parts of water. Multi-effect-agent, Ethrel and Multi-effect-triazole are 100 mg/kg.
Source: *Luo Xinglu, 2002.*

MECHANIZATION

A cassava stem and residue shredding machine was developed by the Agricultural Extension Station of Nanning city in 2005. It was used to shred 80,000 t of cassava stems or branches, which were returned to 3,333 ha of cassava fields in Wuming county in 2005. According to data from the Guangxi Academy of Agricultural Sciences, one tonne of cassava stems or branches is equivalent of 9.6 kg urea, 7.3 kg KCl and 6.95 kg of calcium-magnesium phosphate (Liang Xinrui, 2007). This machine has now become popular in some regions. Also, special machinery was developed for planting on ridges and for harvest and this has been used in some cassava plantations in Hainan and Guangxi provinces (Huang Jie, 2007a).

PRESENT SITUATION

In China, research on cassava fertilization and erosion control has been rather successful and this technology has spread out in major cassava production areas; intercropping and the use of plastic film to cover the soil was successfully developed and adopted large-scale by local technicians and farmers, but little research has been conducted on this practice in Guangxi and Guangdong provinces. Some chemical weed control practices, mechanization, drought and typhoon resistance were introduced to farmers, but without adequate research results (Huang Jie *et al.*, 2005b, 2007a and 2007b). Other practices on rapid propagation, optimum planting and harvesting periods etc were developed in recent years; for example, SC 5 was disseminated in Hainan province through rapid propagation by using younger cuttings (Huang Jie *et al.*, 2005c and 2008a). Moreover, the conducting of agronomic research in cassava growing regions were discussed and established by the Chinese government (Huang Jie *et al.*, 2006 and 2008b).

FUTURE STRATEGIES

In the future more attention will be paid to research on the basic mechanisms of physiology and ecology to obtain high yield, high starch content, as well as on intercropping, water management, mechanization, resistance to drought, typhoon and cold etc. The objective will be to spread some improved technologies which not only increase fresh root yields and starch contents, but also the resistance to different adverse conditions in new developing areas; this will be helpful in promoting cassava industrialization in China.

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DOES CASSAVA CULTIVATION DEGRADE OR IMPROVE THE SOIL?

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is generally perceived as a crop that degrades the soil, both by excessive nutrient absorption and by causing serious soil erosion. A plausible reason for this perception is that cassava is oftentimes found growing on very poor and eroded soils where most other crops would not be able to grow. The question remains whether cassava has caused the degradation or is merely the consequence of that degradation, which was either caused by previous crops or due to the inherent physical and chemical limitations of the soil.

It is well-known that cassava grows well and is often the preferred crop on light-textured soils, which tend to be of low fertility, as the crop is particularly drought tolerant and has a low nutrient requirement, while a sandy soil also facilitates the root harvest. Compared with other crops, cassava is also very tolerant of low soil pH and a high Al-saturation. Thus, cassava can still grow well at a soil pH of 3.8-4.2 and tolerates an Al-saturation as high as 80-85%; under these conditions most other crops would perish. When grown in natural soils, cassava is also extremely tolerant of low soil-P, having a critical level for available soil-P (Bray II extract) of only 4-5 ppm as compared to 15-20 ppm for crops like maize, rice, beans etc. This tolerance of low soil-P is due to a highly effective association with vesicular-arbuscular mycorrhiza (VAM). These fungi occur naturally in practically all soils, but their spore population may be low in the absence of mycorrizal-dependent crops like cassava. Thus, cassava has an exceptional ability to grow on very acid low-fertility soils where it can still produce something while other crops might die. However, under those conditions, cassava will still be very responsive to fertilizer inputs, especially of K and N. Many long-term fertility trials – some continued for more than 30 years – have shown that while the crop may initially respond markedly to applications of P, in the long run the limiting nutrient almost invariably is K, followed by N. Nutrient removal from the field in the harvested product (roots) also tends to be much less for cassava as compared to other crops, with the possible exception of K, as much of the absorbed K is translocated to the swollen roots and is thus removed in the root harvest.

Cassava may, however, seriously degrade the soil if it is grown on slopes, as the crop tends to cause more soil loss by erosion than most other crops. This is due to the wide spacing used and the slow initial growth of the crop, which results in a slow formation of the crop canopy. On sandy soils with low levels of organic matter, cassava cultivation can result in serious gully and sheet erosion even on very gentle slopes. However, many simple and very effective soil erosion control measures are available to reduce this problem to a minimum. Thus, when well-managed, cassava does not degrade soils any more than other annual food crops, and in the absence of disease and pest problems, cassava can continue to produce high yields for many years with only small to medium levels of fertilizer inputs, mainly K and N.

In most countries in Africa, food crops are grown without application of chemical fertilizer or manure. Soil fertility is generally maintained by crop rotations and by leaving parts of the land in bush fallow to recuperate soil fertility. With increasing population pressure, fallow periods are being reduced resulting in decreasing soil fertility. Cassava production in Africa has tripled over the past four decades, partly because cassava will tolerate low soil fertility better than most other crops, and partly because cassava is considered by many farmers as an "imitation fallow" which helps to improve soil fertility. In an experiment in Ghana without N fertilizer application, maize yields were higher when maize followed cassava, rather than a mucuna-maize-mucuna rotation, and considerably higher than when maize followed pigeon pea, cowpea or a previous maize crop. This was attributed to the large amount of N released during the decomposition of the cassava biomass

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returned to the soil, the likely increased mycorrhizal population after the cassava crop which would enhance P uptake by maize, and the lower weed population in the maize grown after cassava. Thus, cassava has certain intrinsic characteristics that makes the crop capable of either degrading or improving the soil; this depends first and foremost on the existing natural conditions as well as on the management of the crop.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) has the reputation to cause serious soil degradation due to excessive uptake of nutrients leading to soil nutrient depletion, or by causing serious soil erosion when grown on slopes. Is this perception correct and based on any scientific evidence? Or is it based on the simple observation that cassava is oftentimes grown on degraded soils, and mainly by poor farmers trying to make a living on the poorest of soils? Thus, the question is whether the planting of cassava is the cause or the consequence of soil degradation.

This paper examines whether cassava does indeed extracts and removes more nutrients from the soil than other crops, and whether or not the planting of cassava on slopes causes more soil erosion than other crops. It also describes some of the reasons why cassava can grow on poor and degraded soils where other crops would not survive, and considers how better management of the crop can reduce nutrient depletion and soil erosion.

Evidence of Soil Degradation

Besides the simple observation that cassava is often grown on degraded soil, there is also good scientific evidence that continued cassava cultivation can have a detrimental effect on the soil's chemical and physical characteristics. **Table 1** shows the effect of land use for different crops on the fertility status of Haplic Acrisols in southern Vietnam. Comparing the long-term effect of forest, rubber, cashew, sugarcane and cassava on the soil's chemical and physical properties, Cong Doan Sat and Deturck (1998) reported that long-term cassava cultivation caused the most serious reduction in the organic C and total N content of the soil, as well as that of the CEC and K and Mg status; however, cassava had increased the levels of available P as compared to forest or cashew, presumably due to some P-fertilizer application. Cassava also caused the soils to have a low clay content, low aggregate stability and a low volumetric water content and infiltration rate. However, the evidence that cassava "caused" these negative changes is not conclusive, because heavier and more fertile soils with greater aggregate stability are generally used for higher value crops like rubber, cashew and sugarcane. Moreover, cassava, an annual crop, is compared mostly with perennial tree crops and sugarcane; the latter generally receives much higher fertilizer rates than cassava and may be ratooned for two or more years before the soil needs to be prepared again. Cassava should have been compared with other annual crops as it is mainly the need for frequent soil preparation that causes the marked reduction in organic matter (OM) content.

Other "evidence" that cassava cultivation causes soil degradation is shown in **Figure 1**, which indicates that continued cassava cultivation over 30 years without fertilizer application resulted in ever lower cassava yields in three soil series in Thailand. However, similar or worse yield declines could be expected if other annual food crops were grown without fertilizers, due to the inevitable nutrient depletion by removal of harvested

products. An example of this is shown in **Figure 2** which indicates that continuous cropping of upland rice without fertilizers in Vietnam resulted in zero yield in the fourth crop cycle, while cassava still produced about 40% of its first year yield after four years of cropping at the same site (Nguyen Tu Siem, 1992),

Table 1. Chemical properties of various horizons of Haplic Acrisols that had been under different land use for many years in southeastern Vietnam.

	Forest	Rubber	Cashew	Sugarcane	Cassava	CV (%)
Organic C (%)	1.032 a	0.839 ab	0.579 ab	0.796 ab	0.496 b	44.7
Total N (%)	0.058 a	0.054 ab	0.032 bc	0.040 abc	0.022 c	36.7
Available P (Bray II) (ppm)						
-1st horizon	5.21 b	20.90 a	4.85 b	20.68 a	15.33 ab	37.5
-2nd horizon	2.48 b	7.03 a	3.19 b	7.92 a	5.31 ab	32.6
-3rd horizon	1.57 b	2.83 ab	1.08 ab	3.82 a	3.82 a	44.6
CEC (me/100 g)	3.43 a	2.94 a	2.39 ab	3.24 a	1.53 b	27.1
Exch. K (me/100 g)						
-1st horizon	0.132 a	0.127 a	0.070 ab	0.051 b	0.060 b	66.3
-2nd horizon	0.073 a	0.046 ab	0.031 ab	0.022 b	0.021 b	75.1
Exch. Mg (me/100 g)	0.145 a	0.157 a	0.046 ab	0.055 ab	0.036 b	89.1

Values are average of 6-10 profiles per cropping system. Within rows data followed by the same letter are not significantly different at 5% level by Tukey's Studentized Range Test.
Source: *Cong Doan Sat and Pol Deturck, 1998.*

Nutrient Extraction by Cassava as Compared to That of Other Crops.

Since cassava root yields are often an order of magnitude higher than those of the cereals and grain legumes, many people assume that cassava roots must extract and remove a large amount of nutrients. However, cassava roots contain about 60-70% water and the rest is mostly starch and some fiber, but with very little N (2-3% protein) and other plant nutrients. **Table 2** shows the yields and nutrient contents in the harvested products of cassava and several other crops as reported in the literature. In spite of a high yield of cassava, the removal of N and P is lower than for most other crops, while that of K is higher than most other crops but similar to tobacco, sugarcane and sweet potato. The table also shows that per tonne of dry matter (DM) produced cassava removes in the root harvest much less N and P, and less K than most other crops.

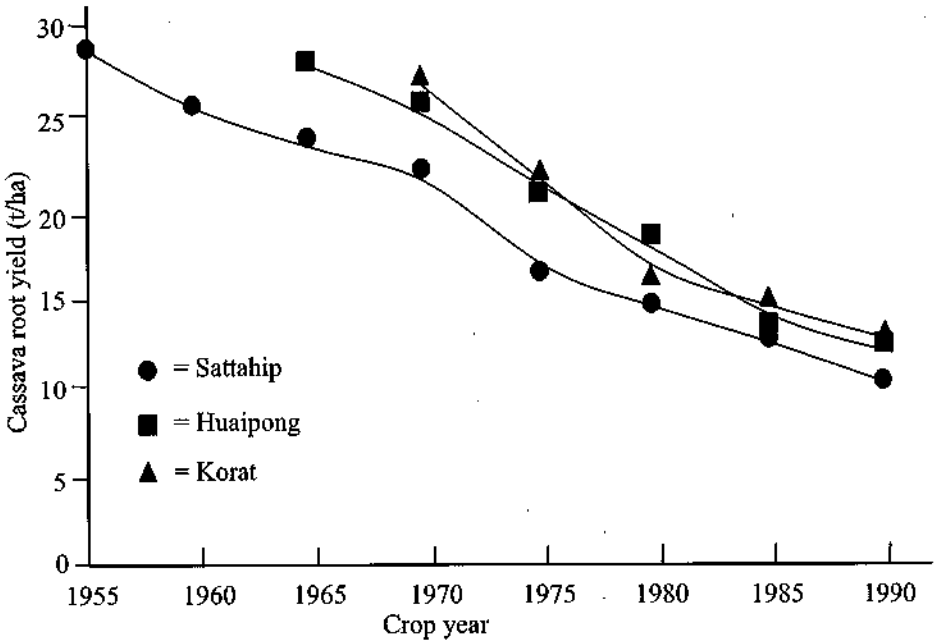

Figure 1. Decline in fresh root yields due to continuous cultivation without fertilizers in three soil series in Thailand.
***Source:** Sittibusaya, 1993.*

Table 2. Average nutrient removal in the harvested products of cassava and various other crops, expressed in both kg/ha and kg/t DM produced, as reported in the literature.

	Yield (t/ha)		(kg/ha)			(kg/t DM produced)		
Crop/plant part	fresh	dry[1)]	N	P	K	N	P	K
Cassava/fresh roots	35.7	13.53	55	13.2	112	4.5	0.83	6.6
Sweet potato/fresh roots	25.2	5.05	61	13.3	97	12.0	2.63	19.2
Maize/dry grain	6.5	5.56	96	17.4	26	17.3	3.13	4.7
Rice/dry grain	4.6	3.97	60	7.5	13	17.1	2.40	4.1
Wheat/dry grain	2.7	2.32	56	12.0	13	24.1	5.17	5.6
Sorghum/dry grain	3.6	3.10	134	29.0	29	43.3	9.40	9.4
Beans[2)]/dry grain	1.1	0.94	37	3.6	22	39.6	3.83	23.4
Soya/dry grain	1.0	0.86	60	15.3	67	69.8	17.79	77.9
Groundnut/dry pod	1.5	1.29	105	6.5	35	81.4	5.04	27.1
Sugarcane/fresh cane	75.2	19.55	43	20.2	96	2.3	0.91	4.4
Tobacco/dry leaves	2.5	2.10	52	6.1	105	24.8	2.90	50.0

[1)]Assuming cassava to have 38% DM, grain 86%, sweet potato 20%, sugarcane 26%, dry tobacco leaves 84%.
***Source:** Howeler, 1991a.*

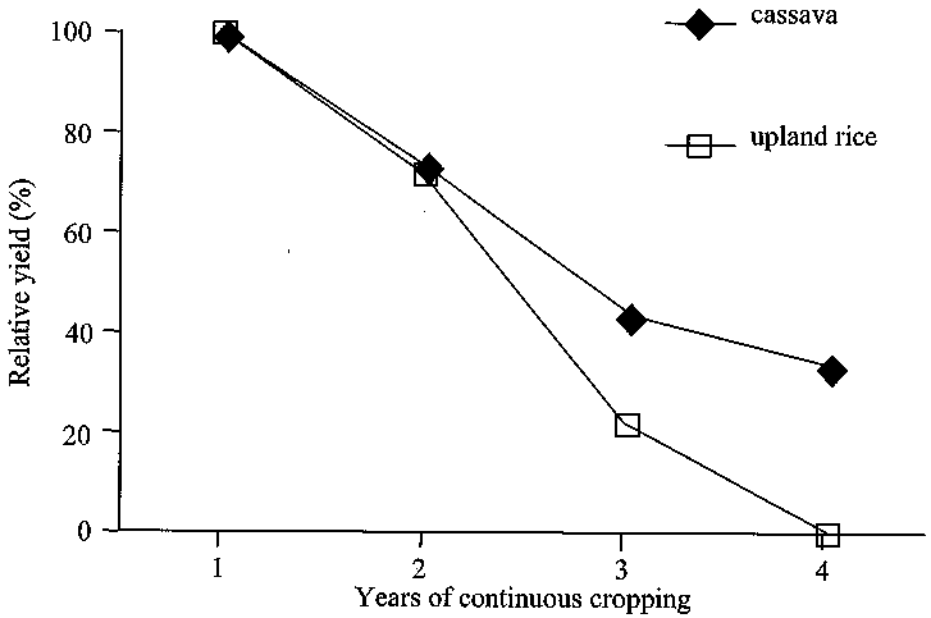

Figure 2. Yield reduction of upland rice and cassava due to fertility decline as a result of continuous cropping without fertilizer application. 100% corresponds to 18.9 t/ha of fresh cassava roots and 2.55 t/ha of rice.
Source: *adapted from Nguyen Tu Siem, 1992.*

Table 3. Dry matter and nutrient distribution in 12-month-old cassava cv. M Ven 77, grown with and without fertilization in Carimagua, Colombia.

	DM (t/ha)	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		(kg/ha)										
Unfertilized												
-Top	5.11	69.1	7.4	33.6	37.4	16.2	8.2	0.07	0.03	0.45	0.33	0.26
-Roots	10.75	30.3	7.5	54.9	5.4	6.5	3.3	0.08	0.02	0.38	0.02	0.10
-Fallen leaves	1.55	23.7	1.5	4.0	24.7	4.0	2.5	0.04	0.01	-	0.37	0.18
Total	**17.41**	**123.1**	**16.4**	**92.5**	**67.5**	**26.7**	**14.0**	**0.19**	**0.06**	-	**0.72**	**0.54**
Fertilized												
-Tops	6.91	99.9	11.7	74.3	55.0	15.3	9.6	0.08	0.03	0.78	0.57	0.30
-Roots	13.97	67.3	16.8	102.1	15.5	8.4	7.0	0.07	0.03	0.90	0.06	0.17
-Fallen leaves	1.86	30.5	2.0	7.1	31.9	4.7	2.6	0.05	0.02	-	0.46	0.19
Total	**22.74**	**197.7**	**30.5**	**183.5**	**102.4**	**28.4**	**19.3**	**0.20**	**0.08**	-	**1.09**	**0.66**

Source: *Howeler, 1985a.*

Table 3 shows that at time of harvest, most DM (about 60%) is in the roots, but most N, P, Ca, Mg, S and micronutrients are in the leaves and stem, which are generally returned to the soil. Only in case of K the removal in roots is higher than that returned in tops and fallen leaves, i.e. about 60 and 40%, respectively. Naturally, when all plant residues are removed from the field for feeding animals or are used as fuel in the kitchen, the removal of nutrients increases substantially, especially that of N as well as Ca and Mg, which are concentrated in the leaves and stems, respectively (Howeler. 1985a).

Table 4 shows the DM production, nutrient uptake and removal of seven crops grown for 22 months in the same experiment in Sri Racha, Thailand. In case of cassava for root production, the total nutrient uptake per ha was similar to that of maize, sorghum, peanut, mungbean and pineapple, but the removal of N, P and Mg in the harvested roots was lower than in the harvested products of any other crop, while the removal of K and Ca was similar to that of other crops but much lower than pineapple (Putthacharoen *et al.*,1998). However, when cassava was grown for forage production, with frequent cutting and removal of whole tops, the nutrient removal was higher than that of any other crop. This management system is highly productive, but also requires large inputs of chemical fertilizers to prevent soil nutrient depletion (Martwanna *et al.*, 2009).

As cassava root yields increase due to fertilization (**Table 3**) or more favorable growing conditions, the nutrient removal in both roots and in the total biomass also increases (**Table 5**). Based on the data set of the 15 sources in **Table 5** that also show the DM yields, the average nutrient removal in an "average" root yield of 28.9 t/ha is about 67.1 kg N, 11.2 kg P and 88.1 kg K/ha, while that by the whole plant would be 179.5 kg N, 22.7 kg P and 156.1 kg K/ha (**Table 6**). This table also shows the average nutrient removal per tonne of fresh and dry roots. However, when the reported N, P and K removal data are plotted against fresh root yields, we see that this is not a linear relationship (**Figure 3**). As yields increase, due to better growing conditions, the nutrient concentrations in the plant tissues also tend to increase, resulting in a curvilinear relationship between nutrient removal and yield. Thus, at an "normal" yield of 15 t/ha the nutrient removal in the roots is only about 30 kg N, 3.5 kg P and 20 kg K/ha rather than 34.8 kg N, 5.85 kg P and 45.75 kg K as predicted from the average values shown in **Table 6**. Thus, at the relatively low yields that farmers usually obtain, the nutrient removal in the harvested roots is actually quite low, especially of P, as long as crop residues are returned to the soil. However, in order to maintain or increase their yields, farmers may have to apply chemical fertilizers or manures, or they may plant green manures, depending on the native fertility of the soil.

Table 4. Total dry matter (DM) production and nutrient uptake (A), nutrients removed (B) and DM and nutrients returned to the soil (C) of seven crops grown during 22 months in Sri Racha Research Station, Sri Racha, Thailand, from 1989 to 1991.

Crop	DM	N	P	K	Ca	Mg
A. Total dry matter produced and nutrient uptake (kg/ha)						
Cassava for roots	14,920	284	39	192	167	42
Cassava for forage	17,186	380	47	256	186	67
Maize	21,538	219	57	357	40	39
Sorghum	22,222	225	52	355	61	46
Peanut	13,489	347	31	236	93	36
Mungbean	5,990	171	21	128	60	25
Pineapple	26,761	243	46	465	136	43
F-test	**	**	**	**	**	**
CV (%)	12.24	11.21	19.10	14.69	15.66	12.20
LSD (P<0.01)	5.081	72.5	19.4	100.6	39.4	11.9
B. Dry matter and nutrient removal from the field in the harvested products (kg/ha)						
Cassava for roots	5,185	48	7	60	14	6
Cassava for forage	15,695	363	43	240	162	62
Maize	8,782	118	44	87	6	11
Sorghum	5,097	79	25	51	10	9
Peanut	4,899	213	19	53	6	8
Mungbean	2,878	117	15	62	9	11
Pineapple	7,582	83	15	190	51	19
C. Dry matter and nutrients returned to the soil in the non-harvested products (kg/ha)						
Cassava for roots	9,735	236	46	132	154	35
Cassava for forage	1,491	17	4	16	24	5
Maize	12,756	101	13	269	34	28
Sorghum	17,125	147	27	304	51	37
Peanut	8,590	133	12	183	87	28
Mungbean	3,112	54	7	66	51	14
Pineapple	19,179	160	31	176	85	24

Source: *Putthacharoen et al., 1998.*

Table 5. Fresh and dry yield, as well as nutrient content in cassava roots and in the whole plant at time of harvest, as reported in the literature.

	Yield (t/ha)		Nutrient content (kg/ha)					
Plant part	fresh	dry	N	P	K	Ca	Mg	Source/cultivar
Roots	6.0	1.52	18	2.2	15	5	2	Putthacharoen *et al.*, 1998
Whole plant	-	4.37	91	12.2	55	46	15	1989/90 Rayong 1
Roots	8.7	2.68	13	0.9	4	3	2	Sittibusaya (unpublished)
Whole plant	-	4.23	39	3.2	10	21	8	unfertilized Rayong 1
Roots	~9.0	3.24	37	1.5	23	4	2	Paula *et al.*, 1983
Whole plant	-	6.54	93	4.0	40	30	9	unfertilized Branca St. Cat.
Roots	~15.9	5.58	66	2.7	17	8	5	Paula et al., 1983
Whole plant	-	10.62	197	8.1	61	100	20	unfertilized Riqueza
Roots	16.1	3.64	30	4.7	45	9	5	Putthacharoen et al., 1998
Whole plant	-	10.55	193	27.0	137	122	27	1990/91 Rayong 1
Roots	18.3	5.52	32	3.6	35	5	4	Sittibusaya (unpublished)
Whole plant	-	9.01	95	9.9	65	37	15	fertilized Rayong 1
Roots	21.0	-	21	9.2	44	8	10	Kanapathy, 1974
Whole plant	-	-	86	37.2	135	45	34	Malaysia, peat soil
Roots	26.0	10.75	30	8.0	55	5	7	Howeler, 1985a
Whole plant	-	17.41	123	16.0	92	67	27	unfertilized MVen 77
Roots	26.6	12.81	91	11.3	47	5	6	Cadavid, 1988
Whole plant	-	19.10	167	19.1	76	32	19	unfertilized CM523-7
Roots	~28.5	10.28	100	8.7	107	15	13	Paula et al., 1983
Whole plant	-	19.56	353	24.8	174	133	37	fertilized Riqueza
Roots	31.0	-	31	18.9	47	-	-	Sittibusaya and
Whole plant	-	-	73	31.9	72	-	-	Kurmarohita, 1978
Roots	32.3	15.39	127	19.1	71	6	5	Cadavid, 1988
Whole plant	-	25.04	243	34.4	147	56	25	fertilized CM523-7
Roots	~36.0	12.60	161	10.0	53	16	12	Paula et al., 1983
Whole plant	-	20.92	330	20.5	100	88	30	fertilized Branca St. Cat.
Roots	37.5	13.97	67	17.0	102	16	8	Howeler, 1985b
Whole plant	-	22.74	198	31.0	184	102	28	unfertilized MCol 22
Roots	45.0	-	62	10.0	164	12	22	Amarisisi and Pereira, 1975
Whole plant	-	-	202	32.0	286	131	108	Sri Lanka

Table 5. (continued)

Plant part	Yield (t/ha) fresh	dry	Nutrient content (kg/ha) N	P	K	Ca	Mg	Source/cultivar
Roots	50.0	-	153	17.0	185	25	6	Cours, 1953
Whole plant	-	-	253	28.0	250	42	29	Madagascar
Roots	52.7	25.21	38	27.9	268	34	19	Nijholt, 1935
Whole plant	111.1	44.65	132	48.5	476	161	52	cv. Manggi
Roots	59.0	21.67	152	22.0	163	20	11	Howeler and Cadavid, 1983
Whole plant	-	30.08	315	37.0	238	77	32	fertilized MCol 22
Roots	64.7	26.59	45	28.2	317	51	18	Nijholt, 1935
Whole plant	110.6	39.99	124	45.3	487	155	43	cv. Sao Pedro Preto
Roots	**30.8**	**-**	**67.0**	**11.7**	**92.7**	**-**	**-**	**Average 19 sources**
Whole plant	**-**	**-**	**174.0**	**24.7**	**162.4**	**-**	**-**	

Source: *Howeler, 2001.*

Table 6. Average fresh and dry root yield, as well as the amount of nutrients removed when cassava roots or the whole plant are harvested, based on data from the literature[1)].

Plant part	Yield (t/ha) fresh	dry	Nutrient removal N	P	K	Ca	Mg
			kg/ha				
Roots	28.87	11.43	67.1	11.2	88.1	13.5	7.9
Whole plant		18.99	179.5	22.7	156.1	81.8	25.8
			kg/t fresh roots				
Roots	28.87	11.43	2.32	0.39	3.05	0.47	0.27
Whole plant		18.99	6.22	0.79	5.41	2.83	0.89
			kg/t dry roots				
Roots	28.87	11.43	5.87	0.98	7.71	1.18	0.69
Whole plant		18.99	15.70	1.99	13.66	7.16	2.26

[1)] Data are average of 15 data sets which have yields reported in dry weight in Table 4.
Source: *Howeler et al., 2001b.*

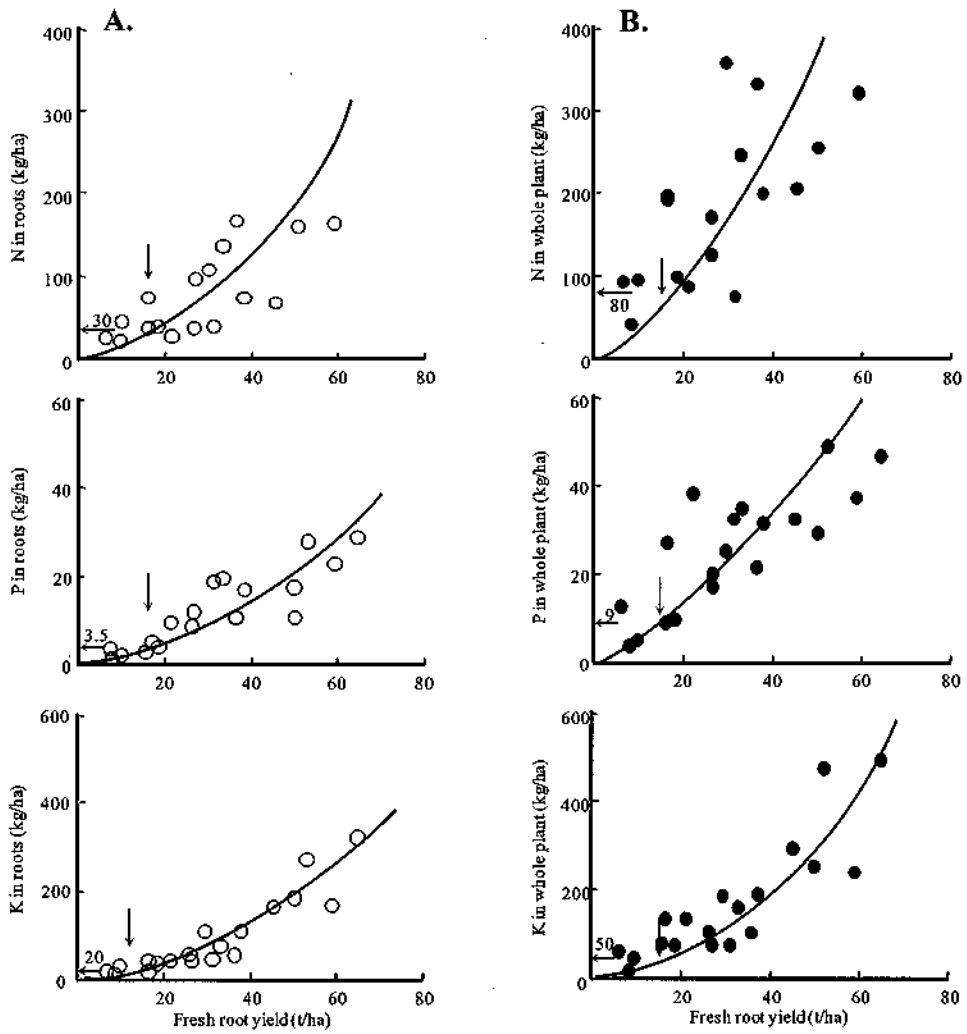

Figure 3. Relation between the amounts of N, P and K in cassava roots (A) or in the whole plant (B) and the fresh root yield, as reported by various sources in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t/ha. ***Source:*** *Howeler, 2004; Howeler et al., 2001a.*

The Ability of Cassava to Grow on Infertile and Degraded Soils

Cassava is an ideal crop for poor farmers living in isolated areas with poor soils as it will tolerate better than most other crops unfavorable soil and climatic conditions, in particular acid infertile soils and low or unpredictable rainfall.

1. Tolerance to soil acidity

It is well-known that cassava is very tolerant of low soil pH and high levels of exchangeable Al; the latter is usually expressed as percent Al saturation, i.e. the exchangeable Al content divided by the exchangeable Al + Ca + Mg + K, all expressed in me/100 g.

Figure 4 shows that in flowing nutrient solution, cassava and ginger were more tolerant than tomato, wheat and maize to very low pH, producing whole plant yields of 40-44% of maximum at a pH as low as 3.2. The reason for this tolerance is not well-known but may have to do with the thick but sparse fibrous roots of cassava as compared to those of other crops. Also, when grown in soil, cassava roots become invariably infected with VA-mycorrhizal fungi, which occur naturally in practically all soils, but with different mycorrhizal strains and with different spore populations.

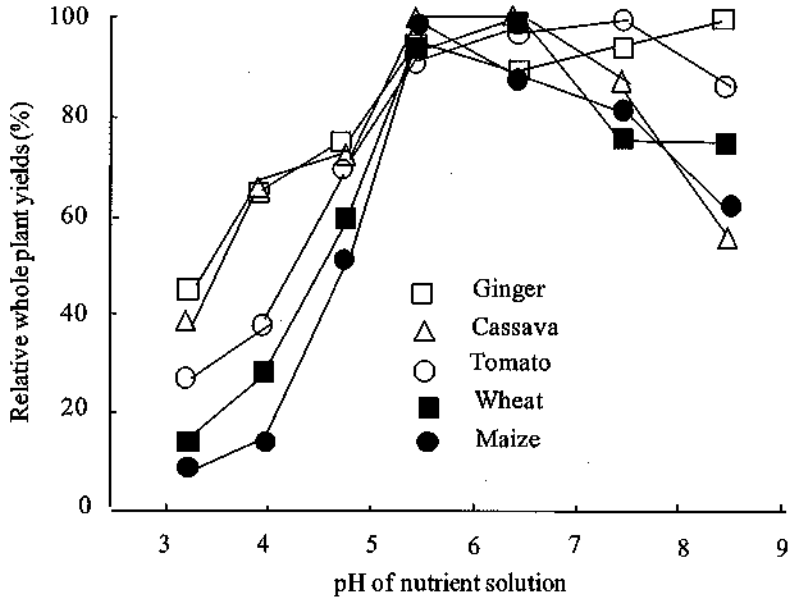

Figure 4. Relative growth response of various plant species to a series of constant pH values in flowing nutrient solution.
***Source:** Islam et al., 1980.*

Figure 5 shows that some VAM strains such as C-10 (*Entrophospora colombiana*) are particularly well adapted to low pH, allowing good cassava growth even at a pH of 3.7.

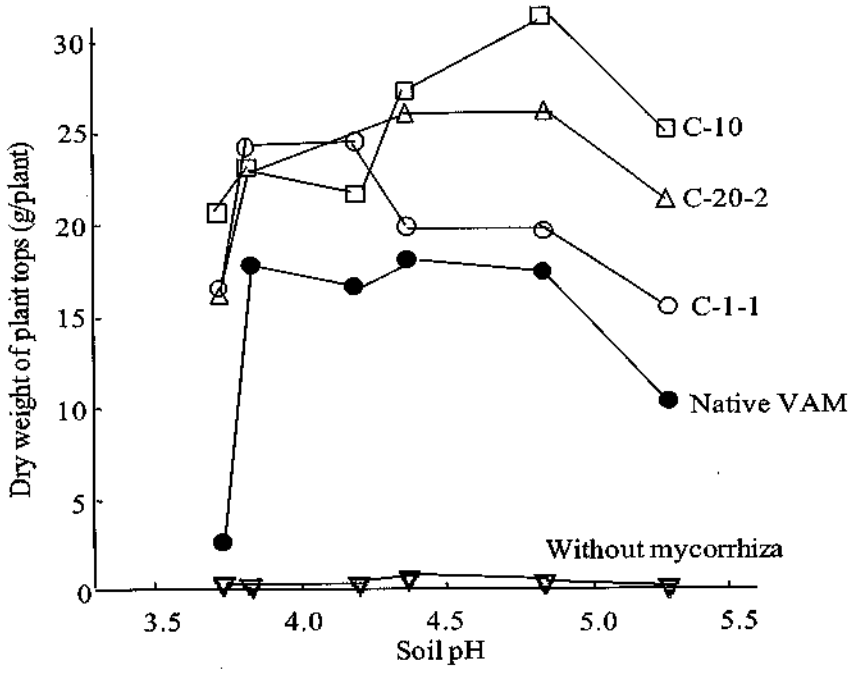

Figure 5. Effect of soil pH on DM production of 2½ month old cassava M Ven 77, grown without inoculation in unsterilized soil (with native VAM), and without inoculation or inoculated with three mycorrhizal strains in sterilized Quilichao soil in the greenhouse.
***Source:** CIAT, 1985.*

In mineral soils a low pH is usually associated with high levels of Al and/or Mn, which can both be toxic at high concentrations, although Al-toxicity is much more common than Mn-toxicity. Lime application to a mineral soil will simultaneously increase pH, reduce the exchangeable Al and increase the exchangeable Ca as well as Mg if a dolomitic lime is used. This will reduce the Al-saturation of the soil. Usually, at pH>5.5 the Al-saturation is zero and Al-toxicity is not a problem. But at pH<5.5 the Al-saturation increases with decreasing pH. Crops differ in their tolerance to high levels of Al, with cotton and some grain legumes being seriously affected by even low levels of Al-saturation of 10-20%, while coffee and cassava will tolerate up to 60 and 80% Al-saturation, respectively (**Table 7**). Within each species there are also varietal differences in tolerance to high levels of Al, and through greenhouse or field screening varieties can be identified with particularly good tolerance to high levels of Al (Howeler, 1991b; Howeler and Cadavid, 1976). **Figure 6** shows that in a field screening of a large number of varieties of five food crops in very acid soils with four levels of lime application, cassava and cowpea were most Al-tolerant, followed by rice, black beans, maize and non-black beans. Without lime this soil had a pH of 4.3 and 85% Al-saturation. The exchangeable Al content decreased from 3.5 to 0.9 me/100 g with the application of 6 t/ha of lime, resulting in an Al-saturation of only 20% (**Figure 7**).

Table 7. Critical levels of nutrients in soil for cassava and some other crops as reported in the literature.

Soil parameter	Crop	Critical level[1)]	Source
pH (1:1 in water)	Cassava	4.6 and 7.8	CIAT, 1977, 1979
	Common beans[2)]	4.9	Abruña *et al*, 1974
Al (% saturation)[3)]	Cassava	80	CIAT, 1979; Howeler, 1980
	Coffee	60	Abruña *et al*, 1964,1965,1975
	Rice	40	Salinas and Sanchez, 1977
	Maize	30-45	Salinas and Sanchez, 1977
	Sorghum	20	Abruña *et al*, 1964,1965,1975
	Soybean	20	Abruña *et al*, 1964,1965,1975
	Common beans	10-3	Abruña *et al*, 1974; Howeler, 1991b
	Cotton	10	Abruña *et al*, 1964,1965,1975
P (µg/g in Bray I)	Cassava	3-8	Howeler, 1978, 1989
	Maize	14	Kang *et al*, 1980
	Soybean	15	Kang *et al*, 1980
P (µg/g in Bray II)	Cassava	4-6	Howeler, 1985a
	Common beans	10-15	Howeler and Medina, 1978
K (me/100 g in NH_4-acetate)	Cassava	0.10-0.18	Howeler, 1985b, 1989
	Rice	0.21	Jones *et al*., 1982
	Potatoes	0.20-1.0	Roberts and McDole, 1985
	Sugarcane	0.16-0.51	Orlando Filho, 1985
Ca (me/100 g in NH_4-acetate)	Cassava	0.25	CIAT, 1979
	Common beans	4.5	Howeler and Medina, 1978
Mg (me/100 g in NH_4-acetate)	Cassava	0.20	Kang, 1984

[1)] The critical level is usually defined as the level corresponding to 95% of maximum yield.
[2)] *Phaseolus vulgaris*
[3)] Al saturation = $\frac{\text{Exchangeable Al}}{\text{Exch. Al + Ca + Mg + K}}$ x 100% where Al, Ca, Mg and K are all expressed in me/100 g of soil

Source: *Howeler, 1991b, 2001.*

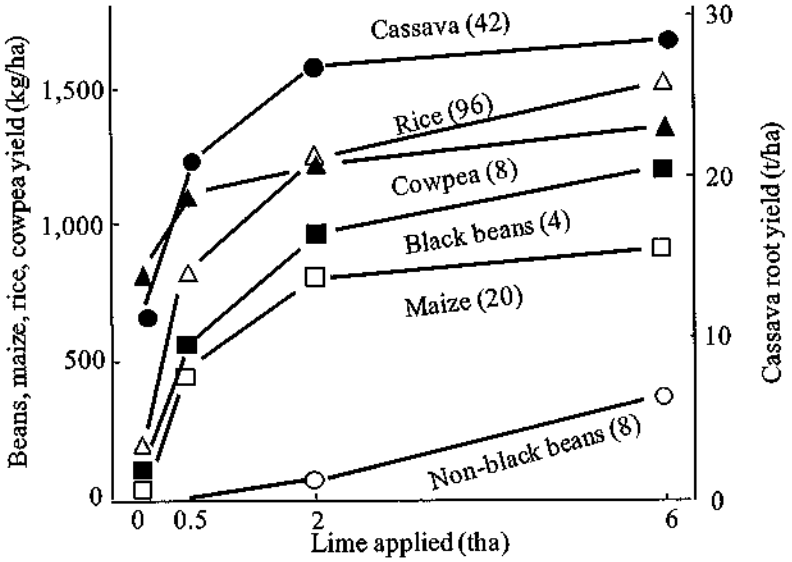

Figure 6. The response of cassava, rice, cowpea, beans and maize to the application of lime in Carimagua. The number of cultivars or lines screeneed is shown in parenthesis.
Source; *Howeler, 1991b.*

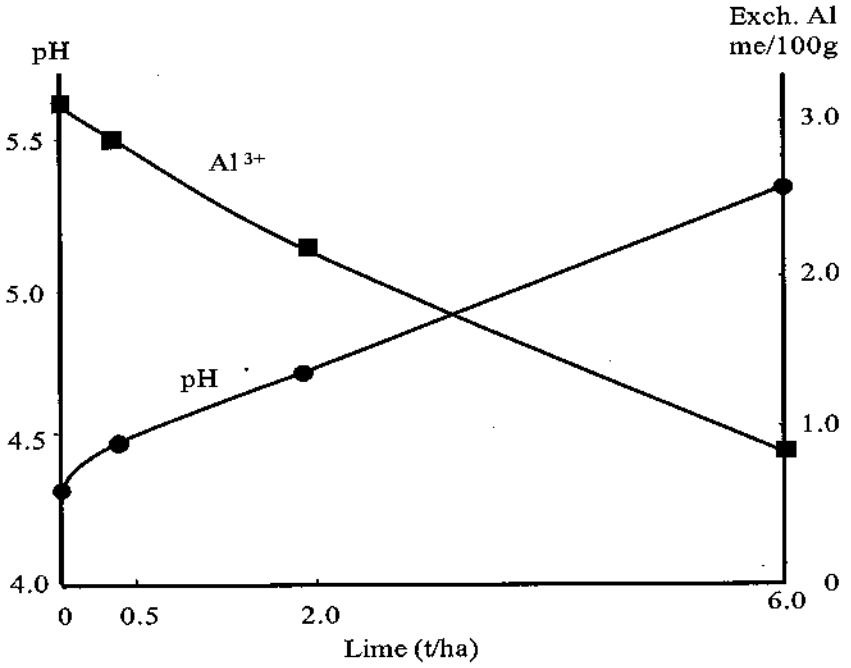

Figure 7. The effect of lime application on the pH and exchangeable Al in a Carimagua Oxisol.
Source: *Spain et al., 1975.*

Another illustration of these differences is shown in **Figure 8**. In a long-term NPK trial conducted for 16 years in Tamanbogo, Lampung, Indonesia, cassava was intercropped with maize and rice in 12 treatments of different levels of N, P and K applied annually in the same plots.

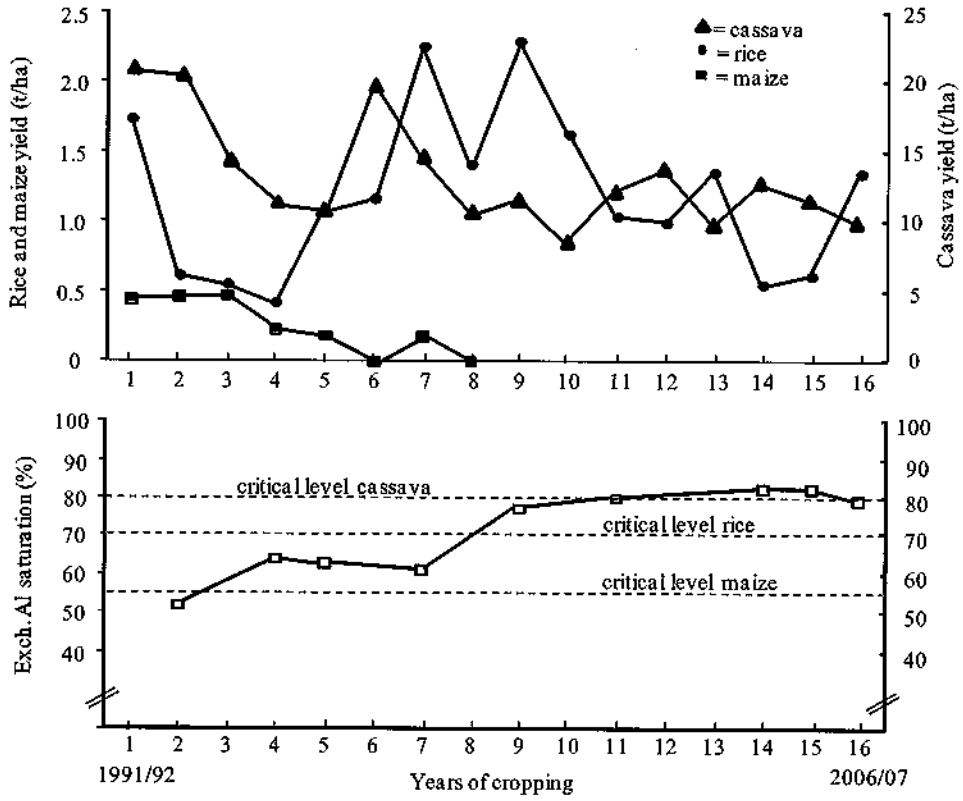

Figure 8. Change in the yields of cassava and intercropped maize and rice during 16 consecutive years of growing cassava, Adira 4, with intercropped rice and maize. Data are average values of 12 NPK treatments in a long-term NPK trial conducted in Tamanbogo, East Lampung, Lampung, Indonesia from 1991 to 2007.
Below: The change in the average percent Al-saturation of the soil and the estimated critical levels for Al-toxity of the three crops.
Note: 2 t/ha of lime were applied in Rep III before the 15th crop cycle and another 2 t/ha in Reps I and III before the 16th crop cycle.
***Source:** Howeler, 2007.*

Over the course of the years, the annual application of fertilizers, especially with high rates of N, resulted in a gradual acidification of the soil with a simultaneous increase in Al-saturation, from 51% in 1992 to 82% in 2004. Intercropped maize yields were low from the start, but decreased to zero as the Al-saturation reached about 65% in the 6th year; intercropped rice yields started to decline drastically when the Al saturation reached about 78% in the 10th year, while the cassava yields remained relatively high (in the well-

fertilized plots) even thought Al-saturation reached above 80% in the 12th year. Rice yields increased again when lime was applied to all plots in the 15th and 16th year of continuous cropping.

2. Tolerance to low levels of P

In the mid 1970s it was observed that in extremely P-deficient soils cassava responded markedly to applications of P, but that the crop was still much more tolerant of low levels of soil P than most other crops. In the mean time, Jintakanon *et al.* (1982) growing different crops at various P concentrations in flowing nutrient solutions, reported that cassava had a higher external P requirement than most other crops, i.e. cassava needed unusually high P concentrations in nutrient solution to reach maximum DM production. It was found that due to its coarse root system cassava is highly dependent on vesicular-arbuscular mycorrhiza (VAM) for P uptake. Many different species of these beneficial fungi occur in natural soils and these can infect the roots of almost all plant species. The fungus forms vesicles and arbuscules inside the cells of the fibrous roots, and produces hyphae which can extend 1-2 centimeters into the soil; through these hyphae P is transported from the soil into the root, thus allowing the roots to take up P from a larger volume of soil. This is of particular importance for crops like cassava which have a relatively coarse and poorly branched root system. Thus, cassava growing in natural soil is very efficient in P-uptake because of this mycorrhizal association, while in a sterilized soil or in nutrient solution the lack of VAM results in very poor growth due to P deficiency, unless very large amounts of P are applied.

Figure 9 shows the effect of mycorrhizal inoculation on the dry weight of tops when cassava, MMex 59, was grown in the greenhouse in a sterilized low-P soil from Santander de Quilichao, Colombia. Without VAM inoculation, plants suffered from severe P deficiency even with 800 kg P/ha applied. These non-mycorrhizal plants needed the application of about 1,600 kg P/ha to reach the same yield as the VAM-inoculated plants without P application (Howeler *et al.*, 1982). (**see photos on page 35**)

When different plant species were similarly grown in a sterilized Quilichao soil with and without VAM inoculation at three levels of applied P, it was found that cassava was the most mycorrhizal dependent, followed by *Stylosanthes guyanensis*, cowpea, beans, *Andropogon gayanus*, maize and rice (**Table 8**). It is because of this highly effective association with VA-mycorrhiza that cassava can grow well with no or little P application even in very P-deficient soils. **Table 7** indicates that the critical level of Bray II-extractable P in the soil is about 4-6 ppm, while this is above 10-15 ppm for most other crops.

In many extremely P-deficient soils that have not been cropped for many years, cassava may need modest applications of P during the first year of cropping to achieve reasonably good growth, which results in a build up of the native mycorrhizal population. In subsequent years cassava yields will improve even without further P applications due to the increasing effectiveness of the mycorrhizal association.

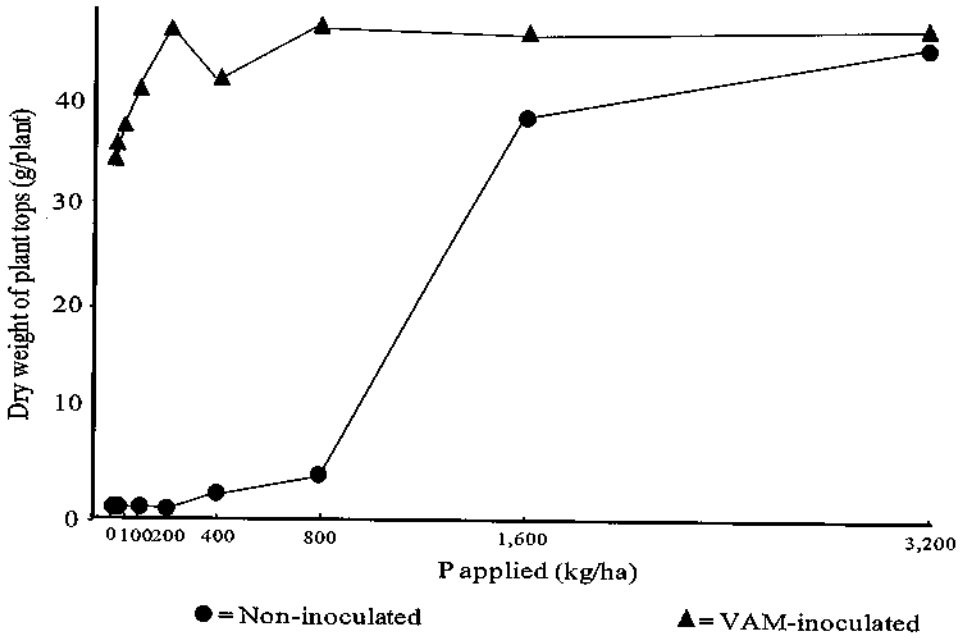

Figure 9. Effect of mycorrhizal inoculation and several levels of applied P on the dry weight of plant tops of cassava, cultivar MMex 59, in a sterilized soil from CIAT-Quilichao in the greenhouse.
***Source:** CIAT, 1981.*

Table 8. Effect of mycorrhizal inoculation and P application on dry matter in tops of seven crop species[1].

	Dry matter in tops (g/pot)									
	Non-inoculated			Inoculated			Mycorrhizal dependence ratio[2]			
Species	P-0	P-100	P-500	P-0	P-100	P-500	P-0	P-100	P-500	Mean
Cassava	0.34	0.72	0.54	4.33	14.21	16.36	0.08	0.05	0.03	0.05
Beans	1.11	3.44	8.29	3.08	18.79	25.01	0.36	0.18	0.33	0.29
Cowpea	0.96	0.64	13.65	2.60	20.68	36.32	0.37	0.03	0.38	0.26
Stylosanthes sp.	0.08	0.08	2.74	1.25	9.33	12.20	0.06	0.01	0.22	0.10
Andropogon sp.	0.15	0.39	34.24	1.26	16.67	32.18	0.12	0.02	1.06	0.40
Maize	1.19	8.74	59.35	4.84	34.75	53.57	0.25	0.25	1.11	0.54
Rice	3.79	26.63	30.60	3.83	22.36	31.23	0.99	1.19	0.98	1.05

[1] Crops grown in sterilized soil from CIAT-Quilichao, in the greenhouse. Fertilized with either 100 or 500 kg P/ha.
[2] Mycorrhizal dependence is in terms of the ratio: $\frac{\text{Dry matter produced without inoculation}}{\text{Dry matter produced with inoculation}}$
***Source:** CIAT, 1981.*

3. Tolerance to low levels of other nutrients

Although cassava stores relatively large amounts of K in the swollen roots, which are removed in the root harvest, the crop needs only rather low levels of exchangeable K in the soil to reach near-maximum growth. The critical level is only about 0.15 me K/100 g as compared to >0.20 me/100 g for most other food crops (**Table 7**). Similarly, the critical levels for Ca and Mg are lower than those of most other crops. The critical level of OM in the soil is difficult to determine as OM has many important functions in the soil besides being a source of N. But since N is only taken up by plants in inorganic form, the availability of N for plant uptake depends on other factors, such as soil temperature, moisture and pH, which all affect the rate of mineralization by soil micro-organisms. Cassava absorbs relatively large amounts of N to sustain its rapid leaf production during the first 5-6 months of growth, but most of this N is returned in the fallen leaves and in the crop's residues at time of root harvest (**Tables 3** and **4**). Thus, cassava can grow quite well in low-OM sandy soils, as found in the NE of Thailand, as long as sufficient N is supplied from fertilizers, manures, composts or green manures, and crop residues are re-incorporated into the soil.

While very tolerant of acid soils, cassava is not well adapted to high pH, alkaline, soils which often have toxic levels of Na and/or salts. Moreover, at high pH the availability of Fe, Cu, Mn and Zn is reduced. Cassava is particularly susceptible to Zn deficiency and young plants of susceptible varieties may actually die due to Zn deficiency, particularly in very acid as well as in calcareous soils. This may have to do with an inadequate mycorrhizal association during the early stages of growth. Plants showing mild symptoms of Zn deficiency often recuperate at a later stage once the root system and the associated mycorrhiza are well established.

Maintaining Soil Fertility and High Cassava Yields

While cassava does not absorb or remove more nutrients than most other crops, there is an inevitable loss of nutrients with every root harvest, and a much greater loss of nutrients if leaves and stems are also utilized for human or animal feeding or as kindling. To prevent soil nutrient depletion and exhaustion, these nutrients should be returned to the soil. N can at least partially be replenished through OM decomposition or through N fixation by intercropping or rotating cassava with leguminous species. Alley cropping with leguminous tree species like *Leucaena* or *Gliricidia* can also be quite effective, not only in supplying N but also other nutrients absorbed from the subsoil. Green manures can be effective in supplying nutrients, particularly fixed N, but may compete strongly with cassava when planted as an intercrop. Compost and manures are good sources of nutrients, but because of their low nutrient content large quantities are required, which increases transport and application costs. A 50-kg bag of compound fertilizers like 15-15-15 oftentimes contains more nutrients than a tonne of manure or compost (**Table 9**). Generally, a combination of 1-5 tonnes/ha of animal manures or compost with chemical fertilizers produces the highest yields. The chemical fertilizers can supplement the nutrients supplied by the organic fertilizers to achieve the right balance of N, P and K for any particular crop or soil.

Table 9. Average nutrient content of one tonne of various types of wet manure and compost as compared to 50 kg of 15-15-15 chemical fertilizers.

		kg		
	% DM	N	P	K
1 t cattle manure	32	5.9	2.6	5.4
1 t cattle manure	40	8.2	5.5	5.5
1 t chicken manure	57	16.6	7.8	8.8
1 t sheep manure	35	10.5	2.2	9.4
1 t city garbage compost	71	6.9	3.3	6.1
50 kg 15-15-15 fertilizer	100	7.5	3.3	6.2

Many long-term fertility trials have been conducted to determine the optimum amount and balance of N, P and K to maintain soil fertility and obtain high cassava yields (or total income when intercropped) for different types of soil. **Table 10** summarizes the results of 19 long-term fertility trials, conducted for 4 to 31 years of continuous cropping. The table shows that during the last year, K had become the most limiting nutrient in 12 trials, N in five trials and P in only two, as indicated by the low relative yields in plots where these nutrients had not been applied. **Figure 10** shows the importance of K in increasing both the root yield and the root starch content, while **Figures 11** and **12** show that over time K became the most limiting nutrient when cassava was grown for many years on the same soil. The latter two figures also show that high yields of 20-30 t of roots/ha and a reasonable level of soil fertility could be maintained for at least 25 years of continuous cropping when medium levels of N, P and K in chemical fertilizers were supplied annually. However, **Figure 12** also shows that incorporation of plant tops, or the application of compost, in combination with chemical fertilizers produced the highest yields.

Effect of Cassava Cultivation on Soil Erosion

The decrease over time in cassava yields shown in **Figures 1** and **2** can be due to nutrient depletion as no fertilizers were applied, but can also be due to loss of nutrients in rainfall run-off and eroded soil. Soil degradation by erosion is more serious than that caused by nutrient removal in the crop harvest as soil erosion not only carries away plant nutrients in the soil and fertilizers but also a disproportionate amount of clay particles, organic matter and beneficial soil micro-organisms. The latter can not be replaced by the simple application of chemical fertilizers. This is of particular concern because cassava is often grown on steep slopes in mountainous areas on acid infertile soils, or in very light-textured soils with low levels of OM and nutrients. The fact that cassava is well adapted to these adverse conditions, also makes its cultivation possible and more common in areas or soils that are prone to have serious soil erosion problems.

Table 10. Cassava root yield response to annual applications of various levels of NPK and the relative response[1)] to each nutrient during the last year of cropping in 16 long-term fertility trials conducted in Asia and Latin America.

Location	Variety	No of years	Yield (t/ha)		Relative yields (%)		
			$N_0P_0K_0$	$N_2P_2K_2$	$N_0P_2K_2$	$N_2P_0K_2$	$N_2P_2K_0$
Bohol, Philippines	VC-1+Golden Yellow	4	7.5	20.4	58	84	33
Negros Oriental, Philippines	Lakan	4	7.1	13.9	71	129	76
Yogyakarta, Indonesia	Adira-1	4	6.2	10.9	60	87	81
Jatikerto, E. Java, Indonesia	Faroka	8	3.1	11.3	31	72	81
GSCRI, Nanning, China	SC201+SC205	8	12.9	18.6	70	82	85
Umas Jaya, Lampung, Indonesia	Adira-4	10	11.1	15.0	111	92	84
Serdang, Malaysia	Black Twig	10	20.7	51.0	69	72	57
Santander de Quilichao, Colombia	MCol 1684	13	12.9	30.0	94	96	71
	MCol 1684	11	12.2	30.7	64	92	42
Trivandrum, Kerala, India	H 1687	13	1.0	22.3	24	42	7
CATAS, Hainan, China	SC205+SC124	16	7.2	15.1	41	77	63
Tamanbogo, Lampung, Indonesia	Adira 4	16	2.9	12.2	58	80	26
	Adira 4	16	3.6	13.2	64	57	26
TNUAF, Thai Nguyen, Vietnam	KM60+Vinh Phu	17	4.4	21.8	67	71	16
Hung Loc ARC, Dong Nai, Vietnam	KM60+SM937-26	17	6.9	16.2	69	76	37
Rayong FCRC, Thailand	Rayong 1	10	8.7	18.3	-	96	51
	Rayong 1 + Rayong 5	21	20.7	41.1	-	55	65
Khon Kaen FCRC, Thailand	Rayong 1 + Rayong 5	30	2.5	31.9	-	77	9
Banmai Samrong FCRC, Thailand	Rayong 1 + Rayong 5	31	21.7	26.9	-	66	99

[1)] Yield in the treatment without the nutrient over the yield with the nutrient ($N_2P_2K_2$).

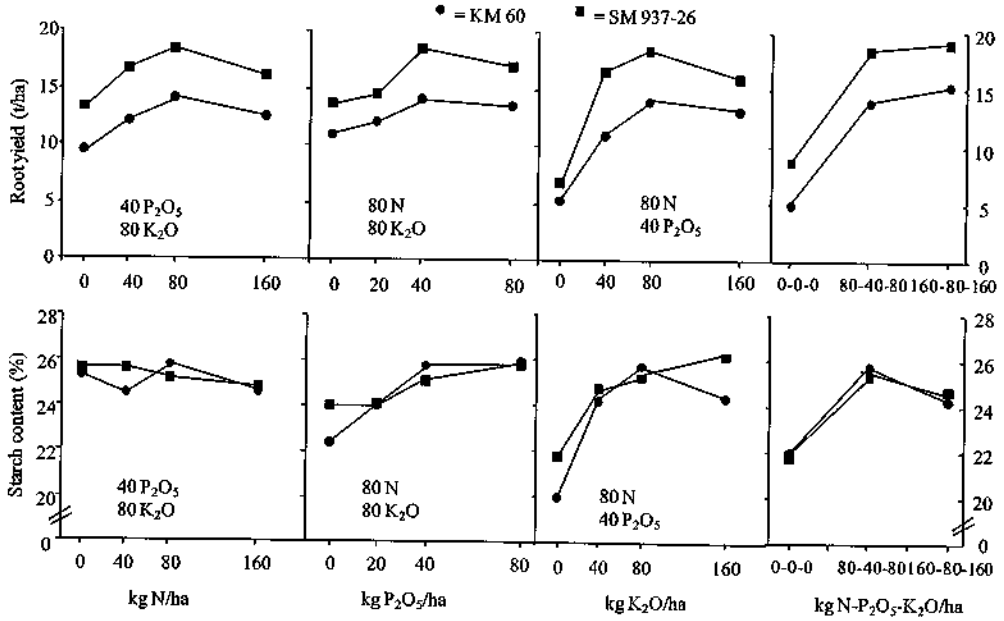

Figure 10. Effect of annual applications of various levels of N, P on the root yield and starch content of two cassava varieties grown at Hung Loc Agriculture Research Center; Thong Nhat, Dongnai, Vietnam in 2006/07 (17th year).
***Source:** Nguyen Huu Hy, Personal communication.*

But even under the same conditions of slope and soil type, cassava cultivation was found to cause more serious soil losses by erosion than most other crops. **Figure 13** shows a comparison in soil loss and run-off between different crops grown for many years in experiments on Terra Roxa soils in Brazil. Cassava cultivation caused more soil loss and run-off than any other crop, except *Phaseolus* beans and castor bean. Similarly, results of erosion experiments conducted in Pernambuco state of Brazil, show that cassava caused more erosion than cotton, maize, velvet bean and *Panicum maximum* (**Table 11**). However, being a long-season crop, cassava requires only one land preparation per year, while short-season crops like *Phaseolus* beans can be grown at least twice a year, and thus require more frequent land preparation and weeding; this results in much greater soil losses by erosion than cassava (Howeler, 1987; CIAT, 1988).

Soil loss by erosion depends mainly on the soil type, degree and length of slope, the rainfall amount and intensity as well as on the degree of soil cover by vegetation. The latter is represented by the "C" factor in the Universal Soil Loss Equation. The degree of soil cover in turn depends on the crop's inherent characteristics as well as on its management, such as frequency and intensity of land preparation and weeding, plant spacing, fertilization etc. Roose (1977) lists cassava as a crop causing intermediate levels of erosion (**Table 12**), with a "C" factor ranging from 0.2 to 0.8 depending on its management (a "C" factor of 1.0 correspond to bare soil while 0 indicates no erosion). Cassava tends to cause more serious erosion than other crops due to its wide plant spacing and slow initial

growth, which result in a slow formation of soil cover (**Figure 14**); this can be improved by intercropping with maize, peanut or creeping crops like watermelon, squash or pumpkin.

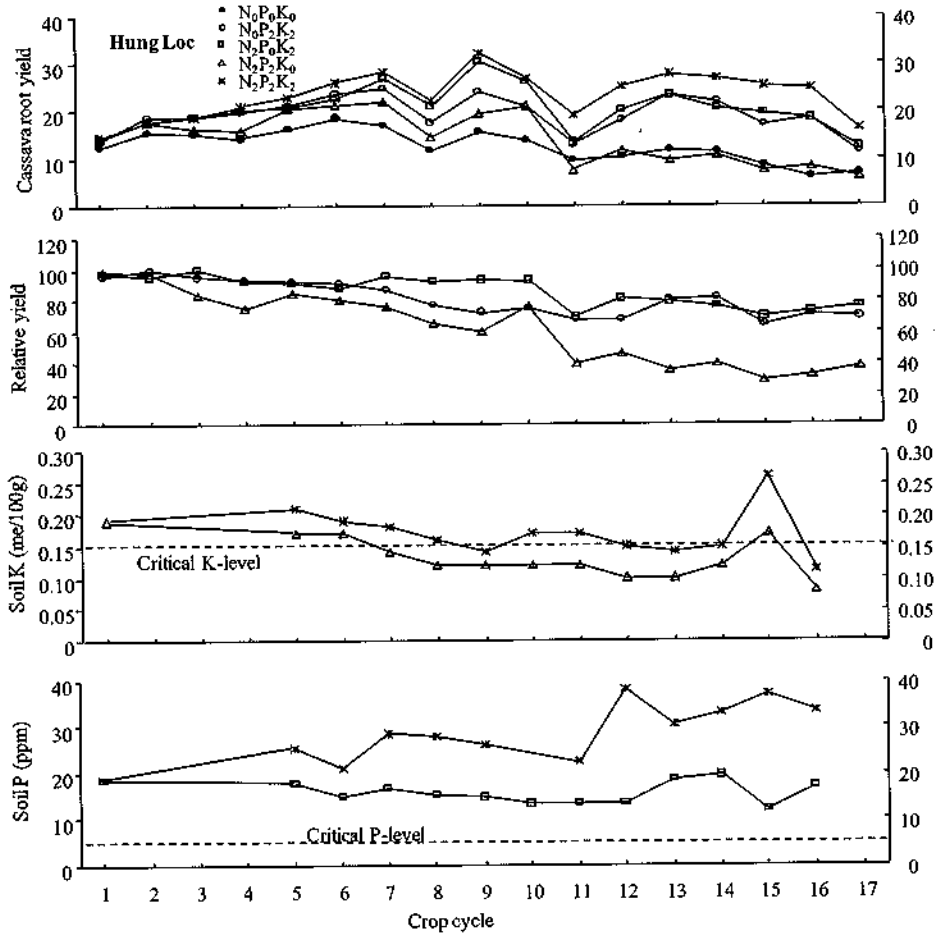

Figure 11. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during 17 years of continuous cropping in Hung Loc Agric. Research Center in Dong Nai, Vietnam.
***Source:** Nguyen Huu Hy, personal communication.*

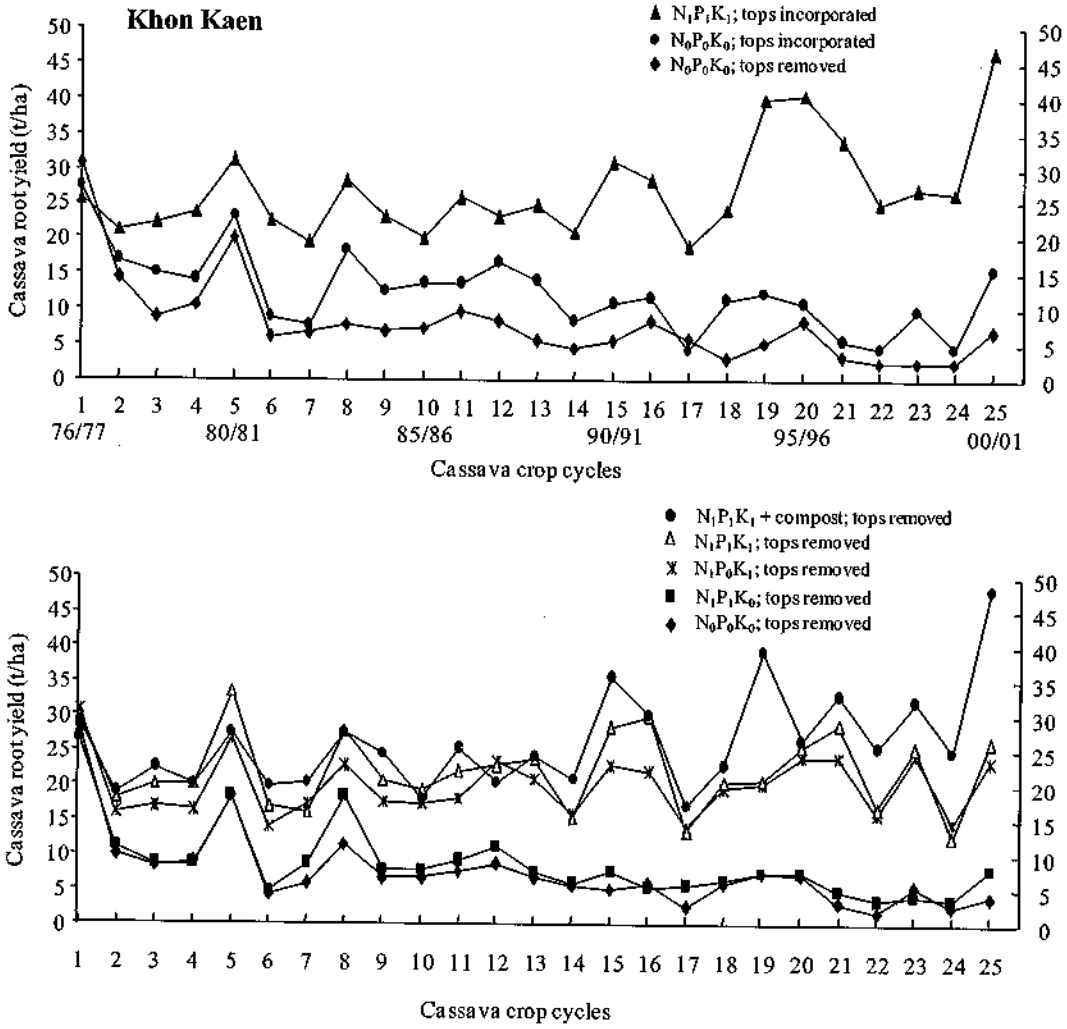

Figure 12. Effect of annual fertilizer application and crop residue management on cassava yields during 25 consecutive crops grown in Khon Kaen, Thailand.
Source: *Chumpol Nakviroj and Kobkiet Paisancharoen, personal communication.*

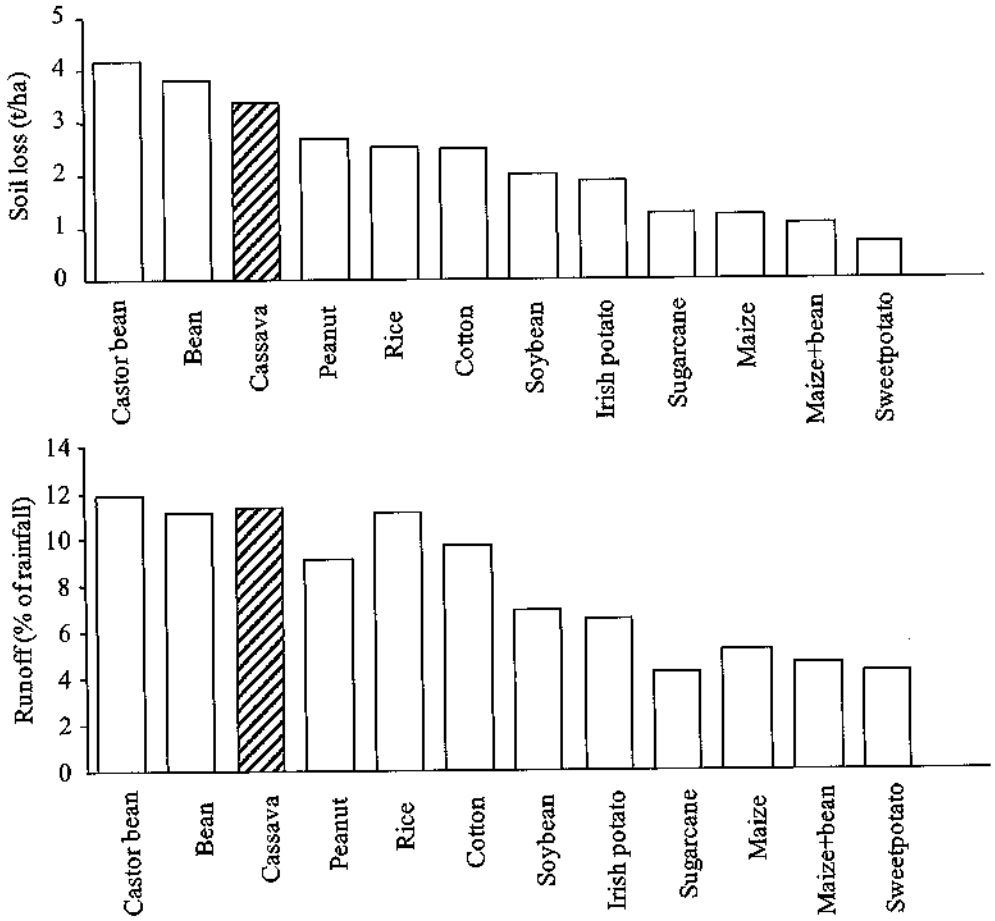

Figure 13. Effect of crops on annual soil loss by erosion (top) and on runoff (bottom). Data are average values (corrected for a standard annual rainfall of 1,300 mm) from about 48 experiments conducted from 1943 to 1959 on sandy, clayey and Terra roxa soils in Sao Paulo state of Brazil with slopes of 8.5-12.8%.
Source: *Quintiliano et al., 1961.*

Table 11. Annual soil losses by erosion caused by planting various crops on 12% slope in Gloria do Goita, Pernambuco, Brazil. Date are average values for ten years (1969-1978).

	Soil loss (t/ha)
Bare soil	59.90
Cassava	11.01
Cotton	8.35
Maize	2.97
Velvet bean (*Mucuna* sp)	2.85
Panicum maximum	0.43

Source: *Margolis and Campos Filho, 1981.*

Table 12. Effect of crop cover on crop management factor "C" in The Universal Soil Loss Equation.

Crop cover	C
No cover (bare soil)	1.0
Maize, sorghum	0.3-0.9
Groundnut	0.4-0.8
Cassava	0.2-0.8
Cotton, tobacco	0.5
Oil palm, coffee, cacao with cover crops	0.1-0.3
Rice	0.1-0.2
Rapidly growing cover crop	0.1
Savannah or pasture (without grazing)	0.01
Forest or crop with thick layer of mulch	0.001

Source: *Roose, 1977.*

Putthacharoen *at al.* (1998) reported the dry soil loss due to erosion of eight crops grown side-by-side on 7% slope in Sri Racha, Thailand, during a 4-year period; this allowed for four consecutive crops of cassava for root production, five crops of maize, sorghum and peanut, six crops of mungbean and two crops of cassava for forage production, pineapple and sugarcane. **Table 13** shows that soil losses due to erosion with cassava grown for root production averaged about 75 t/ha/year, as compared to 15-20 t/ha/year for maize, sorghum, and peanut, and only 13 t/ha/year for pineapple due to the ratooning of the 2nd-cycle pineapple crop. Cassava grown for forage production was planted at a closer spacing resulting in faster canopy cover and less erosion, but still averaging about 50 t/ha/year. Thus, the wider spacing of cassava and its slower canopy formation resulted in more soil being exposed to the impact of rain drops and thus more soil loss by erosion. These high rates of soil loss also mean high losses of soil nutrients (Howeler *et al.*, 2001); this can be as high as, or higher than, that removed annually with the harvested roots. Nutrients lost in the run-off were found to be quite low for N and P, but still substantial in case of K (Phommasack *et al.*, 1996). Erosion seriously affects the fertility of the soil, oftentimes exposing a very acid infertile and highly compacted subsoil, or – in limestone-derived soils – a calcareous subsoil which may cause severe micro-nutrient deficiencies. Cassava grown on seriously eroded soils will have low yields and may require heavy inputs of fertilizers to obtain the same yields as in non-eroded soil even without applied fertilizers (**Figure 15**).

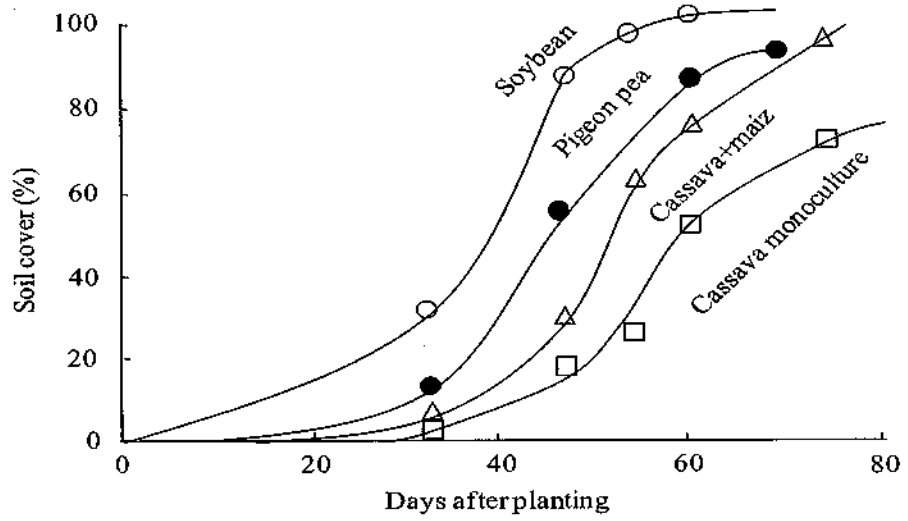

Figure 14. Percent soil cover of various crops and cropping systems.
***Source:** Aina et al., 1979.*

Table 13. Total dry soil loss by erosion (t/ha) due to the cultivation of eight crops during four years on 7% slope with sandy loam soil in Sri Racha, Thailand from 1989 to 1993.

	No. of crop cycles	First period (22 months)	Second period (28 months)	Total (50 months)	Average t/ha/year
Cassava for root production	4	142.8 a	168.5 a	311.3	74.7
Cassava for forage production	2	68.8 b	138.5 ab	207.3	49.8
Maize	5	28.5 d	35.5 cd	64.0	15.4
Sorghum	5	42.9 c	46.1 cd	89.0	21.4
Peanut	5	37.6 cd	36.2 cd	73.8	17.7
Mungbean	6	70.9 b	55.3 cd	126.2	30.3
Pineapple[1)]	2	31.4 cd	21.3 d	52.7	12.6
Sugarcane[1)]	2	-	94.0 bc	-	-
F-test		**	**		
cv (%)		11.4	42.7		

[1)]second cycle is ratoon crop; sugarcane only during second 28-month period
***Source:** Putthacharoen et al., 1998.*

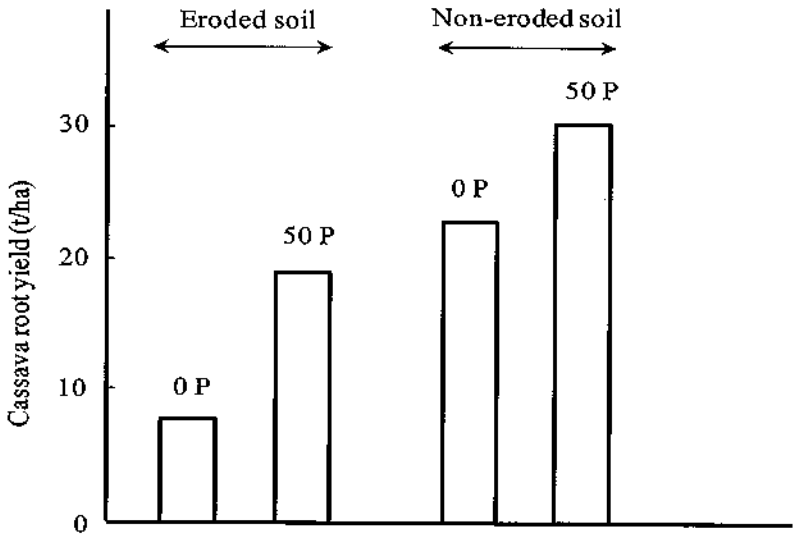

Figure 15. Effect of soil erosion and P application on the yield of cassava, cv. CMC 92, in Mondomo, Cauca, Colombia.
***Source:** Howeler, 1987.*

Management Practices to Reduce Soil Erosion.

Many erosion control experiments have been conducted to determine the most effective ways to reduce soil losses by erosion when cassava is grown on slopes. The results will vary from place to place depending on soil type and slope, rainfall intensity and general crop management. However, there is also a clear consistency in the results of these trials. By calculating the average relative dry soil loss, compared to a check or standard treatment (=100%), the various practices can be more or less ranked in order of their effectiveness in reducing erosion. **Table 14** shows the average relative dry soil loss calculated from numerous experiments and trials conducted in Thailand and Vietnam. The greatest soil loss was generally observed when no fertilizers were applied, resulting in poor growth, slow canopy formation and low cassava yields; this was followed by up-down ridging and intercropping with sweet corn or pumpkin, or hedgerows of sugarcane or *Panicum maximum*. These latter two species are not very good as hedgerows because they compete strongly with nearby cassava. The same is generally true for elephant and king grass, which are all very productive but also very competitive grasses (Huang Jie *et al.*, 2008). Intercropping with peanut was generally not effective in Thailand, but tended to reduce erosion somewhat in Vietnam. While intercropping results in quicker soil cover formation, the intercrops can also compete strongly with nearby cassava resulting in a marked reduction in soil cover once the intercrops are harvested. In Vietnam, however, intercropping with maize was very effective in reducing erosion. Practices of intermediate effectiveness include closer plant spacing, contour ridging, and hedgerows of *Leucaena* or *Gliricidia*. These practices also tend to increase cassava yields (Howeler, 2008). But, most effective in reducing erosion are contour hedgerows of pineapple, lemon grass, *Tephrosia candida, Paspalum atratum* and vetiver grass. These hedgerows generally reduced erosion

losses to about half in the first three years of establishment, whole vetiver grass was the most effective in reducing erosion in the long run, sometimes down to 20% of the soil loss in the check plots without hedgerows (Howeler, 2008). Which of these practices farmers will adopt, if any, depends on the local conditions, both biophysical and socio-economic, as well as on their traditional practices. Farmers themselves should conduct their own FPR erosion control trials in order to decide which practices are most suitable for their own conditions.

Table 14. Effect of various soil and crop management practices on the average[1] relative dry soil loss due to erosion as determined by numerous soil erosion control experiments and farmer participatory trials conducted from 1993 to 2003 in Thailand and Vietnam.

	Relative dry soil loss (%)		
	Thailand	Vietnam	
	Cassava monocult.	Cassava monocult.	Cassava + peanut
No fertilizers, no hedgerows	240 (10)	137 (4)	202 (12)
With fertilizer, no hedgerows, up-and-down ridging, no intercrop	124 (20)	-	-
With fertilizer, sugarcane hedgerows, no intercrop	111 (14)	-	
With fertilizer, no hedgerows, C+sweet corn interrop	110 (14)	-	
With fertilizer, no hedgerows, C+pumpkin or squash intercrop	109 (15)	-	
With fertilizer, *Panicum maximum* hedgerows, no intercrop	107 (4)	-	
With fertilizer, no hedgerows, peanut intercrop	102 (12)	81 (11)	**100**
With fertilizer, no hedgerows, no ridging, no intercrop (check)	**100**	**100**	-
With fertilizer, no hedgerows, closer spacing, no intercrop	88 (9)	103 (5)	-
With fertilizer, no hedgerows, contour ridging, no intercrop	69 (17)	70 (7)	-
With fertilizer, lemon grass hedgerows, no ridging, no intercrop	67 (15)	-	-
With fertilizer, *Tephrosia candida* hedgerows, no ridging, no intercrop	-	49 (16)	64 (23)
With fertilizer, vetiver + *Tephrosia* hedgerows, no intercrop	-	-	62 (7)
With fertilizer, pineapple hedgerows, no intercrop	-	48 (8)	44 (9)
With fertilizer, vetiver grass hedgerows, no ridging, no intercrop	58 (25)	48 (16)	51 (23)
With fertilizer, *Leucaena leucocephala* hedgerows, no intercrop	56 (2)	69 (11)	-
With fertilizer, *Paspal. atratum*, hedgerows, no ridging, no intercrop	53 (7)	50 (17)	62 (3)
With fertilizer, *Gliricidia sepium*, hedgerows, no intercrop	48 (2)	71 (11)	-
With fertilizer, no hedgerows, no ridging, mungbean intercrop	41 (4)	-	-
With fertilizer, no hedgerows, maize intercrop	-	21 (3)	-

[1] Number in parenthesis indicates the number of experiments/trials from which the average values were calculated.

Source: *Howeler, 2008.*

Can Cassava Production Actually Improve Soils?

Cassava is one of the most important food crops in many countries in Subsaharan Africa, but farmers seldom apply any chemical fertilizers or manures to their cassava crop. Traditionally, soil fertility is being maintained through slash-and-burn systems, in which after several years of cropping the land is returned to bush fallow for 10-20 years to let the soil rest and replenish the nutrients that were lost during the cropping cycle. However, because of rapid population growth and the consequent increase in land pressure, the fallow

cycle has steadily been shortened while the cropping cycle and intensity have increased. In many densely populated countries in East and West Africa the fallow cycle has now been reduced to 1-2 years, or has actually been eliminated entirely. Instead, farmers are trying to maintain the fertility of their land through the planting of "improved" fallows of fast growing leguminous trees, alley-cropping systems, or by cereal-legume crop rotations. Farmers in Ghana and Benin in West Africa also use extensive cassava cropping as a "substitute fallow" as they have observed that this system seems to restore soil productivity; the maize crop planted after cassava grows better than maize planted after maize, or even after many legume crops. Cassava cropping in many countries in West Africa is called "jachère manioc", which literally means "cassava fallow" (Saïdou *et al.*, 2004; Adjei-Nsiah *et al.*, 2007). Similarly, the bush-fallow cycle in many countries in East Africa has nearly disappeared, and many farmers are now rotating maize with cassava so that cassava can "rest" the soil and improve soil fertility for the following maize crop (Fermont, 2009).

In an experiment in Ghana yields of maize planted after either cassava or Mucuna (*Mucuna pruriens*) indeed produced higher yields than when maize followed cowpea, maize, or a speargrass (*Imperata cylindrica*) fallow (**Figure 16**). The beneficial effect of cassava was attributed to the relatively high nutrient concentrations, especially N, of the fallen leaves and in the crop residues incorporated into the soil after harvest of the roots. Since cassava has a relatively deep root system, part of these nutrients may have been taken up from the subsoil and are then deposited onto the soil surface where they are available for rapid uptake by the following maize crop.

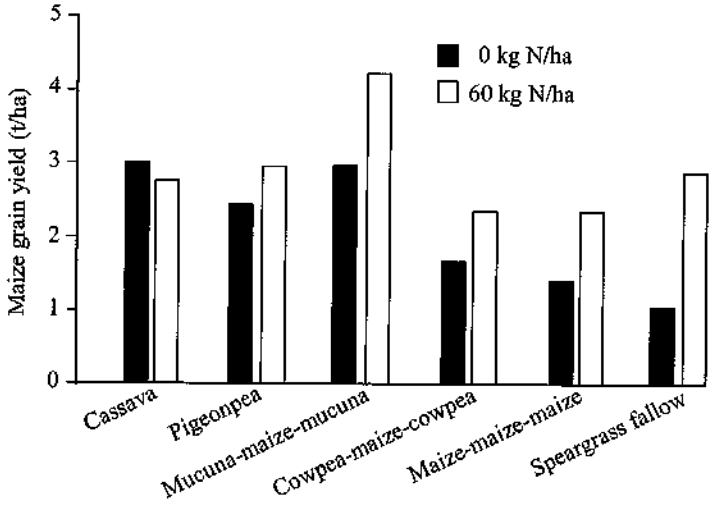

Figure 16. Effect of crop sequence and N rate on maize grain yield produced on researcher-managed plots.
***Source:** Adjei-Nsiah et al., 2007.*

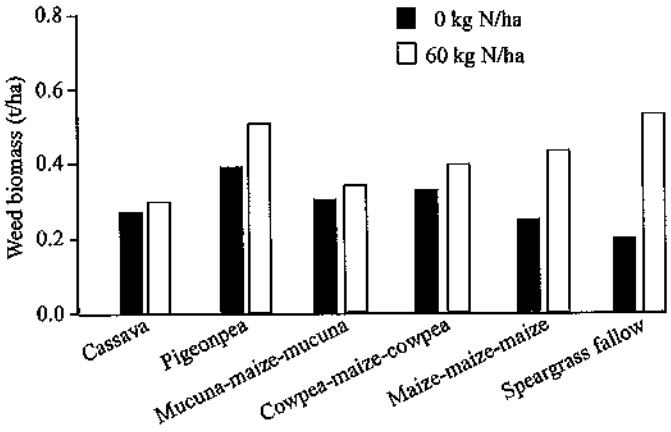

Figure 17. Effect of crop sequence and N rate on weed mass associated with the maize crop at 8 weeks after planting on researcher-managed plots.
***Source:** Adjei-Nsiah et al., 2007.*

CONCLUSIONS

From the numerous experiments conducted about the nutritional requirements of cassava, the amount of nutrients absorbed and removed in different plant parts, as well as on fertilizer and erosion control practices, the following conclusions can be drawn:

1. Cassava grows well on acid and infertile soils because it is more tolerant than other crops to low pH, high levels of Al, and low levels of P, K, Ca and Mg.
2. The crop's tolerance to low levels of P, and possibly to low pH and high Al, is due to a highly effective symbiosis between the plant and naturally occurring mycorrhizal fungi in the soil.
3. The amount of nutrients removed in the harvest of roots is low compared with that in the harvested products of most other crops. However, when leaves and stems are also removed from the field, the nutrient removal increases substantially, especially that of N, Ca and Mg.
4. Soil and nutrient losses due to erosion may be more severe by the cultivation on slopes of cassava as compared to that of other crops, mainly due to cassava's wide spacing and slow initial growth, leaving much soil exposed to the impact of rain drops, which causes soil aggregate disintegration and soil particle movement down-slope with rainfall run-off. However, the adoption of better management practices, such as the use of good quality planting material of varieties that exhibit good germination and vigorous early growth, adequate and early fertilizer application, closer plant spacing, contour ridging and the planting of contour hedgerows of vetiver grass, *Paspalum atratum or Tephrosia candida* can markedly reduce erosion.

5. Cassava production may actually improve the soil for the following crop by providing N from the fallen leaves and top growth, by stimulating the population of native mycorrhizal fungi, and by shading out weeds, which reduces early weed competition in the following crop

Thus, while cassava has certain intrinsic characteristics that makes the crop very suitable for growing on poor and degraded soils, it also has characteristics that may cause more serious soil losses by erosion. However, it is mainly the way the crop is managed that determines whether this results in further nutrient depletion, erosion and soil degradation. Good management will increase yields and farmers' income, while at the same time protecting the soil from degradation. In that case, the continued cultivation of cassava on poor soils is more likely the consequence rather than the cause of soil degradation. In addition, cassava may actually improve the soil condition for the following crop under certain circumstances.

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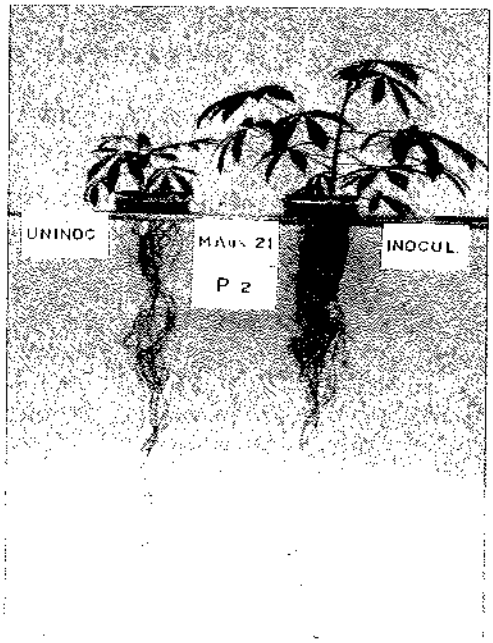
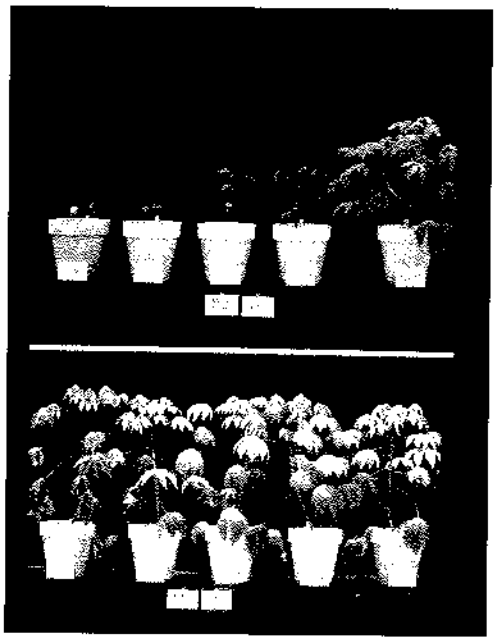
VAM vesicles inside a fibrous cassava root with masses of hyphae growing from the root into the surrounding solution through which the plant can absorb P



Cassava plants growing in flowing solution culture without (on left) and with mycorrhizal inoculation (on right)



Cassava plants growing in sterilized soil at five levels of applied P (from 0 to 3,200 kg P/ha), without (above) and with VAM inoculation (below)

Cassava plants growing in a plot sterilized with methyl bromide (in front) and in non-sterilized soil (in back)

OPENING REMARKS
by Mr. Takeju Okata, President of the Nippon Foundation

Ladies and gentlemen, I am most honored to have this chance to speak to you at this 8th Regional Cassava Workshop. Although I should have been present at this workshop from the first day, inescapable previous arrangements prevented me from attending. However, Dr. Howeler very kindly allowed me to join mid-way, going so far as to give me the chance to speak to you all here today. I am most grateful for this unique opportunity.

The Nippon Foundation is the largest institute in the Japanese non-public sector and conducts activities for the public good, both in Japan and overseas. Over the last 40 years, the Nippon Foundation has conducted activities in more than 100 countries.

At this point in time, around two billion people throughout the world are suffering under great poverty. The Nippon Foundation believes that development of agriculture is critical for solving poverty-related problems. In developing countries, the majority of people lives in rural areas and makes their living through small-scale farming. Their lives can be significantly improved by helping them to raise food production and use their crops efficiently.

For the past 22 years, we have been conducting a project to raise the agricultural production capacity of small-holder farmers and thereby reduce the problem of poverty in Africa. This project is called the Sasakawa Global 2000 Project. The project aims at increasing agricultural production by promoting the use of small amounts of fertilizer and good quality seeds through local extension workers, and has now been implemented in 14 countries in East and West Africa. The result has been a doubling or tripling of harvests by participating farmers and this technique, which is called the "Sasakawa Method", is now widely known throughout Africa.

The aim of the Cassava Program conducted by The Nippon Foundation and CIAT in Asia is, like that of the project in Africa, to improve the lives of small-holder farmers. It was brought to our attention by Dr. Howeler that cassava grows well even in dry areas with poor soil, making it highly valuable in such regions. Furthermore, its high nutritional content makes it an ideal feed for pigs and poultry. The fact that cassava can be used as animal feed is especially important as the demand for pig meat in regional society is stable, and therefore brings a stable income for small-holder farmers. Moreover, through this program, agricultural institutions in various countries are working alongside CIAT to select cassava varieties best suited to particular regions, and to research effective cultivation methods.

Information regarding ways to use and cultivate cassava is passed on to farmers through the Farmer Participatory Research method. Unlike traditional methods where scientists merely guide farmers, this method aims at working alongside the farmers to find and solve problems. For this method to achieve success, it requires a trusting relationship to be built with the farmers. The fact that this method has been a success is, I believe, due to the diligent and courteous manner in which all the persons concerned with the project have interacted with the farmers.

The success of the project is also shown by the fact that it has been evaluated highly

by external organizations. Persons involved with the project have received several awards for their activities in Vietnam and Thailand. For his work on the project, Dr. Howeler received a royal decoration in "the Most Exalted Order of the White Elephant" from Thailand, the supreme honor that Thailand gives to non-Thai individuals. He has also received an International Service in Agronomy Award from the American Society of Agronomy, and was nominated this year for the World Food Prize, along with Dr. Kazuo Kawano. Another project participant, Mrs. Wilawan Vongkasem, received the King of Thailand Vetiver Award. The Nippon Foundation is very proud to support such a wonderful project.

The Cassava Program has made a steady contribution to improving the lives of small-holder farmers in Asia over the last 15 years. Furthermore, I have heard that the demand for cassava has risen for applications we had not even thought of, and this has caused rapid increases in production and income for small-holder farmers. However, I have heard that since our project in Vietnam came to a close, there has been extensive exploitation of mountains and hills for cassava cultivation, bringing with it soil destruction.

Regrettably, the local farmers are not aware of the landslide disasters and water pollution that soil destruction can cause. If this situation does not change, the farmers will face an enormous threat to their livelihood. As I'm sure you are all aware, if farmers use the cassava cultivation practices recommended by Dr. Howeler, it will be possible to continue cassava cultivation without causing soil destruction.

In the coming months, what will be required is to spread the message to the farmers that the knock-on effects of soil destruction are highly dangerous, and to promote appropriate cultivation methods. Because of the close trusting relationships that you have all built up with the farmers, I am sure that the farmers will listen to your advice on this matter.

Thank you very much.

TECHNOLOGY ADOPTION AND IMPACT AS A RESULT OF THE NIPPON FOUNDATION CASSAVA PROJECT IN THAILAND, VIETNAM AND CHINA[1]

Reinhardt H. Howeler[2]

ABSTRACT

Research has shown that cassava yields can be maintained for many years with adequate application of fertilizers or manures, and that there are various ways to reduce erosion. Adoption of erosion control practices, however, has been minimal as farmers generally see little short-term benefits, while initial costs of establishing these practices may be substantial.

In order to enhance the adoption of soil conserving practices and improve the sustainability of cassava production under a wide range of conditions, the Nippon Foundation in Japan agreed to fund a project entitled: "Integrated Crop-Soil Management for Sustainable Cassava-based Production Systems in Asia", starting in April 1993. A farmer participatory research (FPR) approach was used to develop not only the most suitable soil conservation practices, but also to test new cassava varieties, fertilization practices and cropping systems that tend to produce greater short-term benefits. The FPR methodology was initially developed in 2-3 sites each in China, Indonesia, Thailand and Vietnam. The methodology includes the conducting of RRAs in each site, farmer evaluation of a wide range of practices shown in demonstration plots, FPR trials with farmer-selected treatments on their own fields, field days to select the best among the tested practices, scaling-up of selected practices to larger fields, and farmer participatory dissemination to neighbors and neighboring communities. Based on the results of these trials, farmers in the pilot sites have readily adopted better varieties, fertilization and intercropping practices, and many farmers have adopted the planting of contour hedgerows to control erosion.

In the second phase of the project (1998-2004), the farmer participatory approach for technology development and dissemination was further developed and extended to about 34 pilot sites each in Thailand and Vietnam, and in 31 sites in southern China. Farmers were generally very interested in participating in these FPR trials. During this phase of the project, farmers in these 99 pilot sites conducted a total of 1,154 FPR trials, mostly testing new varieties, erosion control measures, fertilization, intercropping, weed control, plant spacing, and using cassava roots and leaves for pig feeding

From the FPR variety trials farmers selected the most suitable variety for their particular location. The most commonly adopted variety in both Thailand and Vietnam was KU-50, in Vietnam called KM 94. With respect to erosion control measures, farmers in Thailand overwhelmingly selected the planting of vetiver grass contour hedgerows, while in Vietnam farmers often selected vetiver grass as the most effective measure, but adopted the planting of *Tephrosia candida, Paspalum atratum* or pineapple, because these were easier to plant and had secondary uses. From FPR fertilizer trials farmers realized the beneficial effect of applying modest amounts of animal manure (5-10 t/ha) in combination with chemical fertilizers high in N and K, such as 80N-80K_2O or 80N-40P_2O_5-80K_2O. In Thailand where farmers use mostly compound fertilizers, there was a shift away from 15-15-15 to fertilizers like 15-7-18, if and when those were available on the local market.

By the end of the project in early 2004, farmers in 24 villages in Thailand had planted a total of 145 km of vetiver grass hedgerows, practically all had adopted one or more of the recommended new varieties, about 80-100% were using chemical fertilizers, but almost none had

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[1] This paper is a modified and shortened version of part of the End-of-Project Report submitted to the Nippon Foundation in April 2004.

[2] CIAT Cassava Office for Asia, Department of Agriculture, Chatuchak, Bangkok, 10900 Thailand.

adopted intercropping, mainly because of limitations of labor and frequent crop failures of intercrops.

In Vietnam the number of households adopting various new technology components increased year by year, reaching a total of 15,000-20,000 households in or near 15 of the older pilot sites. New varieties were adopted by the greatest number of households and over the largest area, covering at least 7,000 ha in or near those pilot sites. A nation-wide survey indicated that new varieties were being planted in about 92,500 ha corresponding to 35-40% of the total cassava area in the country in 2002. In the project pilot sites, better fertilization and erosion control measures had been adopted in about 600 ha each, while intercropping was practiced by many farmers but covering only a total of 160 ha. In the pilot sites of three districts of Hue province over one thousand households had raised about 3,370 pigs fed with silage of cassava roots and leaves. The increase in cassava yields and additional pig meat resulting from the adoption of these new technologies was valued at 2.2 million US dollars per year in those 15 pilot sites.

In China farmers tested mainly new varieties. Out of many promising breeding lines farmers in one village in Hainan selected two lines and these were later released as recommended varieties under the names of SC 5 and SC 6. Once released these two varieties spread rapidly and in 2003 covered about 1,300 ha in Hainan. In the major cassava growing province of Guangxi, two recently released varieties, GR 911 and GR 891, as well as two older ones, SC 124 and Nanzhi 199, were planted in about 16,000 ha. It is estimated that in all of China new varieties were being planted in over 30,000 ha covering about 8% of the total cassava area. Soil conservation practices had been tested extensively in FPR trials in Hainan, but had been adopted in only very small areas.

In order to estimate the economic benefit of all cassava research and extension activities (not only of this project) in China, Thailand and Vietnam, we can look at the overall effect of the adoption of new varieties and production practices on yield. According to FAO data, from 1994 to 2004, cassava yields in China increased 0.30 t/ha with an approximate value of 2.21 million US dollars; in Thailand yields increased 6.47 t/ha (47%) with a total value of 178 million US dollars; while in Vietnam yields increased 6.54 t/ha (77%) valued at 77 million US dollars per year. For all of Asia yields increased 4.06 t/ha (31%), resulting in additional income for cassava farmers valued at **397 million US dollars** per year. Using similar data for 2008, cassava farmers in Asia received over **1.6 billion US dollars** in additional gross income due to higher yields in 2008 as compared to 1994. . Although it is impossible to say for certain how much the Nippon Foundation project has contributed to these yield increases, there is no doubt that the direct involvement of several thousand farmers in testing, selecting and adopting locally-suitable varieties and practices, and their participation in field days and training courses have made a significant contribution.

It is clear that cassava yields in Asia, and particularly in Thailand and Vietnam, have markedly increased due to the adoption of higher yielding varieties and better cultural practices, and that the Nippon Foundation-funded FPR project has made a major contribution to this achievement. The question remains whether the adoption of the new technologies documented in 2003 continued to spread to other areas after the project had ended. Was the FPR methodology used in the project robust enough to be self-sustaining, resulting in continued testing and adoption of still better technologies by farmers? And if not, why not? What could be the reasons for eventual non-adoption of technologies that seemed very promising at the time, and are there other ways to enhance the adoption and make cassava production in Asia more sustainable?

1. INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is usually grown by smallholders in upland areas with poor soils and low or unpredictable rainfall. In some countries the crop is grown on steep slopes, but in others it is grown mainly on gentle slopes; in both cases soil erosion can be serious. Moreover, cassava farmers seldom apply adequate amounts of fertilizers or

manures to replace the nutrients removed in the harvested products. Thus, both erosion and nutrient extraction can result in a decline in soil fertility and a gradual degradation of the soil resource.

The fact that farmers do not apply sufficient fertilizers and do not use soil conservation practices when the crop is grown on slopes is more a socio-economic rather than a technical problem. Research has shown many ways to maintain or improve soil fertility and reduce erosion, but farmers usually consider these practices too costly or requiring too much labor. To overcome these obstacles to adoption it is necessary to develop simple practices that are suitable for the local situation and that provide short-term benefits to the farmer as well as long-term benefits in terms of resource conservation. Being highly site-specific these practices can best be developed by the farmers themselves, on their own fields, in collaboration with research and extension personnel.

Thus, a project was initiated, with financial support from the Nippon Foundation in Tokyo, Japan, to develop a farmer participatory methodology for the development and dissemination of more sustainable production practices in cassava-based cropping systems that will benefit a large number of poor farmers in the uplands of Asia.

2. MATERIALS AND METHODS

2.1 First Phase (1994-1999)

The first phase of the project was conducted in four countries, i.e. China, Indonesia, Thailand and Vietnam. The project was coordinated by CIAT and implemented in collaboration with research and extension organizations in each of the four countries. During an initial training course on farmer participatory research (FPR) methodologies, each country designed a work plan to implement the project. The steps in the process, from diagnosing the problem to adoption of suitable solutions, are shown in **Figure 1**. The outstanding feature of this approach is that farmers participate in every step of the process and make all important decisions.

a. Pilot site selection

Suitable pilot sites were pre-selected in areas where cassava is an important crop, where it is grown on slopes and erosion is a serious problem. Detailed information obtained through Rapid Rural Appraisals (RRA) in each site have been reported by Nguyen The Dang *et al.* (1998), Utomo *et al.* (1998), Vongkasem *et al.* (1998) and Zhang Weite *et al.* (1998). After conducting the RRAs, one or two suitable pilot sites (villages or subdistricts) were selected to work with farmers in the development and dissemination of suitable varieties and production practices.

b. Demonstration plots

Each year demonstration plots were laid out on an experiment station or a farmer's field to show the effect of many alternative treatments on yield, income and soil erosion. Farmers from the selected pilot sites visiting the trial were asked to discuss and score the usefulness of each treatment. From this range of many options farmers usually selected 3-4 treatments that they considered most useful for their own conditions. Some farmers then volunteered to test these treatments in FPR trials on their own fields.

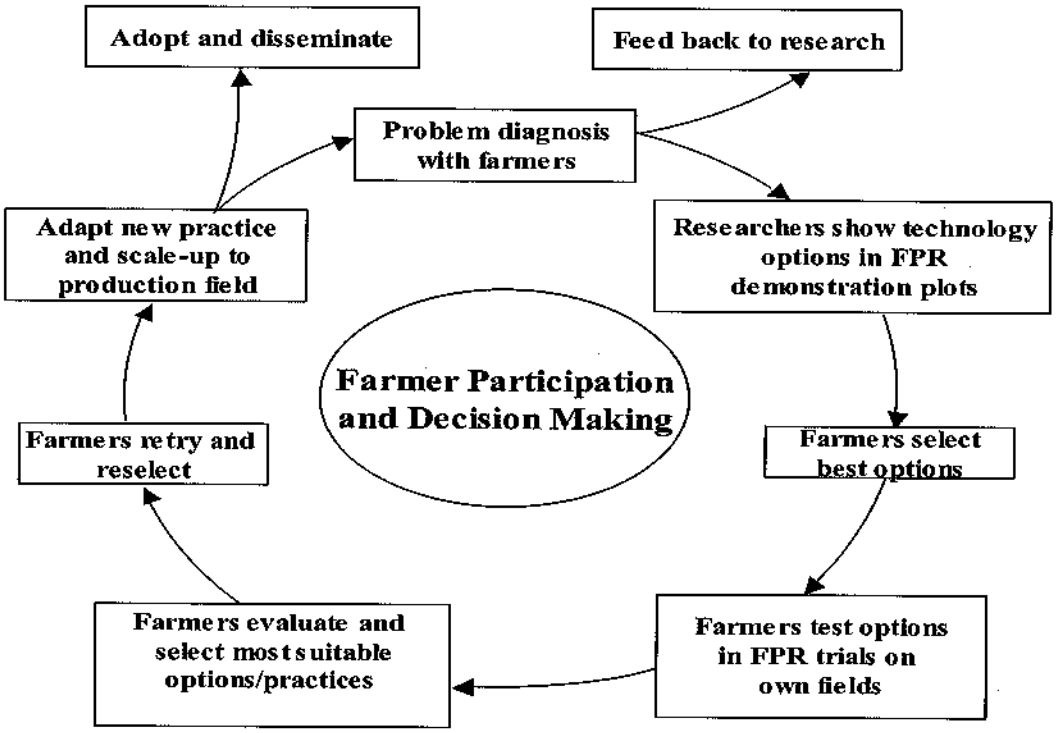

Figure 1. Farmer participatory model used for the development of sustainable cassava-based cropping systems in Asia.

In both the demonstration plots and FPR erosion control trials on farmers' fields, a simple methodology was used to measure soil loss due to erosion in each treatment. Plots were laid out along the contour on a uniform slope; along the lower side of each plot a ditch was dug and covered with plastic. Small holes in the plastic allowed runoff water to seep away, while eroded sediments remained on the plastic. These sediments were collected and weighed several times during the cropping cycle. After correcting for moisture content, the amount of dry soil loss per hectare was calculated for each treatment. This simple methodology gives both a visual as well as a quantitative indication of the effectiveness of the various practices in controlling erosion (Howeler, 2001; 2002).

c. FPR trials

The FPR trials did not only involve soil conservation practices, but also new varieties, intercropping systems and fertilization, with the objective of developing a combination of practices that would increase farmers' income, reduce erosion and improve soil fertility. During the first phase of the project, farmers in the four countries conducted a total of 177 FPR erosion control trials, 157 variety trials, 98 fertilizer trials and 35 intercropping trials, for a total of 467 trials. At time of harvest, field days were organized in each site to harvest the various trials by the participating farmers and their neighbors. The yields of cassava and intercrops, the dry soil loss due to erosion, as well as the gross

income, production costs and net income were calculated for each treatment and presented in a joint meeting to the farmers. After one or more years of testing in small plots, farmers quickly identified the best varieties and production practices for their area and started using those on larger areas of their production fields (Howeler, 2002).

2.2 Second Phase (1999-2004)

The second phase of the project was conducted in collaboration with five institutions in Thailand, six in Vietnam and three in China (**Table 1**). During the second phase the emphasis shifted from participatory research (FPR) to extension (FPE) in order to reach more farmers and achieve more widespread adoption.

Once farmers had selected certain practices and wanted to adopt those on their fields, the project staff tried to help them; for instance, in setting out contour lines to plant hedgerows for erosion control, or to obtain seed or vegetative planting material of the selected hedgerow species, intercrops or new cassava varieties.

During both the first and second phase of the project some collaborative research continued on-station in order to develop better technologies that farmers could test on their own fields.

Table 1. Partner institutions collaborating in the second phase of the Nippon Foundation cassava project in Asia.

1. Research and extension organizations in Thailand
-Department of Agriculture (DOA)
-Department of Agricultural Extension (DOAE)
-Land Development Department (LDD)
-Kasetsart University (KU)
-The Thai Tapioca Development Institute (TTDI)
2. Research and extension organizations in Vietnam
-Thai Nguyen University of Agriculture and Forestry (TNUAF)
-National Institute for Soils and Fertilizers (NISF)
-Vietnam Agricultural Science Institute (VASI)
-Hue University of Agriculture and Forestry (HUAF)
-Institute of Agricultural Sciences of South Vietnam (IAS)
-Tu Duc University of Agriculture and Forestry (TDUAF)
3. Research and extension organizations in China
-Chinese Academy for Tropical Agricultural Sciences (CATAS)
-Guangxi Subtropical Crops Research Institute (GSCRI)
-Honghe Animal Husbandry Station of Yunnan

3. RESULTS AND DISCUSSION

3.1 First Phase (1994-1999): Farmer Participatory Research (FPR)

a. FPR trials

Table 2 shows a typical example of an FPR erosion control trial conducted by six farmers having adjacent plots on about 40% slope. It is clear that contour hedgerows of vetiver grass, *Tephrosia candida* or pineapple reduced erosion to about 30% of that in the check plot, while intercropping with peanut and planting vetiver hedgerows markedly increased net income. Results of many other FPR trials have been reported by Nguyen The Dang *et al.* (2001), Huang Jie *et al.* (2001), Utomo *et al.* (2001) and Vongkasem *et al.* (2001).

b. Scaling-up and adoption

After having selected the most promising varieties and production practices from FPR trials, farmers generally like to test some of these on small areas of their production fields, making adaptations if necessary. Some practices may look promising on small plots, but are rejected as impractical when applied on larger areas; this may be due to lack of sufficient planting material (like vetiver grass) or lack of markets for selling the products (like pumpkin or lemon grass).

Table 2. Effect of various crop management treatments on the yield of cassava and intercropped peanut as well as the gross and net income and soil loss due to erosion in a FPR erosion control trial conducted by six farmers in Kieu Tung village of Thanh Ba district, Phu Tho province, Vietnam in 1997 (3rd year).

Treatment[1]	Slope (%)	Dry soil loss (t/ha)	Yield (t/ha) cassava	Yield (t/ha) peanut[1]	Gross income[2] (mil. dong/ha)	Product. costs (mil. dong/ha)	Net income (mil. dong/ha)	Farmers ranking
1. C monocult., with fertilizer, no hedgerows(TP)	40.5	106.1	19.17	-	9.58	3.72	5.86	6
2. C+P, no fertilizer, no hedgerows	45.0	103.9	13.08	0.70	10.04	5.13	4.91	5
3. C+P, with fertilizer, no hedgerows	42.7	64.8	19.23	0.97	14.47	5.95	8.52	-
4. C+P, with fertilizer, *Tephrosia* hedgerows	39.7	40.1	14.67	0.85	11.58	5.95	5.63	3
5. C+P, with fertilizer, pineapple hedgerows	32.2	32.2	19.39	0.97	14.55	5.95	8.60	2
6. C+P, with fertilizer, vetiver hedgerows	37.7	32.0	23.71	0.85	16.10	5.95	10.15	1
7. C monocult, with fert., *Tephrosia* hedgerows	40.0	32.5	23.33	-	11.66	4.54	7.12	4

[1] Fertilizers = 60 kg N + 40 P_2O_5, + 120 K_2O/ha; all plots received 10 t/ha pig manure
TP=farmer traditional practice

[2] Prices: cassava (C) dong 500/kg fresh roots
peanut (P) 5000/kg dry pods
1US$ = approx. 13.000 dong

3.2 Second Phase (1999-2004): Farmer Participatory Research (FPR) and Extension (FPE)

Since the objective of the second phase was to achieve widespread adoption of more sustainable production practices by as large a number of farmers as possible, it was necessary to markedly expand the number of pilot sites and to develop farmer participatory extension (FPE) methodologies to disseminate the selected practices and varieties to many more farmers.

a. Strategic and applied research to develop better technology options

Farmers are interested in testing new technologies only if those technologies promise substantial economic benefits over their traditional practices. Thus, strategic and applied research need to continue to produce and select still better varieties, better production practices and new utilization options. As such, some collaborative research in the area of agronomy, soil management and the use of cassava roots and leaves for animal feeding, continued, mostly on experiment stations, during the course of the project.. The results of many of these experiments have been reported by Nguyen Huu Hy *et al.*(2007), Le Duc Ngoan and Nguyen Thi Hoa Ly (2007), Howeler (2008) and Nguyen Thi Hoa Ly *et al.*(2010).

b. Farmer participatory research (FPR)

Implementing the project in collaboration with many different institutions in China, Thailand and Vietnam (**Table 1**), and with generous financial support from the Nippon Foundation, it was possible to expand the number of pilot sites each year. In 2001 the project was working in about 50 sites, and this further increased to 99 sites by the end of the project in 2003 (**Figure 2**). Once the benefits of the new technologies became clear, the number of sites increased automatically, as neighboring villages also wanted to participate in order to increase their yields and income.

Whenever the project extended to a "new" site, the process outlined above was re-initiated, i.e. an RRA was conducted, interested farmers visited demonstration plots and/or made a cross-visit to an already established site, they conducted FPR trials, discussed results and eventually adopted those varieties or practices they had selected as most suitable for their own conditions. **Table 3** shows the number and type of FPR trials conducted in China, Thailand and Vietnam during the second phase of the project. While initially farmers were mainly interested in testing new varieties, fertilization, intercropping and erosion control practices, during the later part of the project they also wanted to test the use of organic or green manures, weed control, plant spacing and even leaf production and pig feeding. During the second phase of the project a total of 1,154 FPR trials were conducted by farmers on their own fields. The results of many of these trials have been reported by Nguyen The Dang (2007), Nguyen The Dang *et al.* (2008), Nguyen Thi Cach *et al.*(2007), Nguyen Thi Cach (2008), Tran Thi Dung and Nguyen Thi Sam (2007), Li Kaimian *et al.*(2007), Tian Yinong *et al.*(2007), Watananonta *et al.* (2002; 2003; 2005; 2006; 2007), Trinh Thi Phuong Loan *et al.*(2008), Nguyen Thi Hoa Ly *et al.*(2008; 2009) and Nguyen Huu Hy *et al.* (2008).

c. Farmer participatory extension (FPE)

The following farmer participatory extension methods were found to be very effective in raising farmers' interest in soil conservation, in disseminating information about improved varieties and cultural practices, and in enhancing adoption of soil conserving practices:

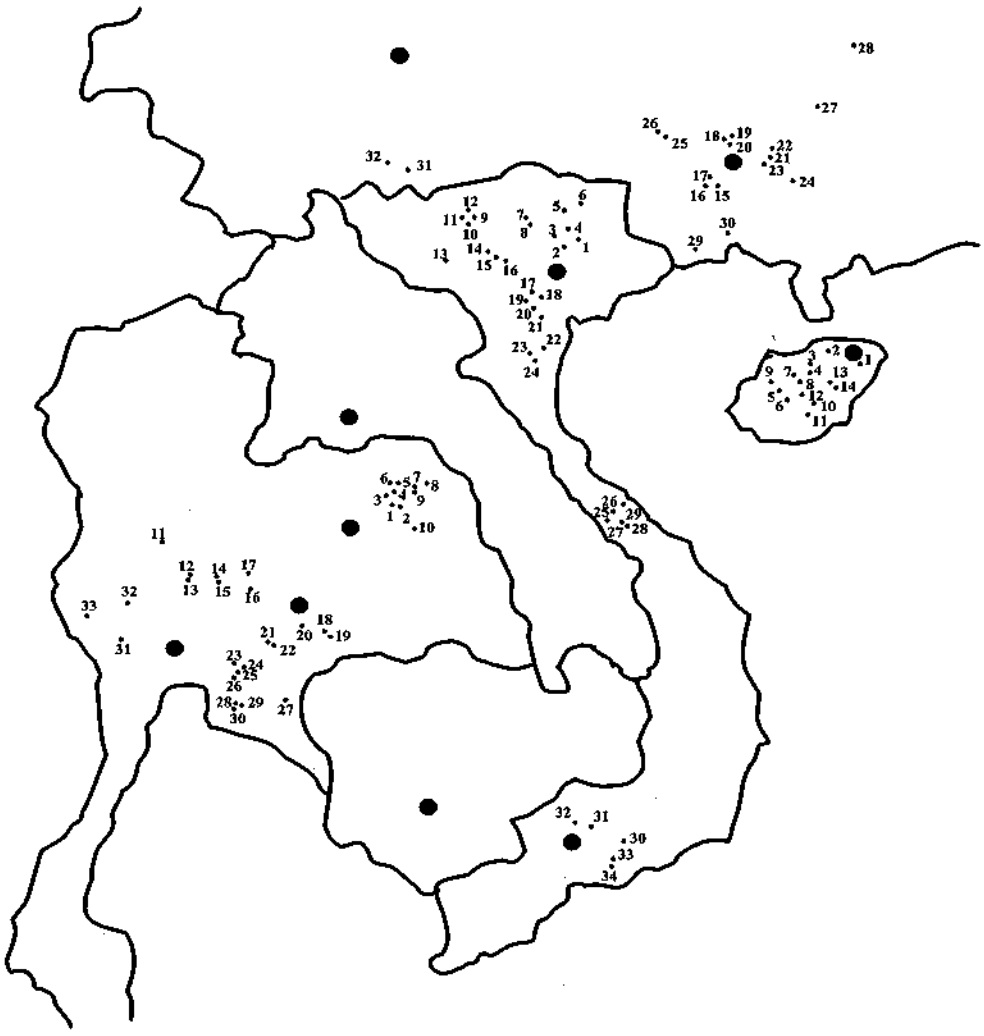

Figure 2. Location of FPR pilot sites in China, Thailand and Vietnam in the Nippon Foundation cassava project in 2003.

Cross-visits

Farmers from new sites were usually taken to visit older sites that had already conducted FPR trials and had adopted some soil conserving technologies. These cross-visits, in which farmers from the older site could explain their reasons for adopting new technologies was a very effective way of farmer-to-farmer extension. After these cross-visits, farmers in some new sites decided to adopt some technologies immediately, while others decided to conduct FPR trials in their own fields first. In both cases, the "FPR teams" of the various collaborating institutions, together with provincial, district or subdistrict extension staff, helped farmers to establish the trials, or they provided seed or planting materials required for the adoption of the new technologies.

Table 3. Number of FPR trials conducted in the 2d phase of the Nippon Foundation Project in China, Thailand and Vietnam.

Country	Type of FPR trial	1999	2000	2001	2002	2003	**Total**
China	Varieties	9	9	20	69	20	**127**
	Erosion control	3	5	8	17	-	**33**
	Fertilization	-	-	-	4	-	**4**
	Intercropping	-	-	-	9	-	**9**
	Pig feeding	-	-	-	59	-	**59**
		12	**14**	**28**	**158**	**20**	**232**
Thailand	Varieties	11	16	16	19	25	**87**
	Erosion control	14	10	6	-	11	**41**
	Chemical fertilizers	16	6	23	17	17	**79**
	Chem.+org fertilizers	-	-	10	11	11	**32**
	Green manures	-	-	13	11	15	**39**
	Weed control	-	-	17	5	10	**32**
	Plant spacing	-	-	3	-	2	**5**
	Intercropping	-	-	16	7	-	**23**
		41	**32**	**104**	**70**	**91**	**338**
Vietnam	Varieties	12	31	36	47	35	**161**
	Erosion control	16	28	29	30	23	**126**
	Fertilization	1	23	36	24	24	**108**
	Intercropping	-	14	32	31	26	**103**
	Weed control	-	3	-	-	3	**6**
	Plant spacing	-	1	7	19	8	**35**
	Leaf production	-	-	2	2	1	**5**
	Pig feeding	-	-	11	16	13	**40**
		29	**100**	**153**	**169**	**133**	**584**
Total		**82**	**146**	**285**	**397**	**244**	**1,154**

Field days

At time of harvest, field days were organized at the site in order to harvest the trials and discuss the results. Farmers from neighboring villages were usually invited to participate in these field days, to evaluate each treatment in the various trials and to discuss the *pros* and *cons* of the various practices or varieties tested.

In a few cases, large field days were also organized with participation of hundreds of neighboring farmers, school children, local and high-level officials, as well as representatives of the press and TV. The broadcasting or reporting about these events also helped to disseminate the information about suitable technologies. During the field days farmers explained the results of their own FPR trials to the other visiting farmers, while literature about the project and the results obtained was distributed.

Training

Research and extension staff involved in the project had previously participated in Training-of-Trainers courses in FPR methodologies, including practical training sessions with farmers in some of the pilot sites. While some participants were initially skeptical,

most course participants became very enthusiastic about this new approach once they started working more closely with farmers.

In addition, 2-3 key farmers from each site together with their local extension agent were invited to participate in FPR training courses. The objective was to learn about the various FPR methodologies, the basics of doing experiments as well as the implementation of commonly selected technologies, such as setting out contour lines or the planting, maintenance and multiplication of hedgerow species. By spending several days together in these courses, the farmers and extensionist got to know each other well, and they were encouraged to form a local "FPR team" to help other farmers in their community conduct FPR trials or adopt the new technologies.

Community-based self-help groups

Realizing that effective soil conservation practices, such as planting of contour hedgerows, can best be done as a group, farmers from some sites decided to form their own "soil conservation group". These community-based self-help groups are similar to "Land Care units", that have been very effective in promoting soil conservation in the Philippines and Australia. In Thailand, the Dept. of Agric. Extension has encouraged farmers to set up these groups as a way of organizing themselves, to conduct FPR trials, to implement the selected practices, and to manage a rotating fund, from which members of the group can borrow money for production inputs. Thus, by 2003, a total of 21 "Cassava Development Villages" had been set up in the pilot sites. Each group needed to have at least 40 members, elect five officers to lead the group, and establish their own bylaws about membership requirements, election of officers, use of the rotating fund, etc. The formation of these groups helped to decide on collective action and to strengthen the community, while people gained confidence and the group became more self-reliant. When necessary, the group could request help from local or national extension services, obtain information about certain production problems, or get planting material of vetiver grass or other species for hedgerows or green manures. Some groups started their own vetiver grass nurseries to have planting material available when needed.

3.3 Training of Research and Extension Personnel and Farmers

a. FPR training courses

At the beginning of the project in 1994 none of the project staff, both from CIAT and in national programs, had any experience in farmer participatory methodologies. Thus, the project started with a one-week Training-of-Trainers (TOT) course on farmer participatory methodologies with staff from CIAT and others with more experience presenting their ideas. After lengthy discussions about methodologies, and practice sessions in the classroom and with farmers in the field, most participants felt more or less comfortable with this new approach and were willing to test it out in their own countries.

This initial course in English was followed by several TOT in-country courses for researchers and extensionists of national programs taught partially in English (with translation) and partially in the native language by resource persons from that country. Project staff that had participated in the first phase and had gained experience with the methodologies then served as resource persons in subsequent TOT courses for staff joining in the second phase. By that time, manuals on farmer participatory approaches had been

prepared in Chinese, Thai and Vietnamese, making the teaching more efficient. **Table 4** shows the total number of training courses conducted during the first and second phase of the project.

Table 4. FPR training courses conducted as part of the Nippon Foundation project.

Country	Year	Type of training course	Location	Number of participants
China	1998	Researchers and extensionists	Danzhou	27
	2001	Researchers, Extensionists and farmers	Danzhou	32
	2003	Farmers and local extensionists	Yongning	100
				159
Indonesia	1998	Researchers and extensionists	Malang	31
Thailand	1994	Training-of-trainers in FPR methodologies	Rayong	29
	1997	Researchers and extensionists	Paakchong	28
	1999	Researchers and extensionists	Prachinburi	28
	2000	Farmers and local extensionists	Huay Bong	51
	2001	Researchers and farmers on vetiver grass	Khaw Hin Sorn	47
	2002	Researchers and extensionists of LDD	Huay Bong	30
	2002	Farmers and local extensionists	Khon Kaen	31
				244
Vietnam	1997	Researchers and extensionists	Thai Nguyen	28
	1999	Researchers and extensionists	Ho Chi Minh	29
	2000	Farmers and local extensionists	Thai Nguyen	29
	2001	Farmers and local extensionists	Ho Chi Minh	24
	2001	Farmers and local extensionists	Hue	29
	2002	Farmers and local extensionists	Van Yen	53
	2002	Farmers and local extensionists	Hue	34
	2003	Farmers and local extensionists	Nhu Xuan	66
				292
Total number of participants				**726**

After training of project staff in TOT courses, focusing mainly on tools and methodologies used in participatory diagnoses, in the implementation of FPR and FPE as well as in participatory monitoring and evaluation (PM&E), the emphasis shifted to training of local extension workers together with key farmers from each pilot site. By inviting one subdistrict extension worker together with two farm leaders from a project site in that subdistrict it was hoped that this three-man (or women) team could form a local "FPR team" that would work together in teaching others in the community to conduct FPR trials or adopt new technologies. Although these "FPR teams" were never formalized as such, the people that had participated in these FPR training courses would oftentimes lead the village as coordinators of the FPR trials or as officers on the Administration Committee of the "Cassava Development Villages".

At the end of the project in 2003, about 726 people had participated in FPR training

courses organized and funded by the project, of which about 200 were researchers and extensionists and about 400 were farmers and local extension workers (some people participated in more than one course). These training courses were extremely important to create a cadre of people with knowledge and experience in farmer participatory methodologies and to motivate people to work enthusiastically in extending the project to more and more sites. Similarly, the training of local extensionists and farmers was not only useful in extending knowledge about FPR and cassava production technologies, but also to motivate and empower local extension workers and key farmers to work together as a team for the benefit of members of the community.

b. Training manuals

To facilitate training in FPR methodologies and to hand out material that can serve as a reference for researchers, extensionists and farmers who have participated in these courses, the following training materials were prepared, mostly in the local language:

1. Video/CD: The use of farmer participatory research to develop and extend the use of soil conservation practices in cassava growing areas of Thailand (in Thai and English)
   by: Department of Agricultural Extension, Bangkok, Thailand
2. CD: Cassava resources development and research on preventing soil erosion and soil loss using cassava contour hedgerows in Honghe district, Yunnan, P.R. China (in Chinese)
   by: Honghe Regional Animal Husbandry Station, Mengzhe, Yunnan, China
3. Training Manual: Farmer Participatory Research; Methods and Tools; Planning FPR Trials (in Thai)
   by: Department of Agricultural Extension, Bangkok, Thailand
4. Training Manual: Farmer Participatory Research (in Vietnamese)
   by: Tran Ngoc Ngoan, Thai Nguyen Univ., Thai Nguyen, Vietnam
5. The Nippon Foundation Project to Control Erosion in Cassava Fields (in Vietnamese)
   by: Tran Ngoc Ngoan, Thai Nguyen Univ., Thai Nguyen, Vietnam
6. Cassava Varieties and Cultural Practices – FPR Project Training Manual (in Chinese)
   by: Li Jun, Guangxi Subtropical Crops Research Institute, Nanning, Guangxi, P.R. China
7. Several extension posters about the Control of Soil Erosion in Cassava, presented at End-of-Project Workshop, Thai Nguyen, Oct 2003.

4. ADAPTATION

After 2-3 years of testing of various options in FPR trials, slowly narrowing down the number of best options, farmers started to adopt some of the tested varieties or practices on their larger production fields. In some cases they made adaptations so as to make the practices more suitable on a larger scale. For instance, in Thailand farmers planted contour hedgerows of vetiver grass on their fields, but left enough space between hedgerows (usually 30-40 m) to facilitate land preparation by tractor. In some cases, especially in Vietnam, farmers planted hedgerows on plot borders rather than along contour lines. This

reduces the amount of land occupied by hedgerows, but also reduces their effectiveness in controlling erosion.

While contour hedgerows of vetiver grass are usually the most effective in reducing soil losses by erosion in experiments and FPR trials conducted in small plots on a uniform slope, when this practice is scaled up to a larger production field the results are sometimes disappointing. In areas of rolling terrain large amounts of runoff water may accumulate and run down-slope in natural drainage ways. The force of the water is likely to wash out vetiver grass recently planted along the contour across the drainage way, and this may result in serious gully erosion. Attempts to repair these gullies by placing sand bags or other obstacles across them have usually failed as these obstacles too are washed away. Over the past few years farmers and project staff have experimented informally with ways to reduce the speed of water in these gullies. They found that it is most effective to place a row of soil-filled plastic fertilizer bags across the gully in line but slightly below the washed out vetiver hedgerow. The bags need to be secured in place by pounding bamboo stakes into the soil behind them (**Figure 3**). Once eroded soil is deposited in the gully above the soil bags, vetiver grass can be planted in this moist and fertile sediment. When the vetiver grass is well-established across the gully and in line with the rest of the hedgerow, this will further slow the speed of runoff water resulting in further deposition of sediments in the gully above the vetiver hedgerow. This allows weeds to reestablish in the gully bottom protecting the gully from further erosion. With the next plowing along the contours, parallel to the hedgerows, the gully will generally be filled up again with soil, while the hedgerow prevents further gully formation (**Figure 3**). In some sites in Thailand, terraces of up to a meter height were formed within two years by the placing of soil bags and planting of vetiver hedgerows across the gully. This local adaptation of the traditional contour hedgerow system markedly increased its effectiveness under real field conditions.

5. ADOPTION AND IMPACT

Adoption of new technologies is a gradual process; it is also influenced by the activities of various government and non-government organizations as well as by social, political and economic forces both within and beyond the village. For instance, the amount of fertilizers applied by Thai cassava farmers depends to a large extent on the cassava price received in the previous year; this price is determined by international markets for coarse grains and sugar, which are beyond the farmers' control. It is also difficult to measure adoption beyond the actual pilot sites (usually village or commune) and to know whether it was entirely or only partially a result of the project.

5.1 China

In China the first phase of the project was conducted only in Hainan province and concentrated on the testing of new varieties, erosion control and fertilization. In the second phase the project extended to include also Guangxi and Yunnan provinces, and the emphasis shifted to testing mainly new varieties and some erosion control (in Hainan and Guangxi provinces), and to the feeding of ensiled cassava leaves and roots (only in southern Yunnan province) (**Table 3**).

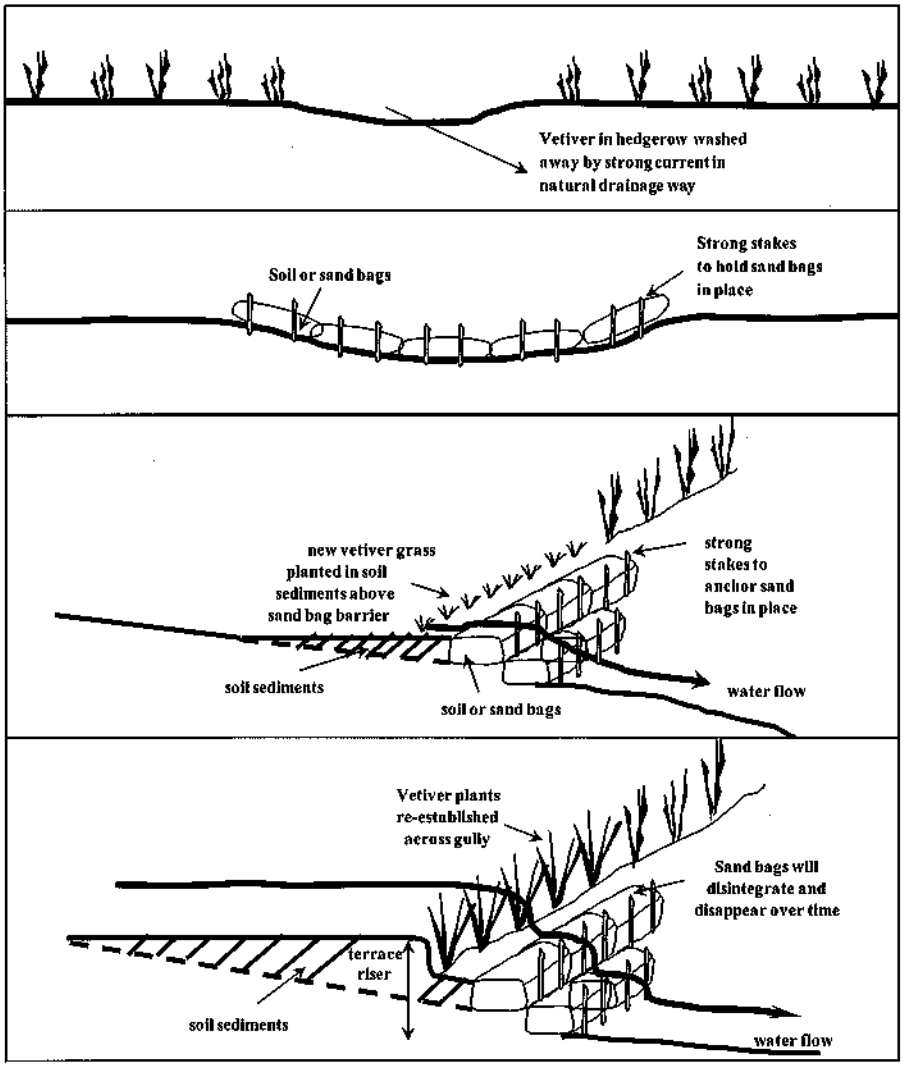

Figure 3. Simple and effective way to repair gullies by placing soil bags across gully and planting vetiver grass in the soil sediments accumulating above the barrier.

FPR variety trials conducted in Kong Ba village in Hainan in 1995-1998 resulted in the farmer selection of the breeding lines ZM 9057 and OMR 33-10-4 because of good adaptation, high yield and resistance to strong winds (typhoons). In 2002 these two lines were officially released as recommended varieties under the names of SC 5 and SC 6, respectively. In addition, CATAS in Hainan also released SC 8013 and SC 8002, both

from crosses made at CATAS, while GSCRI in Guangxi released the high yielding varieties GR 891 and GR 911. Two other varieties, SC 124 released in the 1980s by CATAS, and Nanzhi 199, released in the early 1990s by the South China Institute of Botany (SCIB) in Guangdong, became popular new varieties in Guangxi.

Due to the rapid expansion of FPR variety trials to many sites in Hainan and Guangxi during the second phase, these new varieties are now spreading throughout the cassava growing regions of these two major cassava growing provinces. The importance of cassava in Guangdong province, once the major producer, has been declining and little is known about the area still being planted and the varieties used. Thus, **Table 5** is at best an estimate of the extent of adoption of new varieties in the five cassava growing provinces of China. According to these data, new varieties are now planted in about 30,000 ha or approximately 8% of the total cassava growing area in China. This is likely to increase substantially as cassava is becoming a major industrial crop in Guangxi and Hainan provinces.

Table 5. Estimated adoption of new cassava varieties in five provinces of China in 2003.

Province	Variety	Area under cassava	Area under new varieties	Percent under new varieties
Guangxi	GR 891 and GR 911	-	3,333	-
	SC 124 and Nanzhi 199	-	13,333	-
		260,000	16,666	6.4
Guangdong		<66,000	?	?
Yunnan	Mostly SC 124; some Nanzhi 188	27,000	12,000	44.0
Hainan	Mostly SC 5; some SC 6	20,000	1,333	6.7
Fujian		?	133	?
Total China		**<373,000**	**30,132**	**~8**

FPR erosion control trials conducted in Hainan from 1995 to 1998 showed mainly the effectiveness of vetiver grass hedgerows in reducing soil losses. Demonstration plots conducted for many years at CATAS also indicated the effectiveness of hedgerows of vetiver grass, *Clitoria ternateo, Cassia rotundifolia* and *Tephrosia candida* in reducing erosion and increasing cassava yields (Huang Jie *et al.*, 2008). Of these various options, only vetiver grass hedgerows were adopted by a few farmers and in a very limited area (less than 5 ha), mainly because of lack of planting material and the labor involved in transporting and planting the vegetative material. The search for cheaper solutions, such as seed-propagated hedgerow species, contour ridging and closer plant spacing should continue, as these options are more likely to be adopted.

While FPR fertilizer trials conducted in Kongba village in Hainan showed a substantial response to application of chemical fertilizers, few farmers in that village adopted this practice; they preferred to open new land for cassava on the higher slopes and leave the rest in fallow rotation or convert to rubber plantations. Both at CATAS in Hainan

and at GSCRI in Guangxi long-term fertilizer trials indicated the importance of applications of K and N, respectively, for maintaining high cassava yields. It is not clear, however, to what extent improved fertilizer practices have been adopted by farmers.

Farmers in some parts of China have traditionally intercropped cassava with maize, peanut, and watermelons. To increase the yields of watermelon, many farmers started to cover the soil with plastic sheets to reduce weed growth, increase soil temperature in early spring and reduce evaporation. With cheap plastic available on the market this was a highly profitable practice. Now they have adopted the same practice for cassava grown in monoculture. In 2002, in one subdistrict (town) of Wuming county in Guangxi, about 25% of cassava was grown on plastic mulch. Apparently, the increased cassava yields obtained and the reduced need for weeding more than compensates for the cost of the plastic. This practice is now being investigated in replicated on-station trials – an example of farmer-to-researcher extension!

5.2 Thailand

In Thailand both the government and the private sector (through TTDI) are actively involved in cassava research and extension, including the training of cassava farmers. From 1993 to 2000 TTDI trained about 30,000 cassava farmers and distributed about 40 million stems of new varieties, free of charge to these farmers (Vankaew *et al.*, 2008). In addition, from 1993 to about 1998 the Thai government spent over US$1 million per year for the multiplication and distribution of new high-yielding cassava varieties. This has resulted in the rapid spread of new varieties; in 2002/03 these covered about 1 million ha or 98% of the total cassava area in the country (**Table 6**). Thus, in Thailand many farmers in the pilot sites had already adopted new varieties before the Nippon Foundation project started; but, they may have changed from one new variety to another as a result of FPR variety trials conducted as part of the project. For instance, in Baan Khlong Ruam in Sra Kaew province farmers in 1993 planted mainly Rayong 90 while presently they plant mainly Rayong 5 (**Table 7**) as the latter variety was only released in 1994 and tested as part of FPR trials from 1995 to 1998. Similarly, in Thaa Chiwit Mai, farmers in 1995 (before the project) planted mainly the local variety Rayong 1 but changed to KU 50 after testing in FPR trials. Data collected from a Participatory Monitoring and Evaluation (PM & E) conducted in four project sites in Aug 2002 (**Tables 7** and **8**) indicate that in 2002 one hundred percent of the cassava area in those four sites were planted with new varieties (Watananonta *et al.*, 2008). It is very difficult, however, to know to what extent the adoption of new varieties was due to the project, as new varieties were also adopted by farmers all over the country (see Section 5 on Impact Assessment below).

According to a survey conducted by DOAE, in 1992 only 46% of cassava farmers in Thailand applied chemical fertilizers. In 1999/2000 a similar survey of "advanced" cassava farmers conducted by TTDI indicate that between 44 and 80% of farmers applied chemical fertilizers to most fields. Recent data from the Dept. of Agric. Statistics of Thailand indicate that in 2001 66.4% of the cassava area was fertilized, but that this decreased to 56.2% in 2002. The PM&E project survey (**Table 7**) indicates that at the start of the project most farmers either did not apply chemical fertilizers or applied small amounts of 15-15-15 compound fertilizers. In 2002, however, according to the PM&E in four project sites, chemical fertilizers were applied in 79 to 100% of the cassava area in those sites (**Table 8**). In most sites this was still 15-15-15, but farmers also applied more

and more 13-13-21 or other compound fertilizers high in N and K and low in P. These fertilizers are more appropriate for cassava, but are still not widely available on the market.

Table 6. Spread of new cassava varieties in Thailand from 1989/90 to 2002/03.

	Area (ha)							% in
Variety	1989/90	1991/92	1994/95	1995/96	1997/98	1999/00	2002/03	2002/03
Local variety[1)]	1,470,382	1,400,256	949,204	840,253	416,113	146,297	18,270	1.7
others	-	-	-	-	-	-	3,481	0.3
Rayong 3	17,158	50,283	135,421	14,953	NA	27,004	9,242	0.8
Rayong 60	-	-	125,049	207,589	206,057	216,897	38,297	3.6
Rayong 90	-	-	35,461	81,049	143,055	220,926	150,961	14.4
Kasetsart 50	-	-	322	17,846	149,270	410,852	465,951	44.3
Sri Racha 1	-	-	NA	NA	NA	4,125	NA	-
Rayong 5	-	-	NA	66,424	129,594	125,823	304,721	29.0
Rayong 72	-	-	-	-	-	-	60,444	5.8
Total new varieties	**17,158**	**50,283**	**296,253**	**387,861**	**627,976**	**1,005,627**	**1,029,616**	
Total cassava area	1,487,540	1,450,539	1,245,457	1,228,114	1,044,089	1,151,924	1,051,368	
% with new varieties	1.1	3.5	23.8	31.6	60.1	87.3	97.9	

[1)] >90% Rayong 1

Source: *Klakhaeng et al., 1995; Rojanaridpiched et al., 1998; Office of Agric. Economics, 2000; NE Tapioca Trade Assoc. 2003.*

Presently, more and more farmers are applying animal manures, mostly chicken manure as this is becoming more available as a result of the booming poultry industry. But its use is still rather limited, probably no more than 10-20%. Farmers in some areas are also becoming interested in testing and planting green manures, such as *Canavalia ensiformis*, *Crotalaria juncea*, mungbean and cowpea. Some of these were tested in FPR trials. When the green manures are intercropped and planted at the same time as cassava, the yield of cassava is usually reduced due to strong competition. But when the green manures were planted one month after cassava and pulled up 1-2 months later, the competition was less and cassava yields sometimes (but not always) increased. **Tables 7** and **8** indicate that green manures were planted in only two of the four sites surveyed in 2002; in those sites green manures were planted in 15 and 50% of the cassava area and most farmers preferred *Canavalia* as it is well adapted to poor and acid soils, is drought tolerant, easy to plant and less competitive as compared to other species.

Although 23 FPR intercropping trials were conducted in Thailand in 2001 and 2002, this technology component was almost universally rejected by Thai farmers, mainly because it is too labor intensive, interferes with mechanized weed control, and intercrop yields are very much affected by either drought or excess rainfall; in addition, many intercrops have serious pest and/or disease problems. While the potential economic benefits from intercropping can be high, most farmers are not willing to spend the labor and money required and then risk crop failure. Intercropping with pumpkin might be attractive, but the marketing of large amounts becomes a serious problem.

Table 7. Change in the use of new cassava production technologies[1)] in four pilot sites[2)] in Thailand from 1995 to 2002[2)] as a result of the Nippon Foundation project.

Technology component	Baan Khlong Ruam			Thaa Chiwit Mai			Sapphongphoot			Huay Suea Ten		
	1993	1995	2002	1995	1997	2002	1995	1997	2002	1995	1997	2002
Varieties	R90 (60%) R3 (30% R60 (10%)	R90 (60%) R5 (20%) KU50 (20%)	R5 (67%) R90 (19%) KU50 (12%) R72 (2%)	R1 (94%) R60 (3%) R5 (3%)	KU50 (41%) R60 (32%) R5 (22%) R90 (5%)	KU50 (81%) R5 (18%) R72 (1%)	R1 R60 R90	KU50 R5 R90	KU50 (91%) R90 (5%) R72 (3%) R5 (1%)	R1 R90 KU50	KU50 R5 R90	KU50 (54%) R5 (20%) R90 (15%) R72 (11%)
Chemical fertilizers	not apply	15-15-15 13-13-21	15-15-15 (35%) 13-13-21 (17%) 21-4-21 (13%) 14-4-24 (10%) 16-20-0 (5%) other (20%)	not apply	15-15-15	15-15-15 (50%) 13-13-21 (38%) other (12%)	not apply or 15-15-15 (little)	15-15-15 46-0-0	15-15-15 (44%) 46-0-0 (27%) 13-13-21 (4%) other (25%)	not apply or 15-15-15 (little)	15-15-15 and 16-8-8 mixed at 2:1 ratio	15-15-15 (47%) 16-8-8 (33%) 21-0-0 (12%) 46-0-0 (7%) 13-13-21 (1%)
Vetiver	not plant	46%	29%	not plant	3%	20%	not plant	70%	55%	not plant	32%	39%
Green manures	not plant	not plant	*Canavalia* (little) cowpea (little	not plant	not plant	*Canavalia* (little)	not plant	not plant	*Canavalia* (little) *Crotalaria* (little)	not plant	*Canavalia* (20%)	*Canavalia* (50%)

[1)]Date collected from Participatory Monitoring and Evaluation (PM&E) with farmers in Aug 2002; percentages are in terms of cassava area

[2)]Baan Khlong Ruam village, Wang Soombuun district, Sra Kaew province
Thaa Chiwit Mai village, Sanaam Chaikhet district, Chachoengsao province
Sapphongphoot village, Soeng Saang district, Nakhon Ratchasima
Huay Suea Ten village, Sahatsakhan district, Kalasin province

[3)]Nippon Foundation project started in these pilot sites around 1997, except in Baan Khlong Ruam where it started in 1995

Table 8. Extent of adoption[1)] of various cassava technology components in four pilot sites in Thailand in 2002 as a result of the Nippon Foundation project.

Technology component	Baan Khlong Ruam Sra Kaew		Thaa Chiwit Mai Chachoengsao		Sapphongphoot Nakhon Ratchasima		Huay Suea Ten Kalasin	
	(ha)	(%)	(ha)	%)	(ha)	(%)	(ha)	(%)
Varieties	480	100	469	100	396	100	228	100
Chemical fertilizers	480	100	469	100	364	92	180	79
Vetiver grass hedgerows	139	29	94	20	218	55	89	39
Green manures	72	15	0	0	0	0	114	50
Intercropping	0	0	0	0	0	0	0	0

[1)] Estimated by farmers in each site during Participatory Monitoring and Evaluation (PM&E) in Aug 2002
Source: Watananonta et al., 2008.

As most cassava in Thailand is grown on very gentle slopes, usually between 0 and 10%, erosion would normally not be a problem. However, most cassava soils are very light textured (sandy loams or loamy sands) and are very low in organic matter (0-1%); these soils have thus poor aggregation, which makes them very susceptible to erosion. Moreover, yearly land preparation with disk plows has resulted in the formation of a very compacted plow layer at 20-25 cm below the soil surface, which impedes internal drainage. Thus, after heavy rains, the top soil becomes quickly saturated and excess water runs down the slope causing both sheet and gully erosion. Also, the large size of land holdings allows water to run freely over long distances resulting in water concentration and strong currents in natural drainage ways. This can result in very severe gully erosion.

In Thailand 33 FPR erosion control trials were conducted in the 1st phase and 41 in the second phase of the project (**Table 3**). After testing several ways to control erosion, farmers generally narrowed this down to contour hedgerows of either lemon grass or vetiver grass. While lemon grass has some commercial value, its marketing in large quantities is difficult; moreover, it is less drought tolerant than vetiver grass. Thus, almost 100% of farmers in Thailand selected vetiver grass hedgerows as the most suitable soil conservation practice. The fact that the Royal Family and most government organizations also promote the use of vetiver for soil and water conservation has certainly influenced that selection. In any case, many farmers in the project sites have adopted the planting of vetiver grass hedgerows, especially since the vegetative planting material was usually provided free of charge and LDD staff helped in setting out contour lines. **Table 7** indicate that there were no vetiver hedgerows planted before the start of the project, but that this soil conservation practice was used in 20-55% of the cassava area in the four sites surveyed in 2002. In Baan Khlong Ruam the area with vetiver hedgerows reached 46% in 1995 but decreased to only 29% in 2002; some had been destroyed by tractor drivers during land preparation, as these hedgerows interfere with straight-line and/or up-and-down land preparation. Nevertheless, the number of households adopting these soil conservation practices increased year by year (**Figure 4**). In 2003 about 145 km of vetiver hedgerows had been planted, covering about 580 ha in 20 project sites (Vongkasem *et al.*, 2008). While this is a major accomplishment and far exceeds initial expectations, it still corresponds to less than 0.1% of the total cassava growing area in Thailand. Obviously, not all cassava areas have an erosion problem, but both low soil fertility and soil erosion were listed as some of the most serious problems in cassava cultivation by farmers

participating in training courses at TTDI (Vankaew *et al.*, 2008).

The strong government support for planting vetiver grass has no doubt contributed greatly to the relatively rapid adoption of this technology; however, it could well have impeded the search for, and adoption of, other soil conservation options that are almost equally as effective and cheaper to establish, such as contour hedgerows of seed propagated species like *Paspalum atratum, Brachiaria brizantha* and possibly *Tephrosia candida* (or other leguminous species).

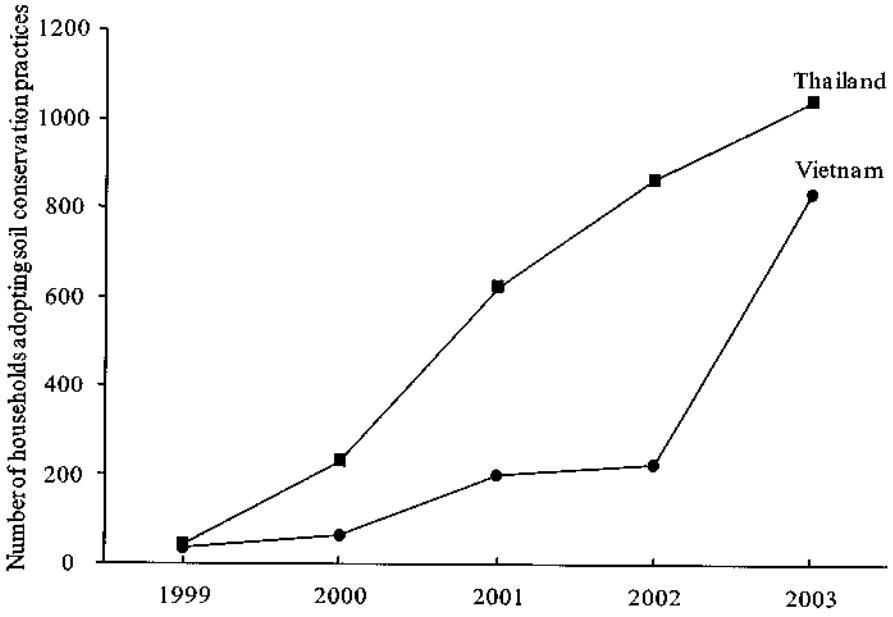

Figure 4. Number of farmers adopting soil conservation measures in their cassava fields in FPR pilot sites in Thailand and Vietnam from 1999 to 2003.

Using data from many erosion control experiments, demonstration plots and FPR trials conducted in Thailand from 1994 to 2003, it was found (**Table 9**) that on average hedgerows of vetiver grass and *Paspalum* were almost equally effective in reducing erosion (by 42 and 47%, respectively), while both reduced cassava yields about 10%. Closer plant spacing reduced erosion only slightly (12%), but increased yields by 16%, while contour ridging reduced erosion 31% and increased yields 8%. Lack of fertilizer application did not significantly reduce yields in FPR trials (only 4%) but markedly increased erosion by 140%. Thus, the adoption of more or better fertilizer use and closer plant spacing, almost universally adopted by farmers for economic reasons, may actually have contributed more to erosion control than any of the "soil conservation" practices adopted as a direct result of the project. In the future, it would be recommended to test the use of vetiver grass mainly for control and repair of gullies (**Figure 3**), and hedgerows of *Paspalum atratum* or *Brachiaria brizantha* variety Toledo for control of sheet erosion in the upper parts of the landscape (all except the drainage ways), all combined with contour ridging, closer plant spacing and the combined use of animal manures and chemical fertilizers high in N and K.

Table 9. Effect of various soil conservation practices on the average[1] relative cassava yield and dry soil loss due to erosion as determined from soil erosion control experiments, FPR demonstration plots and FPR trials conducted in Thailand from 1994 to 2003.

	Soil conservation practices[2]	Relative cassava yield (%)	Relative dry soil loss (%)
1.	With fertilizers; no hedgerows, no ridging, no intercrop (check)	100	100
2.	With fertilizers; vetiver grass hedgerows, no ridging, no intercrop**	90 (25)	58 (25)
3.	With fertilizers; lemon grass hedgerows, no ridging, no intercrop**	110 (14)	67 (15)
4.	With fertilizers; sugarcane for chewing hedgerows, no intercrop	99 (12)	111 (14)
5.	With fertilizers; *Paspalum atratum* hedgerows, no intercrop**	88 (7)	53 (7)
6.	With fertilizers; *Panicum maximum* hedgerows, no intercrop	73 (3)	107 (4)
7.	With fertilizers; *Brachiaria brizantha* hedgerows, no intercrop*	68 (3)	78 (2)
8.	With fertilizers; *Brachiaria ruziziensis* hedgerows, no intercrop*	80 (2)	56 (2)
9.	With fertilizers; elephant grass hedgerows, no intercrop	36 (2)	81 (2)
10.	With fertilizers; *Leucaena leucocephala* hedgerows, no intercrop*	66 (2)	56 (2)
11.	With fertilizers; *Gliricidia sepium* hedgerows, no intercrop*	65 (2)	48 (2)
12.	With fertilizers; *Crotalaria juncea* hedgerows, no intercrop	75 (2)	89 (2)
13.	With fertilizers; pigeon pea hedgerows, no intercrop	75 (2)	90 (2)
14.	With fertilizers; contour ridging, no hedgerows, no intercrop**	108 (17)	69 (17)
15.	With fertilizers; up-and-down ridging, no hedgerows, no intercrop	104 (20)	124 (20)
16.	With fertilizers; closer spacing, no hedgerows, no intercrop**	116 (10)	88 (11)
17.	With fertilizers; C+peanut intercrop	72 (11)	102 (12)
18.	With fertilizers; C+pumpkin or squash intercrop	90 (13)	109 (15)
19.	With fertilizers; C+sweetcorn intercrop	97 (11)	110 (14)
20.	With fertilizers; C+mungbean intercrop*	74 (4)	41 (4)
21.	No fertilizers; no hedgerows, no or up/down ridging	96 (9)	240 (10)

[1] number in parenthesis indicates the number of experiments/trials from which the average values were calculated.
[2] C = Cassava
** = most promising soil conservation practices; * = promising soil conservation practices

5.3 Vietnam

Table 10 shows how the number of households in the pilot sites adopting the various technology components increased over time, with most farmers adopting new varieties. This is partially due to the testing in FPR variety trials, but is also due to the planting of new varieties by non-participating farmers in or near the pilot sites.

Table 11 shows one example of the extent of adoption in 2002/03 of new varieties in six communes in Pho Yen district of Thai Nguyen province and in three communes in Son Duong district of neighboring Tuyen Quang province, both in north Vietnam. According to the RRA's conducted in 1994 in Pho Yen and in 1999 in Son Duong districts, the average cassava yields of the local variety Vinh Phu were 8.5 and 3.7 t/ha, respectively. In 2002/03 (**Table 11**), the average yield of the same variety but with improved practices were 24.5 and 18.4 t/ha in the project sites of the same two districts. With the adoption of new varieties, i.e. KM 95-3 and KM 98-7 in Pho Yen and KM 94 in Son Duong, yields further increased to 30.3 and 36.0 t/ha, respectively. Thus, in Son Duong the adoption of new varieties and improved practices (mainly more balanced fertilization) increased yields nearly ten times, while in Pho Yen yields increased about 3.5 times. In 2003/04, new varieties (KM 94) had been planted in 56.5 ha in seven communes in Son Duong district,

out of a total of about 400 ha of cassava in the district; in Pho Yen in 2003 new varieties had been planted in 51.3 ha in six communes, out of a total of about 650 ha of cassava in the district (other communes may also have planted new varieties, but data is not available).

Table 10. Trend of adoption of new cassava technologies in the Nippon Foundation project sites in Vietnam from 2000 to 2003.

	Number of households adopting			
Technology component	2000	2001	2002	2003
1. New varieties	88	447	1,637	14,820
2. Improved fertilization	64	123	157	1,710
3. Soil conservation practices	62	200	222	831
4. Intercropping	127	360	689	4,250
5. Pig feeding with cassava root silage	-	759	967	1,172

[1]Number of project sites: 1999 = 9; 2000=15; 2001=22; 2002=25; 2003=34

***Source:** Tran Ngoc Ngoan, 2008.*

Tran Ngoc Ngoan (2008) reported that in Vietnam, KM 94 (= KU-50 from Thailand) is the most widely adopted new variety; it is by far the most popular variety in almost all regions of Vietnam except in parts of Thai Nguyen province where farmers have adopted KM 98-7 and KM 95-3, in Hue province where farmers prefer the more edible variety KM 98-1 (=Rayong 72 from Thailand), and in Binh Phuoc province where KM 94 is now being replaced by KM 98-5 which tends to produce higher yields.

Besides varieties, most farmers in the Vietnam pilot sites also adopted a more balanced fertilization, i.e. they combined the traditional practice of applying 5-10 t/ha of pig manure (FYM) with chemical fertilizers high in N and K (such as 40N-20P_2O_5-80K_2O or 80N-80K_2O) as these combinations usually produced highest yields and net income in the FPR fertilizer trials. Although the number of households applying fertilizers to cassava did not increase as much as expected (**Table 10**) as most farmers already applied FYM with some fertilizer (mainly P), the level of application increased and the nutrient balance is now more appropriate as a result of the project. **Table 12** shows that adoption of more balanced fertilization on average increased yields from 21.4 to 30.5 t/ha, or a 43% increase over the traditional farmer's practice. The adoption of new varieties increased cassava yields more than the adoption of any other technology component, including improved fertilization.

Table 10 shows that the number of households adopting soil conservation practices – mostly the planting of contour hedgerows of *Tephrosia candida*, vetiver grass, *Paspalum atratum* and pineapple – increased from 62 in 2000 to 831 in 2003. These practices were used in 612 ha of cassava in the project pilot sites (**Table 13**). In some sites these hedgerows had been in place for 5-8 years, while in many others they had been recently established. Average results from many FPR trials and demonstration plots indicate that in Vietnam contour hedgerows of vetiver grass increased cassava yields about 13-15%, while those of *Tephosia* increased yields 5-10%; soil losses by erosion decreased 49-52% by vetiver grass and 36-51% by *Tephrosia* hedgerows (**Table 14**). Hedgerows of *Paspalum atratum* increased yields 12% and decreased erosion 50%, about the same as vetiver grass hedgerows; pineapple was also similarly effective in decreasing erosion (52-56%) but had basically no effect on yield. Contour ridging and intercropping with peanut both increased

yields by about 6% and decreased soil losses by 30% and 19%, respectively.

Table 11. Extent of the dissemination of new cassava varieties in six communes of Pho Yen district, Thai Nguyen, and three communes in Son Duong district of Tuyen Quang province, Vietnam in 2002/03 and their effect on yield and gross income.

District	Commune	Variety	No. of farmers	Area (ha)	Cassava yield (t/ha)	Gross income[1] ('000 d/ha)
Pho Yen						
1.	Tien Phong	Vinh Phu (local)	18	0.64	25.4	12,700
		KM 95-3	50	1.60	32.3	16,150
		KM 98-7	50	3.56	34.3	17,150
2.	Dac Son	Vinh Phu (local)	6	0.27	25.1	12,550
		KM 95-3	5	0.22	28.3	14,065
		KM 98-7	11	0.49	30.5	15,250
3.	Minh Duc	Vinh Phu (local)	34	1.62	23.5	11,750
		KM 95-3	34	0.65	27.4	13,700
		KM 98-7	34	0.86	28.1	14,050
4.	Hong Tien	Vinh Phu (local)	12	0.61	25.4	12,700
		KM 95-3	16	0.58	31.1	15,550
		KM 98-7	28	1.42	32.3	16,150
5.	Nam Tien	Vinh Phu (local)	9	0.40	23.5	11,750
		KM 95-3	9	0.29	28.1	14,050
		KM 98-7	9	0.36	30.2	15,100
6.	Van Phai	Vinh Phu (local)	9	0.32	23.8	11,900
		KM 95-3	17	0.70	29.2	14,600
		KM 98-7	25	1.46	31.3	15,650
Son Duong						
1.	Am Thang	Vinh Phu (local)	14	2.57	19.8	9,900
		La Tre (local)[2]	10	3.65	16.1	8,050
		KM 60	9	0.42	28.3	14,150
		KM 94	23	5.06	36.3	18,150
		KM 95-3	13	1.05	27.1	13,550
		KM 98-7	3	0.14	30.0	15,000
2.	Hong Tien	Vinh Phu (local)	2	0.25	17.0	8,500
		La Tre (local)	26	11.39	15.4	7,700
		KM 94	30	4.29	36.1	18,050
		KM 98-7	1	0.14	28.0	14,000
3.	Cap Tien	La Tre (local)	20	12.25	19.6	9,800
		KM 60	20	0.20	29.4	14,700
		KM 94	20	0.28	35.7	17,850
		KM 98-7	20	0.20	30.0	15,000

[1]Price: cassava dong 500/kg fresh roots.
[2]La Tre = SC 205 introduced from China in 1967-1972.

Data in **Table 13** indicate that adoption of soil conservation practices in all project sites in Vietnam increased yields from 13.5% in 2000 to 23.7% in 2002. **Table 13** also shows that the gross income, both per ha and per household, as a result of the adoption of soil conservation practices also increased very markedly over time. Results from both FPR trials and on-station research also indicate that the beneficial effect of contour hedgerows in terms of increasing yields and decreasing erosion increases over time (**Figure 5**). This is mainly because contour hedgerows, almost independent of the species used, will result in

natural terrace formation, which over time reduces the slope and enhances water infiltration, thus reducing runoff and erosion. Well established hedgerows also become increasingly more effective in trapping eroded soil and fertilizers. Unfortunately, most FPR erosion control trials are conducted for only 1-2 years at the same site, so farmers do not quite appreciate the increases in beneficial effects that accrue over time. This, coupled with the fact that planting and maintaining hedgerows requires additional labor (and sometimes money for seed or planting material) while hedgerows take some land out of production and have initially little beneficial effect on yield, has hampered the more widespread acceptance and adoption of these soil conservation practices.

Table 12. Estimated increase in cassava fresh root yield due to the adoption of various new technology components in Vietnam in 2002/03[1)].

Technology component	Cassava yield (t/ha)		New practice as % of farmers' practice[2)]
	Farmers' practice[2)]	With adoption of new technology component	
1. New varieties	17.61	29.93	170
2. Improved fertilization	21.37	30.50	143
3. Soil conservation practices	20.60	25.48	124
4. Intercropping	29.95	28.94	97

[1)] Based on results from 15 FPR sites where new technologies have been adopted by farmers.
[2)] Farmers' practice usually includes most new technologies except the technology being tested
Source: *Tran Ngoc Ngoan, 2008*

Table 13. Extent of adoption of soil conservation practices and the estimated increase in yield and gross income of farmers in the FPR pilot sites in Vietnam from 2000 to 2003.

Year	Number of farmers	Area with soil conser. (ha)	Cassava yield (t/ha)		Percent yield increase	Increase in gross income (mil VND)[2)]		
			Farmers' practice[1)]	With soil conservation		per ha	total	per household
2000	62	21.12	12.11	13.75	13.5	0.574	12.123	0.196
2001	200	59.87	16.50	19.95	20.9	1.112	66.596	0.333
2002	222	88.85	20.60	25.48	23.7	1.952	173.728	0.782
2003	831	612.00	20.60[3)]	25.48[2)]	23.7	1.561	955.699	1.150
Total	831	612.00					1,208.146	

[1)] Farmers' practice includes most new technologies except soil conservation
[2)] Fresh root price: in 2000 350 VND/kg
in 2001 350 VND/kg in north, 200 in central and 290 in south
in 2002 400 VND/kg
in 2003 320 VND/kg (estimated)
[3)] Yields estimated from 2002
Source: Tran Ngoc Ngoan, 2008

Table 14. Effect of various soil conservation practices on the average[1] relative cassava yield and dry soil loss due to erosion as determined from soil erosion control experiments, FPR demonstration plots and FPR trials conducted in Vietnam from 1993 to 2003.

		Rel. cassava yield (%)		Rel. dry soil loss (%)	
	Soil conservation-practices[2]	Cassava monoculture	Cassava + peanut	Cassava monoculture	Cassava + peanut
1.	With fertilizers; no hedgerows (check)	100	-	100	-
2.	With fertilizers; vetiver grass hedgerows**	113 (17)	115 (23)	48 (16)	51 (23)
3.	With fertilizers; *Tephrosia candida* hedgerows**	110 (17)	105 (23)	49 (16)	64 (23)
4.	With fertilizers; *Flemingia macrophylla* hedgerows*	103 (3)	109 (4)	51 (3)	62 (3)
5.	With fertilizers; *Paspalum atratum* hedgerows**	112 (17)	-	50 (17)	-
6.	With fertilizers; *Leucaena leucocephala* hedgerows*	110 (11)	-	69 (11)	-
7.	With fertilizers; *Gliricidia sepium* hedgerows*	107 (11)	-	71 (11)	-
8.	With fertilizers; pineapple hedgerows*	100 (8)	103 (9)	48 (8)	44 (9)
9.	With fertilizers; vetiver+*Tephrosia* hedgerows	-	102 (7)	-	62 (7)
10.	With fertilizers; contour ridging; no hedgerows*	106 (7)	-	70 (7)	-
11.	With fertilizers; closer spacing, no hedgerows	122 (5)	-	103 (5)	-
12.	With fertilizers; peanut intercrop; no hedgerows*	106 (11)	100	81 (11)	100
13.	With fertilizers; maize intercrop; no hedgerows	69 (3)	-	21 (3)	-
14.	No fertilizers; no hedgerows	32 (4)	92 1(5)	137 (4)	202 (12)

[1] number in parenthesis indicates the number of experiments/trials from which the average values were calculated.

[2] IC = intercrop, HR = hedgerows

** = most promising soil conservation practices; * = promising soil conservation practices

Nevertheless, adoption of soil conservation practices increased markedly from 2002 to 2003 (**Table 13**), partially because more farmers had seen the effectiveness of contour hedgerows in FPR trials, but also because the extension office in Van Yen district of Yen Bai province distributed 12 tonnes of free seed of *Tephrosia candida* and *Paspalum atratum* so as to encourage farmers to control erosion when planting cassava on steep slopes. Thus, in the spring of 2003 at least 500 km of double hedgerows of *Tephrosia* or *Paspalum* were planted in this district alone, covering 300-500 ha. This, combined with the use of new varieties (mainly KM 94), better fertilization (60N-40P_2O_5-80K_2O) and intercropping with peanut, increased average cassava yields in the district from about 10 t/ha to 30 t/ha.

Table 10 shows that the number of households adopting intercropping – mainly with peanut and, to a lesser extent, black bean (= black cowpea) – increased from 127 in 2000 to 4,250 in 2003. The very large increase in adoption from 2002 to 2003 is due to a marked increase in the number of project sites, but is also due to the rapid expansion of intercropped cassava in Van Yen district of Yen Bai province due to the distribution of seed of a new high-yielding peanut variety (LD-7) by the district extension office.

Although the small size of farm holdings and the abundance of labor in rural areas (especially in the north) of Vietnam favor very intensive crop production, including intercropping, this practice is still not so widespread. One reason is that intercropping oftentimes (but not always) decreases the yield of the main crop (**Tables 12** and **14**); secondly, it requires considerable extra labor for planting, harvesting and post-harvest

handling as well as money for buying the seed (0.3 mil. VND/ha), while weather conditions as well as pests and diseases make intercropping very risky. While intercropping can markedly increase gross and net income, many farmers are reluctant to invest in this practice because of the high risks involved.

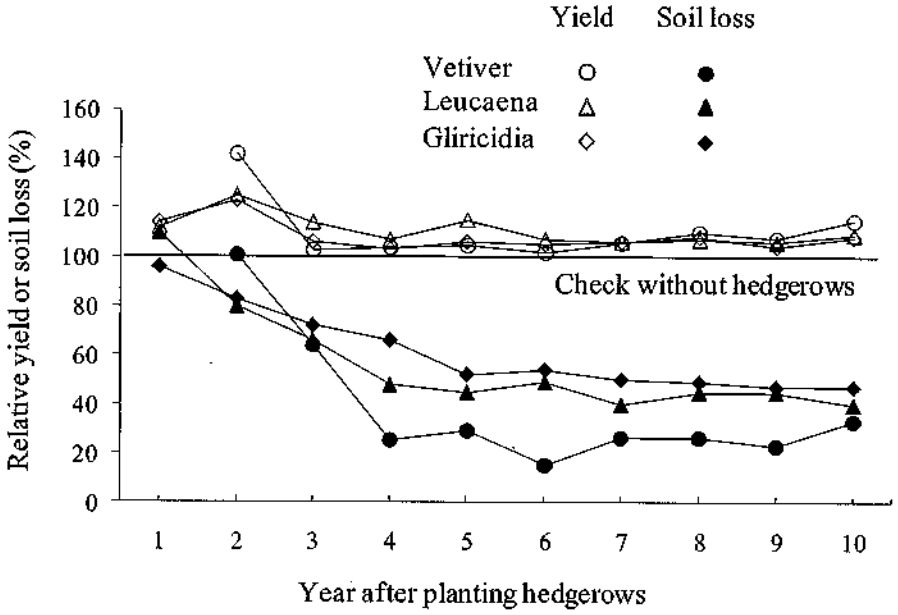

Figure 5. Trend in relative yield and relative soil loss by erosion when cassava was planted with contour hedgerows of vetiver grass, Leucaena leucocephala or Gliricidia sepium in comparison with the check without hedgerows during ten consecutive years in Hung Loc Agric. Research Center in South Vietnam from 1997/98 to 2006/07.

Table 10 also shows that the number of households adopting cassava root and leaf silage for feeding pigs increased markedly from practically zero in 2000 to 1,172 households in 2003, mainly in the pilot sites of Hue province in central Vietnam. In 2003, 1,172 households adopted this practice raising 3,370 pigs, which resulted in additional gross income of 145.5 mil. VND (US$ 9,400), or 0.124 mil. VND ($8.00) per household. The use of cassava silage has mainly an effect on reducing feed costs and may thus increase net income more than gross income (Nguyen Thi Hoa Ly *et al.*, 2008; 2009).

A good example of the extent of adoption of various technology components over time is shown in **Table 15** for Tien Phong commune in Pho Yen district of Thai Nguyen province, as well as the impact of this adoption on net income from cassava per ha and for the total community. This commune was selected as a suitable pilot site when the project commenced in 1994. At that time, according to the RRA, about 115 households planted cassava, cv Vinh Phu, on a total of 50 ha with an average yield of 8.5 t/ha. This produced a net income of 0.47 mil. VND/ha or 23.50 mil. VND for the whole commune. After conducting many FPR trials in 1995-1999 farmers started to adopt new varieties,

intercropping, more balanced fertilization and soil conservation practices (in small areas only, as most fields are rather flat). Over the years, more and more households adopted these new technologies in ever larger areas resulting in marked increases in yields, both of the local variety Vinh Phu and the new varieties. In 2003 new technologies had been adopted in a total of about 32 ha with an average yield of 36 t/ha. Net income per ha increased from 0.47 mil. VND in 1994 to about 14 mil VND in 2003, while total net income from cassava in the community increased from 23.5 mil VND ($2,350) in 1994 to over 450 mil. VND ($29,200) in 2003. Thus, during the 10-year period, the net income from cassava in the community increased in dollar terms more than ten times even though the area under cassava may have decreased from 50 to about 32 ha. This has had a profound effect on the standard of living of farmers in this commune. The impact is probably less pronounced in other sites mainly because of a shorter duration of involvement in the project and thus less adoption of new technologies. With time similar beneficial effects can be expected in many other communities in Vietnam.

Table 16 summarizes the extent of adoption of new cassava technologies in 15 pilot sites in Vietnam in 2003 and the resulting expected increase in gross income due to higher yields obtained. Although balanced fertilization produced the highest yields, it was not adopted over a very wide area. New varieties were most adopted resulting in the greatest increase in gross income. The total increase in gross income due to new technologies was estimated at 2.2 million US dollars or $96.03 per household.

5.4 Adoption of New Cassava Technologies and their Effect on Yield and Farm Income in Asia

The extent of adoption of specific technologies on a country-or continent-wide basis is almost impossible to determine. Nevertheless, surveys conducted in Thailand, Vietnam and China indicate the approximate extent of adoption of new varieties (**Table 17**). Information from RRAs, the Vietnam cassava survey of 1991/92 as well as published data in Thailand can give an average value for the area under cassava per household. Assuming that any one household has completely replaced their traditional cassava variety with new higher yielding varieties, we can get an idea about the minimum number of households in each country which planted new varieties. According to the data in **Table 17** at least 90,000 farmers in China, about 350,000 in Thailand and 718,000 in Vietnam or a total of at least 1.16 million farmers have benefited from planting new higher yielding varieties in these three countries. While it is impossible to say to what extent the Nippon Foundation project contributed to this rapid adoption of new varieties in Asia (**Figure 6**), it is probably fair to say that the project made a considerable contribution, either directly by conducting FPR trials with farmers, organizing field days and training courses, but also indirectly through the publication of booklets, pamphlets, as well as newspaper articles and TV. In Vietnam at least 15,000 farmers in 15 pilot sites have adopted new technologies, in Thailand at least 1000 farmers are members of "Cassava Development Villages" and in China over 700 farmers participated in FPR or regional training courses. Thus, it is likely that our target of benefiting at least 8000 farmers by this project was achieved, and probably surpassed by a considerable margin.

Table 15. Impact of the adoption of new cassava varieties and improved production practices on the livelihoods of farmers in Tien Phong commune, Pho Yen districtl of Thai Nguyen, Vietnam.

Year	Variety or practice[1)]	No. of farmers	Cassava area (ha)	Cassava yield (t/ha)	Peanut yield (t/ha)	Gross income[2)]	Production costs	Net income	Total net income
						(mil. dong/ha)			(mil.dong)
1994[3)]	Vinh Phu	115	50	8.5	-	3.40	2.93	0.47	23.50
	New varieties	0	-	-	-	-	-	-	-
			50						**23.50**
2000	Vinh Phu	NA[4)]	NA	21.5	-	NA	NA	NA	NA
	New varieties	25	1.31	30.9	-	15.45	4.36	11.10	14.54
	Intercropping	37	2.59	29.3	0.81	18.70	6.16	12.54	32.48
	Erosion control	4	0.20	24.7	-	12.35	4.66	7.69	1.54
			>4.10						**>48.56**
2001	Vinh Phu	61	2.17	22.7	-	11.35	4.36	6.99	15.17
	New varieties	122	4.70	29.0	-	14.50	4.36	10.14	47.66
	Intercropping	40	3.38	26.2	0.77	16.94	6.16	10.78	36.44
	Erosion control	4	0.20	NA	-	NA	NA	NA	NA
			10.45						**>99.27**
2002	Vinh Phu	18	0.64	25.4	-	12.70	4.33	8.37	5.36
	New varieties	100	5.16	33.7	-	16.85	4.33	12.52	64.60
	Intercropping	118	3.69	32.3	1.73	24.80	6.13	18.67	68.89
	Balanced fert.	48	2.95	33.4	-	16.70	4.83	11.87	35.02
	Erosion control	5	0.18	25.4	-	12.70	4.63	8.07	1.45
			12.62						**175.32**
2003	Vinh Phu	NA	NA	NA	-	NA	NA	NA	NA
	New varieties	225	17.00	36.8	-	18.40	4.33	14.07	239.19
	Intercropping	120	11.00	36.0	0.67	21.35	6.13	15.22	167.42
	Balanced fert.	54	3.40	33.6	-	16.80	4.83	11.97	40.70
	Erosion control	5	0.60	27.0	-	13.5	4.63	8.87	5.32
			>32.00						**>452.63**

[1)] In Tien Phong farmers traditionally grow mainly Vinh Phu variety but have now largely changed to KM 95-3 and KM 98-7; the new practices include intercropping with peanut, balanced fertilization of 10 t/ha of pig manure plus 80N-40P_2O_5-80 K_2O, and erosion control by contour hedgerows of *Tephosia candida*

[2)] Price of cassava in 1994: 400 VND/kg fresh roots
Price of cassava in 2000-2003: 500 VND/kg fresh roots
Price of peanut in 2000-3003: 5,000 VND/kg dry pods

[3)] Data from RRA at the start of project

[4)] NA = data not available

Another way of estimating the monetary benefits of adoption of new cassava technologies would be to look at the yield trends in the three countries where the Nippon Foundation project was most active. **Figure 7** shows the average cassava yields in India, Thailand, China, Indonesia and Vietnam from 1994 to 2004, i.e. the ten-year period corresponding to the Nippon Foundation project. Yields in all countries have increased, but the rate of increase was rather low in India, China and Indonesia, and very high in Thailand and Vietnam. From 1994 to 2004 yields in Thailand increased from 14.28 to 20.28 t/ha, a 47% increase corresponding to an annual rate of increase of 4.3%; during the same period yields in Vietnam increased from 8.44 to 14.98 t/ha, a 77% increase corresponding to an annual rate of increase of 5.9%, while in all of Asia yields increased

from 12.93 to 16.99 t/ha or at an annual rate of 2.77%. In Thailand cassava yields have increased steadily since 1995, a few years after some of the high yielding varieties were released and started to be adopted (**Table 6**). In Vietnam the same thing happened but only about five years later. In China the process has barely started with only about 8% coverage of new varieties, *versus* about 50% in Vietnam and 100% in Thailand. Yields in China are expected to increase substantially, especially in Guangxi and Hainan provinces where the project has been quite active in developing and disseminating new varieties.

Table 16. Extent of adoption of new cassava production technologies in 15 FPR pilot sites in Vietnam in 2003/04, the effect on cassava yields, and the increase in gross income resulting from the yield increase in those sites.

Technology component	No. of households	Area (ha)	Cassava yield (t/ha)		Increase in gross income ('000 US$)[2)]
			Farmers' practice[1)]	Improved technology	
1. New varieties	14,820	7,849	17.61	29.93	1,996
2. Balanced fertilization	1,710	607	21.37	30.50	114
3. Soil conservation practices	831	612	20.60	25.48	62
4. Intercropping	4,250	160	29.95	28.94	15 [4)]
5. Root and leaf silage for pig feeding	1,287	-[3)]	-	-	12
Total	**22,898**	**9,228**			**2,199**

[1)] Farmers' practice usually includes most new technologies except the technology being tested
[2)] based on an expected price of 320 VND/kg fresh roots in 2003/04; 1 US$ = 15,500 VND
[3)] 3,370 pigs
[4)] increase in gross income from the harvest of intercrops
Source: *adapted from Tran Ngoc Ngoan, 2008.*

Table 17. Estimate of the area under new cassava varieties in China, Thailand and Vietnam in 2003 and the minimum number of households that planted these varieties.

	Area under new varieties (ha)	Average cassava area per household (ha)[1)]	Average no. of farmers adopting new varieties[2)]
China -Guangxi	16,666	0.22	75,500
-Guangdong	~6,000	0.53	~11,320
-Hainan	1,333	0.53	2,500
Thailand	1,000,000	2.86	350,000
Vietnam	194,000	0.27	718,000
Total			**~1,157,820**

[1)] Data estimated from RRA in China in 1994 (Henry and Howeler, 1996) and the Vietnam Cassava Survey of 1991/92 (Pham Than Binh *et al.*,, 1996) and Office Agric. Economics, Thailand (2002); Hoang Kim *et al.*, 2005
[2)] Assuming complete replacement of old by new varieties

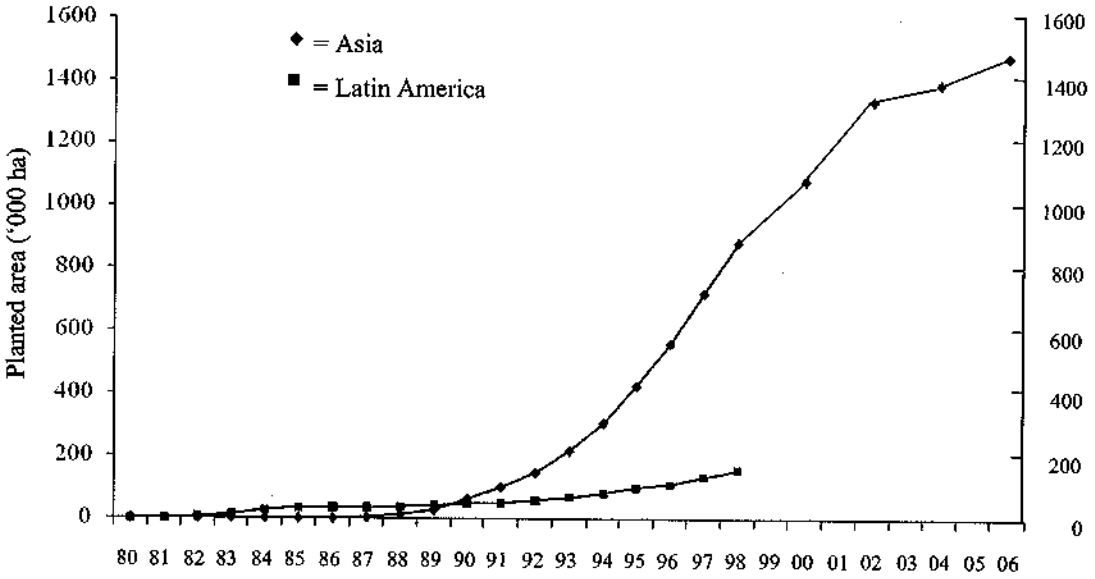

Figure 6. Adoption of CIAT-related cassava varieties in Latin America and Asi from 1980 to 2006.
Source. *C.H. Hershey; 2000-06 estimated by R. Howeler.*

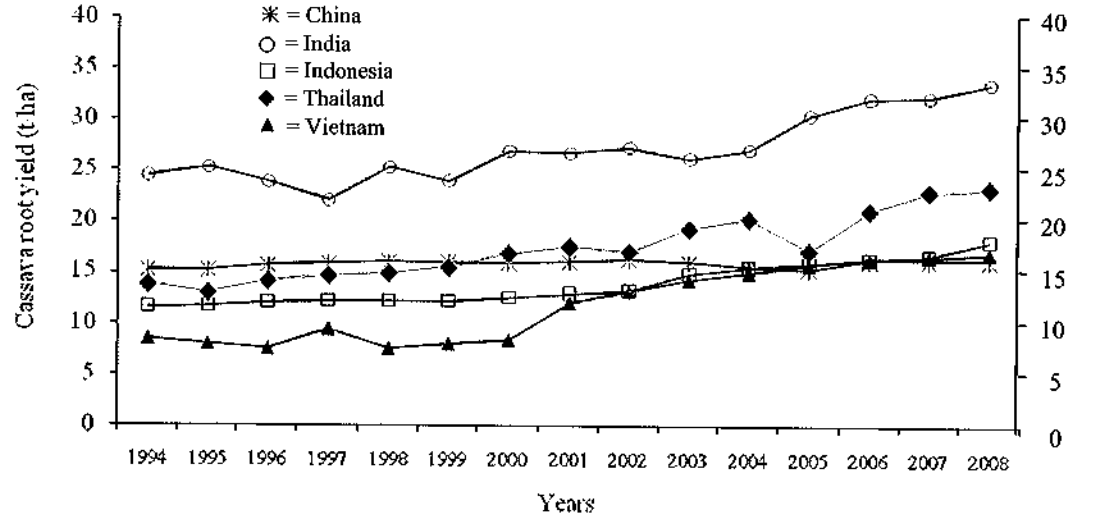

Figure 7. Change in cassava yield in five countries in Asia from 1994 to 2008.
Source*: FAOSTAT, 2010.*

Table 18 shows the impact of these yield increases on gross income in China, Thailand and Vietnam as well as for all of Asia, based on FAO data. During the past ten years yields in China increased 0.79 t/ha (our Chinese colleagues insist that those data are incorrect and that both the area under cassava and the yield increase is actually much higher), in Thailand 5.49 t/ha, in Vietnam 5.84 t/ha, and in all of Asia 3.68 t/ha. Considering the area under cassava in 2003 and the average price of fresh roots, it is possible to calculate the annual additional gross income from the increased cassava yields as compared to ten years ago. For China this was calculated to be 5.35 million, for Thailand 123.42 million and for Vietnam 54.30 million US dollars. In addition, Thai farmers received a price premium for planting varieties with higher starch content, which is not included in these calculations. For Asia as a whole the yield increase of 3.68 t/ha corresponds to an extra 318 million US dollars in the pockets of cassava farmers every year. If we estimate that there are about 8-10 million cassava farmers in Asia, this means that the increased cassava yields provided about $30-40 extra income per family as compared to ten years ago. In Thailand this may be as high as $350.-; in many countries it will be much less than $20.-. This is not insignificant considering that the net farm income in NE Thailand is $375.- per year; in other countries it is much lower. The economic benefits of the project continued to increase in subsequent years, as both cassava yields and area planted increased while in many countries in Asia the cassava root price more than doubled between 2003 and 2008 (see **Table 21** below).

Table 18. Estimated increase in gross income of cassava farmers in China, Thailand, Vietnam and in all of Asia as a result of increased cassava yields in 2004 as compared to 1994.

	Total cassava area (ha)[1)]	Cassava yield (t/ha)[1)]		Yield increase (t/ha)	Cassava price ($/tonne)	Increased gross income due to higher yields (mil. US$)
		1994	2004			
China	245,767	15.23	15.53	0.30	30	2.21
Thailand	1,057,338	13.81	20.28	6.47	26	177.86
Vietnam	388,600	8.44	14.98	6.54	28	71.16
Asia total	3,494,567	12.93	16.99	4.06	28	397.26

[1)] Data from FAOSTAT in 2010

[2)] In addition, farmers also benefited from higher prices due to higher starch content

In Vietnam the official government policy ten years ago was to maintain the area under cassava constant but increase yields. In fact, both area and yields have increased substantially, resulting in a 147% increase in cassava production between 1994 and 2004. Ten years ago their were no medium- to large-scale starch factories and most cassava was used either for human consumption or on-farm pig feeding. In 2003 there were 24 medium- to large-scale factories in operation and another 18 in the planning or construction stage. In much of Asia cassava has been transformed from a food-security crop to an important industrial crop, used mostly for production of starch and animal feed, both for domestic use and export. Many national and provincial governments now consider cassava as an ideal vehicle for rural development: the crop is easy to grow, tolerates poor soils and long droughts, has no diseases or pests, requires little in terms of inputs or infrastructure

and has multiple end-uses, providing both rural and urban employment. While many social, political and economic factors determined that change, the dedicated and hard work of our collaborators in the Nippon Foundation project - researchers, extension workers and farmers - surely contributed to this development. Moreover, without the sustained and generous financial support from the Nippon Foundation, as well as the technical and methodological support from CIAT this would not have been achieved. It is a case of many people working together towards a common goal: to enhance the sustainability of cassava cropping systems while increasing the livelihood of poor farmers.

5. IMPACT ASSESSMENT

In order to determine what impact the implementation of the Nippon Foundation project has had on the adoption of new cassava varieties and various production practices and the subsequent effect on cassava yields and income, an Impact Assessment study was conducted by an outside consultant, Dr. Tim Purcell, using funding generously provided for that purpose by SPIA (the CG's "Standing Panel on Impact Assessment"), in collaboration with the CG's System-wide Participatory Research and Gender Analysis (PRGA) program at CIAT. The study started in Oct 2003, coinciding with the End-of-Project Workshop, in order to discuss the methodology to be used with various project collaborators. Selection of appropriate and representative sites and the design of questionnaires were discussed between Tim Purcell, Nina Lilja of PRGA and Reinhardt Howeler, project coordinator. It was agreed that the study would collect data in four project sites each in Thailand and Vietnam, both from "participating" and "non-participating" farmers, in "project" and nearby (within 10 km) "non-project" villages[3]. Data would be collected from 1) government officials in the subdistrict; 2) from interviews of focus groups of about 20 farmers each in project and non-project villages; and 3) from a questionnaire filled out by farmers in the focus groups, both for their own family as well as for two neighbors. Thus, data were collected from officials in eight sites (in addition, similar data from subdistrict offices from all project sites was solicited by mail), from focus groups in 16 villages, and from survey forms from 832 households. The field work was conducted by Tim Purcell in collaboration with staff from DOAE and DOA in Thailand, and from IAS, TNUAF and NISF in Vietnam during Nov-Dec 2003. The final report entitled "Integrating Germplasm, Natural Resource, and Institutional Innovations to Enhance Impact: the Case of Cassava-Based Cropping Systems Research in Asia" was submitted to CIAT in April 2004. The 81 page report is supplemented with 215 tables and 26 figures for a total of over 500 pages (Purcell, 2004).

Tables 19 and **20** show the number of participating and non-participating farmers (out of 832) and the percentage of farmers, respectively, that had adopted specific technologies in the eight selected project sites in Thailand and Vietnam. The last three columns show whether there were statistically significant differences between "participating" and "non-participating" farmers. Some important conclusions are as

[3] *Participating* farmers were mostly but not exclusively from the *project village* (pilot site) and *Non-participating* farmers were mostly but not exclusively from the nearby *non-project village*. *Participating* farmers are defined as those that have either conducted FPR trials and/or participated in FPR training courses. *Non-participating* farmers may have attended project field days, but had otherwise not been directly involved in the project.

follows:

1. Overall, chemical fertilizers were adopted by 84% of farmers, new varieties by 69%, contour ridging by 30%, contour hedgerows by 30%, and intercropping by 37% of surveyed farmers.
2. There were no statistically significant differences between participating and non-participating farmers in the adoption of new varieties, but there were highly significant differences in the adoption of contour ridging, planting of vetiver, *Tephrosia* (in Vietnam only) and *Paspalum* hedgerows, intercropping, and the application of chemical fertilizers and animal or green manures. In general, a larger percentage of participating than non-participating farmers had adopted new technologies, including new varieties (though the latter was not significant).
3. In Thailand, 100% of participating farmers and 87%[4] of non-participating farmers had adopted new varieties; in Vietnam, this was 48 and 45%, respectively.
4. Since new varieties spread nearly equally among participating and non-participating farmers and well beyond the project sites (all over the country in case of Thailand), the use of an FPR approach may not be essential as standard training and extension approaches seemed to be equally effective. Still, testing new varieties in FPR trials is an excellent way to get farmers interested in testing other technologies as well. Moreover, from the results of FPR trials farmers may select certain "new" varieties that are particularly suitable for their own conditions, such as KM 98-7 and KM 95-3 in Pho Yen district in north Vietnam **(Table 28)**. In China, some of the officially released varieties now promoted by the extension service were actually selected by farmers from their FPR trials.
5. The use of an FPR approach seems to be particularly useful to enhance the adoption of practices with no- or little immediate benefits, such as erosion control measures and green manuring. The beneficial effects of these practices tend to accrue over time and are not clearly visible except when demonstrated in small plots side-by-side with the local practice.
6. Among soil conservation practices, about an equal percentage of farmers adopted contour ridging as contour hedgerows (of any type), while slightly over 50% of farmers did not adopt any soil conservation measures. The FPR project was particularly successful in enhancing the adoption of vetiver grass hedgerows in Thailand and *Tephrosia* or *Paspalum* hedgerows in Vietnam. However, it is also clear that these technologies did not spread widely beyond the immediate project sites indicating that the dissemination of these practices was not very successful. Adoption of vetiver grass in Thailand was partially a result of the promotion of this technology by the Royal Family and most government institutions. The adoption of *Tephrosia* and *Paspalum atratum* in Vietnam was also largely due to the distribution of free seed. Without these or other incentives it is unlikely that many farmers would have adopted these hedgerow technologies.
7. Fertilizers were widely adopted, but whether or not farmers adopt and how much fertilizer is applied depends largely on the economic status of the farmers; for that reason, adoption is not very different between participating and non-participating farmers (not significant in Vietnam).

[4] This figure seems low since nation-wide surveys indicate 98% adoption of new varieties; the 87% figure may refer to *new* varieties adopted since the project started in 1994.

However, many participating farmers in both Vietnam and Thailand changed the *type* of fertilizers they applied, increasing the levels of N and K and decreasing that of P as a result of FPR trials.

8. Adoption of intercropping has been very limited, especially in Thailand; only in a few sites cassava is intercropped with maize or green manures. In Vietnam intercropping with peanut was the most widely adopted (35%) and this was significantly higher among participating than non-participating farmers.
9. Adoption of all technology components as well as changes in cassava yields over the course of the project were highly dependent on site characteristics.
10. Cassava yields increased significantly more for participants than non-participants (**Figure 8**); this change was mainly due to participation in FPR training courses. It is likely that the knowledge gained in these courses contributed to significant increases in cassava yields.
11. Among all surveyed farmers, cassava yields in Thailand increased from 20.11 t/ha before the project to 24.04 t/ha after the project. In Vietnam yields increased from 14.92 t/ha before the project to 22.35 t/ha after the project. These are significant yield increases obtained over a relatively short time (2-8 years) of participation (or not) in the project. However, in both Thailand and Vietnam cassava yields country-wide also increased significantly over the past five years[5] (**Figure 8**), indicating that the project may have had a direct effect on the yields of participating farmers as well as an indirect effect on yields nation-wide. But many other factors, such as site characteristics and wealth status of farmers were significant determinants of yield.
12. Univariate analysis indicate that yields increased significantly by the adoption of new varieties, soil conservation practices and intercropping; whether or not fertilizers had been adopted (not the level of fertilizers applied) had a significant effect only on cassava yields after the project but not on the change in yield. In multivariate analyses, however, the change in cassava yields was significantly determined only by site effects and participation in the project; among cassava technologies only the adoption of new varieties had a significant effect on yield after the project, while the effects of soil conservation practices, fertilizers or intercropping on yield were not significant as these effects are partially obscured by other factors such as site effects and wealth status of the household.

Thus, in general terms, participation in the project had a significant effect on the extent of adoption of soil conservation practices, intercropping and fertilizer use, but not on the adoption of "new varieties"; most likely it had an effect on the selection of a particular variety. Adoption of new varieties and chemical fertilizer use was widespread, but this was achieved mostly by traditional extension approaches used by various government institutions; fertilizer adoption was largely determined by the available financial resources of each household. Soil conservation measures and intercropping practices were not widely adopted beyond the pilot sites as the perceived benefits did not always justify the costs and labor involved.

[5] roughly corresponding to the same period between "before" and "after" the project

Table 19. Extent of adoption (number of households) of new technologies by participating and non-participating farmers in the Nippon Foundation project in Thailand and Vietnam in 2003.

	Participants			Non-Participants			Total		
Technologies adopted	Thailand	Vietnam	Overall	Thailand	Vietnam	Overall	Thailand	Vietnam	Overall
Varieties									
- >75% improved varieties	117	71	188	279	110	389	396	181	577
- about 50% improved varieties	0	50	50	1	51	52	1	101	102
- mainly traditional varieties	0	24	24	0	85	85	0	109	109
- no cassava	0	2	2	42	0	42	42	2	44
Soil conservation practices									
- contour ridging	62	46	108	71	71	142	133**	117	250**
- hedgerows - vetiver grass	72	17	89	31	9	40	103**	26**	129**
- *Tephrosia candida*	0	48	48	0	17	17	0	65**	65
- *Paspalum atratum*	1	17	18	0	5	5	1	22**	23**
- pineapple	0	4	4	0	2	2	0	6	6
- sugarcane	2	0	2	2	0	2	4	0	4**
- other hedgerows	4	11	15	1	4	5	5*	15**	20**
- no soil conservation	24	43	67	228	146	374	252**	189**	441**
Intercropping									
- with peanut	1	60	61	2	76	78	3	136*	139**
- with beans	0	35	35	0	67	67	0	102	102**
- with maize	12	4	16	9	9	18	21**	13	34
- with green manures	24	0	24	13	0	13	37**	0	37**
- other species	3	64	67	5	53	58	8	117**	125**
- no intercropping	84	30	114	291	117	408	375**	147**	522**
Fertilization									
- chemical fertilizers	115	117	232	272	197	469	387**	314	701**
- farm yard or green manure	66	96	162	82	136	218	148**	232	380**
- no fertilizer	0	24	24	40	35	75	40**	59	99**
Total	117	147	264	322	246	568	439	393	832

Households can adopt more than one type of technology simultaneously

Significant Difference between Participants and Non-Participants; *=95% Significance Level, **=99% Significance Level

Source: *Impact Assessment (Agrifood Consulting International, 2004)*

Table 20. Extent of adoption (percent of households) of new technologies by participating and non-participating farmers in the Nippon Foundation project in Thailand and Vietnam in 2003.

	Participants			Non-Participants			Total		
Technologies adopted	Thailand	Vietnam	Overall	Thailand	Vietnam	Overall	Thailand	Vietnam	Overall
Varieties									
- >75% improved varieties	100	48.3	71.2	86.6	44.7	68.5	90.2	46.1	69.4
- about 50% improved varieties	0	34.0	18.9	0.3	20.7	9.2	0.2	25.7	12.3
- mainly traditional varieties	0	16.3	9.1	0	34.6	15.0	0	27.7	13.1
- no cassava	0	1.4	0.8	13.0	0	7.4	9.6	0.5	5.3
Soil conservation practices									
- contour ridging	53.0	31.3	40.9	22.0	28.9	25.0	30.3**	29.8	30**
- hedgerows - vetiver grass	61.5	11.6	33.7	9.6	3.7	7.0	23.5**	6.6**	15.5**
- *Tephrosia candida*	0	32.7	18.2	0	6.9	3.0	0	16.5**	7.8
- *Paspalum atratum*	0.9	11.6	6.8	0	2.0	0.9	0.2	5.6**	2.8**
- pineapple	0	2.7	1.5	0	0.8	0.4	0	1.5	0.7
- sugarcane	1.7	0	0.8	0.6	0	0.4	0.9	0	0.5**
- other hedgerows	3.4	7.5	5.7	0.3	1.6	0.9	1.1*	3.8**	2.4**
- no soil conservation	20.5	29.3	25.4	70.8	59.3	65.8	57.4**	48.1**	53.0**
Intercropping									
- with peanut	0.9	40.8	23.1	0.6	30.9	13.7	0.7	34.6*	16.7**
- with beans	0	23.8	13.3	0	27.2	11.8	0	26.0	12.3**
- with maize	10.3	2.7	6.1	2.8	3.7	3.2	4.8**	3.3	4.1
- with green manures	20.5	0	9.1	4.0	0	2.3	8.4**	0	4.4**
- other species	2.6	43.5	25.4	1.6	21.5	10.2	1.8	29.8**	15.0**
- no intercropping	71.8	20.4	43.2	90.4	47.6	71.8	85.4**	37.4**	62.7**
Fertilization									
- chemical fertilizers	98.3	79.6	87.9	84.5	80.1	82.6	88.2**	79.9	84.3**
- farm yard or green manure	56.4	65.3	61.4	25.5	55.3	38.4	33.7**	59.0	45.7**
- no fertilizer	0	16.3	9.1	12.4	14.2	13.2	9.1**	15.0	11.9**
Total	100	100	100	100	100	100	100	100	100

Percentages may total more than 100 percent as households can adopt more than one type of technology simultaneously

Source: Impact Assessment (Agrifoood Consulting International, 2004)

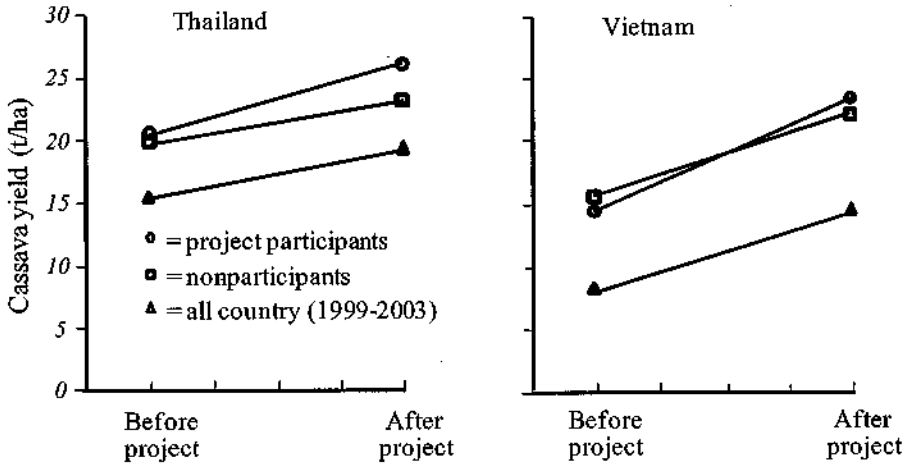

Figure 8. Average cassava yields of farmers participating in the Nippon Foundation cassava project of nearby but non-participating farmers, before the project started and at the end of the project. Data are from PRRA census forms collected from 439 households in Thailand and 939 households in Vietnam. For comparison, the national average cassava yields in 1999 (before) and 2003 (after) are also shown.

Based on the results of the Impact Assessment a farm-level decision model was formulated by Dalton *et al.* (2005, 2007) to calculate the benefits of the project by type of beneficiary and by village. Also, the internal rate of return (IRR)) of the project was calculated at 20% during the project's implementation phase, and 34.1% if the benefits are extrapolated to an additional five years; if spillover effects are included, the IRR reached 49.2% (Dalton *et al.*, 2005).

Another study (Calkins and Vu Thi Thao, 2005) looked at the institutional impact of the Nippon Foundation Project in Thailand and Vietnam. While the authors concluded that the project was highly successful, both agronomically and institutionally, they showed quite marked differences among countries and institutions in the factors responsible for the perceived impacts of the FPR project.

6. CONCLUSIONS AND LESSONS LEARNED

From the implementation and results of the second phase of the Nippon Foundation project the following conclusions and lessons can be drawn:

1. To achieve widespread adoption of new technologies, as many farmers as possible should be involved in conducting FPR trials, participating in field days and in training courses; this can only be achieved by the active collaboration of many research institutions, universities, and extension offices, at national, provincial, district and subdistrict levels. This allows the project to extend rapidly to many sites. Active and enthusiastic participation of the local extension workers are crucial for the success of the project.
2. Training of project staff in FPR methodologies is not only essential to impart knowledge about the various tools and methods, but also to motivate people to

work enthusiastically with and for the benefit of farmers.

3. Training of farmers and local extension workers together in FPR methodologies and cassava production technologies was an effective way to exchange knowledge and experiences between farmers from various regions, and to encourage farmers to experiment, to innovate and to draw their own conclusions.
4. The conducting of FPR erosion control trials on their own fields allowed farmers to see the actual soil losses as a result of erosion, and that simple agronomic practices can markedly reduce erosion. Participating in these trials and in training courses were the determinant factors in the adoption of soil conservation measures.
5. Most farmers are not aware or not concerned about soil erosion and may not be interested in conducting FPR erosion control trials. The simultaneous testing of other technology components such as new varieties, fertilizer practices and intercropping that are likely to have more immediate benefits is a good way to get farmers involved in testing soil conservation measures as well. Only the whole package of "improved" practices (including soil conservation measures) will have an immediate beneficial effect on income.
6. The beneficial effects of various hedgerow technologies became apparent only after some time. As such, some erosion control experiments should be continued for many years to show the long-term effect on terrace formation and increased yields to visiting farmers and extension workers.
7. Besides hedgerows, there are other "soil conservation" measures, such as closer plant spacing, balanced fertilization (including animal and/or green manures) and contour ridging, that are effective in reducing erosion and may be more easily adopted by farmers.
8. Vetiver grass contour hedgerows is one of the most effective ways to control erosion and the grass never becomes a weed. However, its establishment from vegetative planting material is slow and costly. For that reason vetiver grass should be used strategically only in those areas where it is most needed, i.e. across natural drainage ways or gullies; this may require the use of sand bag barriers for initial establishment. Hedgerows of seed-propagated species such as *Palpalum atratum, Brachiaria brizantha* or *Tephrosia candida*, can be planted more quickly and cheaply, and these will serve well in the higher and convex parts of the landscape.
9. Every agricultural research and extension institution, both national and international, has its own areas of strength as well as weaknesses. By pooling their strength and working together they can become more effective in solving problems which contribute to the development of the country and will benefit poor farmers.

7. EPILOGUE

Table 21 shows that after the end of the Nippon Foundation Cassava Project in China, Thailand and Vietnam in 2004, cassava yields have continued to increase, even at an accelerated pace. This is partially due to the continued increase in adoption of higher-yielding varieties and improved agronomic practices developed, together with farmers, during the course of the project, but also due to favorable market forces which increased demand for cassava and the cassava root price, which in turn allowed farmers to invest more in their cassava production practices.

Table 21. Estimated increase in gross income of cassava farmers in China, Thailand and Vietnam and in all of Asia as a result of increased cassava yields in 2007/08 as compared to 1993/94.

	Total cassava area (ha)	Cassava yield (t/ha)		Cassava price ($/tonne)	Increased gross income due to higher yields (mil. US$)	Estimated no. of hh growing cassava (million)	Estimated additional gross income/ hh (US$)
		1994	2008				
China[1)]	268,580	15.23	16.24	62	16.82	0.896	18.77
Thailand	1,183,536	13.81	23.29	57	639.54	0.448	1,427.55
Vietnam	555,700	8.44	16.91	59	277.70	2.074	133.90
Asia total	3,967,563	12.93	19.85	59	1,619.88	7.120	227.51

[1)] Data from the Chinese Ministry of Agriculture indicate much higher yields and much greater area than the FAO data.

Source: *FAOSTAT, Feb 2010.*

The question remains, whether the adoption of those practices that were selected by farmers as a result of their involvement in FPR trials, field days and training courses, continued to spread to other areas after the project had terminated; or whether some of these practices that looked promising and were adopted during the project were later discontinued; and if so, which practices were continued and which were not continued, and why? Was the FPR methodology used in the project robust enough to be self-sustaining, resulting in continued testing and adoption of still better technologies by farmers? If not, why not? Are there other ways to enhance the adoption and make cassava production in Asia more efficient and more sustainable. The following three papers will explore what has happened during the five years after the project terminated in each of the three countries.

8. RECOGNITION

Mrs. Wilawan Vongkasem, principal collaborator from the Thai Department of Agric. Extension (DOAE) in the Nippon Foundation project, was honored with "the King of Thailand Vetiver Award" for her paper entitled "The Use of Vetiver for Soil Erosion Prevention in Cassava Fields in Thailand". Mrs. Wilawan received the award from HRH Princess Maha Chakri Sirindhorn during the International Vetiver Grass Conference held in Aug 10-15, 2003 in Guangzhou, China.

Reinhardt Howeler, Watana Watananonta and Tran Ngoc Ngoan received the "2006 International Service in Agronomy Award" from the American Society of Agronomy (ASA), as representatives of the "Cassava Team" comprising all people directly involved in the implementation of the Nippon Foundation funded FPR Cassava Project. Reinhardt Howeler received the award during the Annual Meeting of ASA on Nov 16, 2006 in Indianapolis, USA. In June 2008 the same three people received the "2007 Distinguished Researcher Award" from the World Association of Soil and Water Conservation for their contribution to enhancing the adoption of soil conservation practices.

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THE IMPACT OF THE NIPPON FOUNDATION CASSVA PROJECT IN THAILAND: FIVE YEARS ON

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ABSTRACT

During the Nippon Foundation Cassava Project on "Improving the Sustainability of Cassava-based Cropping Systems" from 1994 to 2003, the project had conducted about 400 FPR trials in Thailand and had transferred new technologies to increase cassava yields and decrease soil erosion. Farmers had adopted many new technologies, such as new varieties, application of chemical fertilizer and using green manures for improving soil productivity, and growing vetiver grass hedgerows for soil erosion control. They set up "self-help groups" to help each other to develop cassava production in the community by using and managing a rotating credit fund.

This year (2008), five years after the project had terminated, another survey on farmer agricultural activities and adoption of new technologies in four of the project sites was carried out. A Farmer Participatory Evaluation methodology was used, interviewing groups of farmers, mapping and preference ranking, in order to gather the data on cassava production technologies, the planting of vetiver grass hedgerows for soil erosion control, and the functioning of the self-help groups, called "Cassava Development Villages". The survey was conducted in four villages of four provinces: Soeng-Saang district of Nakorn Ratchasima province; Sahatsakhan district of Kalasin province; Wang Somboon district of Sakaew province; and Nadee district of Prachinburi province.

Cassava production in all four villages had significantly increased. Most farmers had adopted the new cassava varieties, while some farmers had introduced a new early-maturing variety to the community. Chemical fertilizers are being increasingly applied in comparison with the start of the project. On the other hand, farmers had slightly decreased the use of green manures and vetiver grass hedgerows. But some farmers in Wang Somboon district had extended their vetiver grass hedgerows. By our observation, it was found that most of the vetiver grass hedgerows were not as functional as they should be, because many were now in broken lines due to the effect of herbicides, damaged in land preparation by tractor, or by weeding. Recently, additional activities are carried out in the villages supported by the revolving fund to increase cassava production and other agricultural products.

INTRODUCTION

The Nippon Foundation-funded cassava project was conducted in Thailand from 1994 to 2004. Details about the farmer participatory research (FPR) and extension (FPE) methodologies used and the results obtained have been reported previously (Wilawan Vongkasem *et al.*, 2008; Watana Watananonta *et al.*, 2008; Surapong Charoenrath *et al.*, 2008). During those ten years, about 400 FPR trials were conducted by farmers on their own fields in 33 project sites all over Thailand, mainly testing cassava varieties, various types and rates of chemical and organic fertilizers, erosion control practices, green manures, weed control, intercropping and plant spacing (Howeler, 2008a; 2008b). Towards

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the end of the project in 2002, participatory Monitoring and Evaluation (M&E) exercises were conducted in four sites where the project had been working for at least five years, to determine the extent of adoption of the various technologies that farmers had tested in their FPR trials. This indicated that practically all farmers had adopted the planting of new varieties in 100% of their cassava areas, although they had changed varieties as newer and better varieties were being released. While few farmers were applying chemical fertilizers when the project started, almost all farmers were applying some fertilizers in 80-100% of their cassava areas towards the end of the project. In two of the four sites some farmers were also intercropping cassava with green manures, mainly *Canavalia ensiformis,* to improve the soil. Many farmers had also conducted various intercropping trials, but this technology was not widely adopted as most landholdings in Thailand are relatively large and most households don't have enough labor to attend to the intercrops. Moreover, intercrops make it more difficult to use any mechanized weed control or to apply herbicides, while unpredictable rainfall and various insect and disease problems increase the risk of complete intercrop failure.

After testing various erosion control practices in their FPR trials, almost all farmers considered the planting of vetiver grass contour hedgerows as the most effective and most practical method to reduce erosion; as such, the planting of vetiver grass hedgerows had been adopted in 20-55% of the cassava area in the village, depending largely on the slope of the land and the need to control erosion. In all the 33 project sites combined, farmers had planted about 145 km of vetiver grass hedgerows. This was considered a very successful rate of adoption; as a result, the Department of Agricultural Extension received the "King of Thailand Vetiver Award" in 2003.

Towards the end of the project in Dec 2003, an intensive impact assessment was also conducted by an outside consultant, who collected detailed information from about 400 households in eight villages in Thailand; of these, four were villages that had directly participated in the project and four were nearby but non-participating villages. This impact assessment confirmed that practically 100% of cassava farmers participating in the assessment had adopted new varieties, 85-98% were using chemical fertilizers, only 10-30% of farmers intercropped cassava, and an average of 23% had adopted the planting of vetiver grass hedgerows to control erosion. While the extent of adoption of new varieties was not statistically significantly different between participating and non-participating farmers, this was not the case for the adoption of chemical fertilizers, intercropping and erosion control practices. In case of these three technologies, the extent of adoption was significantly higher for participating *vs* non-participating farmers (Dalton *et al.*, 2007).

While the adoption of most of these technologies was considered very good, which was largely attributed to the effectiveness of the FPR and FPE methodologies used, the question still remains whether more farmers will continue to adopt these technologies, even in the absence of an active FPR project once the project funding had stopped. For that reason, four project sites were revisited five years after the end of the project to assess whether the adoption of the farmer-tested technologies had continued after the end of the project, and if not, which technologies were not continued and for what reason.

OBJECTIVE

To evaluate the impact of technologies that the farmers had adopted after the Nippon Foundation project ended, particularly concerning cassava varieties, fertilizer application, green manures and the planting of vetiver grass contour hedgerows to control erosion.

SITES AND METHODS

Farmers in four project sites, i.e. Huay Suea Ten in Kalasin province, Baan Khlong Ruam in Sra Kaew province, Sapphongphoot in Nakhon Ratchasma province and Aang Thong in Prachinburi province, were revisited in 2008 to conduct a farmer participatory evaluation of current practices. About 20 farmers in each site participated; various tools were used, such as mapping, ranking, time line and cart methodologies, as well as semi-structured interviews.

RESULTS

1. Impact on Cassava Yields

Table 1 shows the change in cassava yields between 2002 and 2007 as reported by the farmers participating in the evaluation, as well as the average for the whole country. In all four project sites yields had increased markedly during the past five years, on average from 19.4 t/ha to 30.4 t/ha, while the average yield for the country increased from 17.1 t/ha to 22.9 t/ha during the same period. Thus, in the project sites yields had increased about 57%, while in the whole of Thailand yields had increased by 34% during the same five year period.

Table 1. Cassava yields reported by farmers in four project sites, as well as the average yield for the whole of Thailand in 2002 and 2007.

	Cassava yields (t/ha)	
Project sites	2002	2007
Huay Suea Ten, Kalasin	18.1	28.1
Baan Khlong Ruam, Sra Kaew	24.0	32.0
Sapphongphoot, Nakhon Ratchasima	19.2	30.8
Aang Thong, Prachinburi	16.4	30.8
National Average	17.1	22.9

2. Adoption of New Varieties and Agronomic Practices

Table 2 shows which varieties and cultural practices were used by the farmers in 2002 and in 2007. In 2002 the main varieties were Rayong 1, Rayong 60, and KU 50 , while in 2007 farmers were planting mainly KU 50 and Huay Bong 60. Not much had changed with respect to the method of land preparation, which continued to be done by hired tractor. Average fertilizer application rates had increased from about 150 kg/ha to 300 kg/ha, while the use of animal manures had also increased. On the other hand, in 2007 fewer farmers were planting green manures or vetiver grass hedgerows .

Table 2. Agronomic practices used by farmers in the four project sites in 2002 and 2007.

Agronomic practices	2002	2007
Varieties	R 1, R 60 and KU 50	KU 50, R 72 and Huay Bong 60
Land preparation	by tractor, 2 times	by tractor, 2 times
Fertilizer application	156 kg/ha	312 kg/ha
Animal manure application	*	**
Green manures	**	*
Vetiver grass hedgerows	**	*

Table 3 shows in more detail which varieties were planted in each site in 2002 and 2007. In most sites the older varieties Rayong 1 and Rayong 60 had been replaced by the new variety Huay Bong 60, while KU 50 remained the most popular variety in all sites, and Rayong 5 and Rayong 90 were planted only in some locations.

Table 3. Cassava varieties planted in the four project sites in 2002 and 2007.

	Kalasin		N. Ratchasima		Sra Kaew		Prachinburi	
Variety	2002	2007	2002	2007	2002	2007	2002	2007
Rayong 1	*							
Rayong 5					*	*	*	*
Rayong 60			*		*			
Rayong 72				*				*
Rayong 90	*	*						
Kasetsart 50	*	*	*	*	*	*	*	*
Huay Bong 60		*		*		*		*

With respect to the type of fertilizers applied, **Table 4** shows that there was some change between 2002 and 2007. There may have been some change towards fertilizers with a higher K content, but it does not seem to be very consistent. On the other hand, **Table 5** shows that the amounts of fertilizers applied had increased in at least three of the four sites. This could have been as a result of the FPR fertilizer trials conducted in each site, but could also be in response to a marked increase in the price of fresh roots in 2007/08, which prompted farmers to increase their inputs in the hope of increasing their yields. In addition, **Table 6** shows that farmers in all four sites had started to use farmyard manure, mostly chicken and cow manure, at rates of 0.8-3.8 t/ha. Highest rates were applied in Nakhon Ratchasima.

Table 4. Types of chemical fertilizers applied to cassava in each site in 2002 and 2007.

Project site	2002	2007
Huay Suea Ten, Kalasin	15-15-15	15-15-15
	16-8-8	16-16-8
	16-16-16	25-10-10
Baan Khlong Ruam, Sra Kaew	15-15-15	15-15-15
	46-0-0	16-8-8
	14-4-40	0-0-60
		46-0-0
		14-4-40
Sapphongphoot, Nakhon Ratchasima	15-15-15	46-0-0
	46-0-0	14-7-35
	15-7-18	
Aang Thong, Prachinburi	15-15-15	15-15-15
	15-7-18	15-7-18

Table 5. Amounts of chemical fertilizer applied to cassava in project sites in 2002 and 2007.

	Amount of fertilizer applied (kg/ha)	
Project site	2002	2007
Huay Suea Ten, Kalasin	156	312
Baan Khlong Ruam, Sra Kaew	156	156
Sapphongphoot, Nakhon Ratchasima	62-94	156-312
Aang Thong, Prachinburi	156	312

Table 6. Types and amounts of animal manures applied to cassava in project sites in 2002 and 2007.

	Type of manure applied		Amount (kg/ha)	
Project site	2002	2007	2002	2007
Huay Suea Ten, Kalasin	-	Pig Chicken Cow	-	780
Baan Khlong Ruam, Sra Kaew	-	Chicken Cow	-	1,562-3,125
Sapphongphoot, Nakhon Ratchasima	-	Chicken Cow	-	3,125-3,750
Aang Thong, Prachinburi	-	Chicken	-	3,125

Table 7 shows that in only one of the four sites the planting of vetiver grass hedgerows had slightly increased, but in the other three sites the planting of hedgerows had markedly decreased to the extent that these hedgerows were no longer being planted. Farmers mentioned that this was because they had changed crops, the cassava area in their village had decreased, they were no longer planting cassava on sloping land, or that the vetiver grass planting material was no longer available. Other reasons mentioned were:

1. the boundary of their land was very irregular, making it inconvenient to plant contour hedgerows
2. they had no time
3. the hedgerows made land preparation by tractor more complicated and thus more expensive
4. there was no planting material of vetiver grass available
5. there was a change in extension agent in the subdistrict
6. some hedgerows had been damaged by herbicides or by tractor drivers during land preparation

Table 7. Length of vetiver grass hedgerows (km) planted in project sites in 2002 and in 2007.

Project site	2002	2007
Huay Suea Ten, Kalasin	12.8	1.1
Baan Khlong Ruam, Sra Kaew	20	1.3
Sapphongphoot, Nakhon Ratchasima	9	12.8
Aang Thong, Prachinburi	4.5	0.1

CONCLUSIONS

From the responses of the farmers it is clear that technologies that require little extra work or additional money, but are likely to increase yields and farmer's income, such as new varieties, are readily adopted and continue to be adopted. Farmers will also continue to use fertilizers and even animal manures, especially when root prices are high, as they expect that this will increase their yields. But those technologies that require additional work or inputs, especiall if those inputs, such as the planting material of vetiver grass, are not readily available, will not be adopted because farmers do not see their immediate benefit. This confirms the earlier observation that soil conservation practices were mostly adopted by those farmers that had participated directly in the project, while adoption was minimal among the non-participating farmers. This may mean that the adoption of contour hedgerows to control erosion is not sustainable unless the government provides free planting materials or other incentives to encourage farmers to use this technology. However, other methods of erosion control can also be effective in reducing erosion, such as the application of adequate and well-balanced fertilizers, preferably in combination with animal manures, closer plant spacing and the use of varieties that germinate well and have a vigorous early growth. Because these practices will result in the early establishment of a crop canopy, which in turn protects the soil from the impact of

raindrops, they are very effective in reducing soil erosion while at the same time increasing cassava yields and the income of farmers. Because of this, these practices will be more readily adopted and their adoption is likely to be more sustainable.

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THE IMPACT OF THE NIPPON FOUNDATION CASSAVA PROJECT IN VIETNAM - FIVE YEARS ON

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ABSTRACT

The Nippon Foundation Cassava Project (1994-2003) entitled "Enhancing the Sustainability of Cassava-based Cropping Systems in Asia" was implemented in three countries, including Vietnam. The project was quite successful. Five new technology components had been adopted by our farmers on a large scale by the end of 2003. These technologies include: new cassava varieties having higher fresh root yields and dry matter contents in the roots; intercropping cassava with peanut, maize or black beans; balanced fertilization to increase yields and maintain soil fertility; soil erosion control by planting contour lines of *Tephrosia candida, Paspalum atratum,* vetiver grass or pineapple; and the use of cassava leaf and root silage for pig feeding.

Now, five years later, in 2008, it is time for us to get feedback from our farmers on the current adoption of these technologies, as well as on the need for new technologies towards more sustainable cassava production. The continued widespread adoption of new technologies, especially the planting of new varieties combined with balanced fertilization for cassava during the last five years, is an indication of the effectiveness of the Nippon Foundation project on cassava development in Vietnam. However, the survey also found that the soil conservation practices for erosion control had not multiplied because these practices require more investment for seed purchase and more labor to make contour lines, while reducing the number of cassava plants as well as the root yields of plants near those hedgerows. Especially, after harvesting some of the hedgerows had been damaged by free-grazing buffaloes. Discussing this with local authorities, extension workers and farmers, we have also found that the interaction between researchers, extension workers and farmers was not strong enough to help farmers gain a deeper understanding about the harmful effect of growing cassava on sloping land without applying practices for soil erosion control. Therefore, future sustainable cassava development will require more involvement and more responsibility at different management levels, working under a framework of new research findings, and on extension and management policies combined with research to develop new technology innovations.

INTRODUCTION

The Nippon Foundation-funded Cassava Project entitled "Enhancing the Sustainability of Cassava-based Cropping Systems in Asia" was coordinated by CIAT and implemented from 1994 to 1999 in four countries, while the second phase was continued from 1999 to 2004 in three countries, including Vietnam. The project was quite successful. There are five new technology components that had been adopted by our farmers on a large-scale by the end of 2003. These components are: new cassava varieties having higher fresh root yields and dry matter contents in the roots; intercropping cassava with peanut, maize or black bean; balanced fertilization suitable for cassava; soil conservation by planting contour lines of *Tephrosia candida, Paspalum atratum*, vetiver grass, or pineapple; and cassava leaf and root silage for pig feeding.

OBJECTIVES

To evaluate the long-term impacts of the Nippon Foundation Project to cassava development at selected FPR sites; to learn from our past experience; to propose new

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strategies towards more sustainable cassava production; and to contribute to the livelihood improvement of cassava farmers.

METHODOLOGY

We applied PRA and RRA methodologies in conducting the survey at the following selected FPR sites: Anvien commune, Thong Nhat district, Dong Nai province; Dong Tam commune, Dong Phu district, Binh Phuoc province; Suoi Rao commune, Chau Duc district, Ba Ria-Vung Tau province; Hong Ha commune, A Luoi district, Thua Thien Hue province; Thuong Am commune, Son Duong district, Tuyen Quang province; and Dong Cuong village, Van Yen district, Yen Bai province.

RESULTS AND DISCUSSION

From 2000 to 2008, cassava production in Vietnam has been increasing from 1,986,300 tonnes to 9,395,800 tonnes, due to the increase of both the cassava area and cassava yield (**Table 1**).

Table 1. Cassava area, yield and production in Vietnam from 2000 to 2008.

Year	Area ('000 ha)	Yield (t/ha)	Production ('000 tonnes)
2000	237.6	8.36	1,986
2003	371.9	14.28	5,309
2004	388.6	14.98	5,821
2005	425.5	15.78	6,716
2006	475.2	16.38	7,783
2007	495.5	16.53	8,193
2008	557.7	16.91	9,396

***Source:** FAOSTAT, Feb, 2010.*

Looking back nearly ten years, based on our RRA data, we see that at that time cassava was grown mainly on steep slopes with very little inputs, using local varieties that had been selected for human consumption. There were only two locations in the south where farmers used new cassava varieties KM 60 and KM 94. As such, cassava fresh root yields were very low, ranging from 7.0 to 15.0 t/ha (**Table 2**). Based on the results of their own problem diagnosis, cassava farmers asked to conduct FPR trials with five main components: 1. New cassava varieties; 2. Soil conservation by planting contour hedgerows; 3. Improved fertilizer use; 4. Intercropping; and 5. Cassava root and leaf silage for pig feeding.

After implementing the project using Farmer Participatory Research (FPR) methods, from 830 FPR trials conducted in 34 villages during ten years, five types of new technologies had been selected and adopted by our farmers. At the end of 2003, with the exception of Hong Ha village where many farmers continued to grow the local variety Nep for food, in all other villages they had replaced most local varieties by new varieties such as KM 94, SM 937-26, KM 98-5, KM 98-1 in the south, and KM 60, KM 94, KM 98-7 in the north. Almost all farmers like to intercrop 1-2 rows of peanut between cassava rows. In those areas where farmers have limited land they apply more pig manure combined with

NPK fertilizer to improve their cassava yields, while in other areas, they mainly apply NPK fertilizers. Especially, on steep slopes they had planted contour hedgerows of *Tephrosia candida, Paspalum atratum,* vetiver grass or pineapple for soil erosion control. In Huong Van village, Huong Tra district, Thua Thien Hue province, many farmers have applied cassava root and leaf silage for pig feeding (**Table 3**).

Table 2. Main features of cassava production in Vietnam in selected FPR pilot sites, based on information obtained through RRAs conducted before starting the project in each site.

Location Commune, province	Topography	Cassava yield (t/ha)	Utilization (%)	Main varieties used	Inputs used [1]
TienPhong,ThaiNguyen	hilly	8.5	30[2]; 70[3]	Vinh Phu	A; A+B
Dong Rang, Hoa Binh	steep slope	11.0-12.0	30[2]; 70[3]	Vinh Phu	A;B
Kieu Tung, Phu Tho	steep slope	8.0-15.0	60[2]; 40[3]	Vinh Phu	A;C
Thuong Am, Tuyen Quang	steep slope	10.2	40[2]; 60[3]	SC205,V.Phu	None
Thong Nhat, Phu Tho	steep slope	8.0	30[2]; 70[3]	SC205,V.Phu	A,B, A+B
Tran Phu, Ha Tay	flat	11.0	30[2]; 70[3]	SC205,V.Phu	A,B, A+B
Hong Ha, Thua Thien Hue	steep slope	7.0	human food	Nep	None
Dong Tam, Binh Phuoc	steep slope	15.0	feed, starch	KM60, KM94	C
An Vien, Dong Nai	flat	16.2	feed, starch	KM60, KM94	B
Suoi Rao, Ba Ria-Vung Tau	hilly	15.0	70[2]; 30[3]	KM60, KM94	B

[1] A = pig manure; B = unbalanced NPK fertilizers; C = urea
[2] for sale ; [3] for animal feeding

Table 3. Types of cassava technologies adopted and dissiminated by farmers in various Nippon Foundation Project sites in Vietnam by the end 2003.

Technology component	Type of technologies
1-New cassava varieties	KM 94; SM 937-26; KM 98-5; KM 98-1; KM 98-7
2-Intercropping	1-2 rows of peanut, black bean or maize
3-Improved fertilizer practices	40N 40P_2O_5 40K_2O; 80N 40P_2O_5 80K_2O
	Pig manure +40N 40P_2O_5 40K_2O
4-Soil conservation practice	Contour hedgerows of *Tephrosia candida, Paspalum atratum*, vetiver grass or pineapple
5-Ensiling	Cassava root and leaf silage for pig feeding

The adoption of new technologies has certainly improved cassava farmers' income. We are proud of our contribution, which has resulted in the amazing development of cassava in Vietnam through the implementation of the Nippon Foundation project (**Table 4**).

In 2008 it was time for us to get feedback from our cassava farmers in some of the old FPR sites on the various technology components that they had adopted since the end of the project in 2003.

Table 4. Average cassava fresh root yields at selected FPR site in 1998 and in 2008.

Commune, province	Before implementation of the project (1998)	Five years after termination of the project (2008)	Percent increase in yield
An Vien, Dong Nai	16.2	20.6	27
Suoi Rao, Baria-Vung Tau	15.0	23.1	54
Dong Tam, Binh Phuoc	15.0	21.8	45
Hong Ha, Thua Thien Hue	7.0	22.5	221
Tien Phong, Thai Nguyen	8.5[1)]	30.0	253
Thuong Am, Tuyen Quang	10.2	28.7	181
Dong Cuong, Yen Bai	11.4	25.6	125

[1)] In Tien Phong commune the project started in 1994; in all other sites in 1998 or 1999.

Table 4 shows that cassava yields had increased significantly in all sites, ranging from 4.4 t/ha at An Vien village of Dong Nai province to 21.5 t/ha at Tien Phong village of Thai Nguyen, which is equivalent to yield increases ranging from 27% to 253% during the implemention of the project at these selected FPR sites.

Table 5 indicates that the main reasons of nearly all our farmers for applying these new technologies on a large scale are: to get higher yields, increase income, improve soil fertility and obtain more stable yields.

Table 5. Percent of farmers mentioning the main reasons for their continued application of new technologies on a large scale.

Main reasons	New variety	Intercrops	Balanced fertilization	Soil erosion control
High yield	100.0[1)]	0.0	100.0	0.0
More stable yield	0.0	53.3	80.0	83.3
Increase income	100.0	80.0	100.0	0.0
Reduce soil erosion	0.0	0.0	0.0	100.0
Reduce weeds	0.0	67.5	0.0	0.0
Improve soil fertility	0.0	80.0	0.0	56.6

[1)] Many farmers mentioned more than one reason.

During the use of these new technologies, farmers also encountered some limitations of the new technologies on soil erosion control, on intercropping, and on fertilization.

Table 6 shows that the limiting factors for applying the new technologies on soil erosion control by planting contour hedgerows are that they are difficult to apply, they reduce the cultivated area, they are easily damaged by free-grazing animals, and that farmers have received little technical support from the extension service.

Table 6. Percent of farmers mentioning the main limiting factors for applying the new technologies on soil erosion control by planting contour hedgerows on a large scale.

Main limiting factors	Suoi Rao	Dong Phu	Hong Ha	Thuong Am	Dong Cuong
Increase cost of inputs	-	-	-	80.0	14.0
Difficult to apply	75.0[1)]	95.0	71.4	66.6	15.0
Reduce the cultivated area	45.0	20.0	-	40.0	12.0
Damaged by free-grazing animals	-	55.0	57.0	100.0	90.0
No seed support	-	-	71.5	100.0	40.0
Limited technical support	75.0	-	-	66.6	56.0
Low economic efficiency	-	5.0	-	60.0	30.0
Lack of labor	55.0	5.0	42.8	-	-
Lack of investment	-	-		-	-

[1)] Many farmers mentioned more than one reason.

Table 7 shows that for intercropping cassava on a large scale, farmers have mentioned the following main limiting factors: the need for increased inputs, difficult to apply, lack of intercrop seed and low economic efficiency.

Table 7. Percent of farmers mentioning the main limiting factors for applying the new technologies on intercropping on a large scale.

Main limiting factors	An Vien	Suoi Rao	Dong Phu	Hong Ha	Thuong Am	Dong Cuong
Increased inputs	62.5	60.0	80.0	57.2	100.0	36.0
Difficult to apply	87.5	40.0	20.0	57.2	100.0	80.0
Reduce the cultivated area	-	-	-	-	-	-
Damaged by free grazing animals	-	-	-	-	-	-
No seed support	-	35.0	30.0	71.5	80.0	50.0
Limited technical support	-	50.0	50.0	57.2	66.6	60.0
Low economic efficiency	75.0	40.0	5.0	42.8	93.3	40.0
Lack of labor	50.0	30.0	-	-	33.3	30.0
Lack of investment	-	-	-	-	-	-

Table 8 shows that for applying new technologies on fertilization on a large scale, farmers mentioned the following principal constraints: lack of support from the government, lack of investments.

Table 8. Percent of farmers mentioning the main limiting factors for applying the new technologies on balanced fertilization on a large scale.

Main limiting factors	An Vien	Suoi Rao	Dong Phu	Hong Ha	Thuong Am	Hong Tien	Dong Cuong
Increased inputs	-	-	-	-	-	-	-
Difficult to apply	-	-	-	-	-	-	-
Reduce the cultivated area	-	-	-	-	-	-	-
Damaged by free-grazing animals	-	-	-	-	-	-	-
Lack of government support	100.0	100.0	100.0	100.0	100.0	35.0	100.0
Limited technical support	-	-	-	-	-	-	-
Low economic efficiency	-	-	-	-	-	-	-
Lack of labor	-	-	-	-	-	-	-
Lack of investment	100.0	100.0	100.0	100.0	100.0	35.0	100.0

The Way Forward

In order to further develop cassava in a more sustainable way, we need to solve these constraints or limiting factors. The first priority is to continue introducing and testing new cassava varieties, that can produce higher fresh root yields and have a higher dry matter content in the roots. The second is on-the-job training, which means farmer training combined with the conducting of FPR trials. Third, is to provide government support or incentives for farmers to plant contour hedgerows, such as hedgerow seeds or plantlets, and fertilizers as well as reimbursement of labor costs, to improve extension support to farmers as well as local regulation for the control of free-grazing animals (**Table 9**).

Table 9. Percent of farmers that mentioned the future needs for more sustainable cassava development.

Future needs	An Vien	Suoi Rao	Dong Phu	Hong Ha	Thuong Am	Hong Tien	Dong Cuong
Introduction of new varieties	100.0	100.0	100.0	100.0	100.0	100.0	78.0
Introduction of new intercrops	87.5	95.0	15.0	42.8	66.6	33.3	18.0
Higher economic efficiency of contour hedgerows	-	20.0	30.0	57.0	-	-	30.0
On-the-job training	100.0	95.0	95.0	100.0	100.0	100.0	100.0
Input support	-	20.0	45.0	100.0	100.0	100.0	100.0
Extension support	-	75.0	95.0	100.0	70.0	80.0	90.0
Better land use planning	-	-	-	-	-	100.0	62.0
Local regulation on free-grazing	-	-	35.0	100.0	100.0	-	75.0

CONCLUSIONS

The demand for cassava by different end users has markedly increased. For that reason the cassava planted area in Vietnam has also increased very fast from 2003 to 2008.

- Cassava yields have also markedly increased between 2003 and 2008 due to the wide-spread and continued adoption of new high-yielding varieties and improved agronomic practices as a result of the Nippon Foundation Cassava Project.
- Of the various technologies tested in the project, farmers preferred the planting of new varieties, intercropping with grain legumes such as peanut or beans, and the application of balanced fertilization, because they can see very clearly the positive effect on cassava yields as compared to their traditional practices.
- The main reasons for farmers not having widely adopted the use of contour hedgerows for soil erosion control is that the hedgerows reduce the cassava area, the lower yield of cassava plants growing near the hedgerows, and that they cannot control free-grazing animals from damaging the hedgerows, while the economic benefits of this technology are not high enough to persuade farmers to apply it.
- In order to improve the sustainability of cassava production there is a need for more research to find more appropriate new technologies, combined with more and better extension activities, and to increase the involvement of local authorities in the development process.

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THE IMPACT OF THE NIPPON FOUNDATION CASSAVA PROJECT IN CHINA: FIVE YEARS ON

Tian Yinong[1] *and Li Kaimian*[1]

ABSTRACT

The Nippon Foundation cassava project in China has achieved the following remarkable results: 1. Several new high-yielding and/or high-starch cassava varieties have been released and are now widely adopted; 2. More efficient crop management practices have been expanded; and 3. The use of cassava root and leaf silage for animal feeding has been widely extended in some rural areas, especially in southern Yunnan province.

Three provinces were involved in the project: Guangxi, Hainan and Yunnan. Presently the project has had an impact in about 80,000 ha of cassava, reaching 300,000 farmers. During the past 15 years, the yield of cassava in the project area has increased by 40%, while the net income from cassava cultivation increased by 200%. Practically all farmers have adopted new varieties with high yield and/or high starch content, 80% have adopted the new technologies, and among these about 40% use these technologies for farming or other related activities. In the major cassava growing areas, 90% of farmers have shown much interest in new varieties as well as some new technologies such as efficient use of fertilizers, intercropping, and the return to the field of composted shredded stems. In some mountainous areas with very poor soil conditions, farmers like very much the technology of silage making because this technology was developed for the conditions in remote areas where it was found to be very useful.

INTRODUCTION

Cassava is the fourth most important crop in southern China, following rice, sugarcane and sweetpotato. It is used mainly as an animal feed and as a raw material for starch processing, and recently for production of ethanol, which plays a more and more important role in the agricultural economy of southern China. Cassava production makes full use of available land resources, especially in upland and hilly areas, as well as in marginal areas with poor soils. In recent years, cassava production and its economic value have increased due to the rapid development of the animal feed, starch and ethanol industries. More and more attention has been paid to the release of new improved varieties and improvements in cultivation management.

But due to the limitation of sufficient land resources for the high population of China, cassava is normally planted in slopy or marginal areas where either drought or soil constraints limit the production of other crops. This has resulted in serious problems of soil erosion whenever appropriate erosion control measures are not taken. This problem was quite common in cassava areas in China before the Nippon Foundation-funded Farmer Participatory Research project was initiated, and it was very extensive. It was a greater challenge to overcome this problem in China as compared with other countries like Thailand, Vietnam, etc. That is also one of the reasons why China has had low yields of cassava for a long time. So, during the conducting of the project, we've paid special attention to trying to extend the use of erosion control measures.

Cassava processing is mainly concentrated in Guangxi and Guangdong provinces, and the main cassava-based products are native and modified starch, ethanol and MSG.

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Table 1 shows that starting in the mid 1990s, cassava production in Guangdong province was on a decreasing trend, while in Guangxi province cassava production increased gradually. This is because cassava has a low economic value compared with other crops or farming enterprises in Guangdong province, which is the most developed of all provinces in China. Presently the main cassava growing areas are concentrated in the western part of Guangdong province, which is a mountainous area (Henry and Howeler, 1996). But in Guangxi province, which has had a comparatively slow economic development, very suitable conditions of climate and soil (unfertile, acid, sandy in the south) exist for cassava cultivation. And with more and more cassava processing industries developing over the past 20 years, cassava has been a very traditional and reasonably economic crop for a long time, with the roots used either as an animal feed or for sale to starch or alcohol processing factories.

Table 1. Cassava area, yield and production in Guangxi and Guangdong provinces of China from 1994 to1996.

	Guangxi province			Guangdong province		
	Area (ha)	Yield (t/ha)	Prod. ('000 t)	Area (ha)	Yield (t/ha)	Prod. ('000 t)
1994	234,800	12.30	2,889	150,933	14.26	2,153
1995	272,900	13.70	3,738	145,247	15.43	2,241
1996	288,900	13.41	3,874	145,313	15.15	2,201

Source: *Statistics Bureau of Guangdong and Guangxi provinces.*

Table 2 shows that the cassava area in Guangdong province has continued to decrease while Guangxi province has clearly become the number one cassava producing province in the country, accounting for 65% of total production. The yields in both provinces have increased a lot. In 2008, because much of the planting materials had been damaged by a very strong frost, the area of cassava in Guangxi had decreased significantly. Currently, about 500,000 tonnes of cassava starch and about 150,000 tonnes of ethanol are produced in Guangxi province every year, accounting for more than 70% and 80% of the national production (local statistics), respectively. The cassava industry is playing a more and more important role in the rural economic development, both by increasing farmers' income and by paying more taxes to the government.

Table 2. Cassava area, yield and production in China in 2008.

	Area (ha)	Yield (t/ha)	Production ('000 t)
Guangxi	220,000	23.4	5,150
Guangdong	85,000	18.7	1,590
Yunnan	35,000	10.6	370
Hainan	32,000	18.8	600
Total	**387,000**	**20.5**	**7,940**

Source: *Office of Southern Subtropical Crops, Ministry of Agriculture of China*

But in the past, as shows in **Table 1**, cassava yields had remained rather low for a long time. As a result of the research cooperation between CATAS, GSCRI and CIAT on

cassava varietal improvement and cultivation management from the late 1980s to the early 2000s, cassava yields increased substantially. Around the mid 1990s we started the Farmer Participatory Research (FPR) project with funding from the Nippon Foundation to enhance the adoption of improved cassava technologies in rural areas of south China. The project involved the testing by farmers of high-yielding and high-starch cassava varieties, erosion control practices, fertilization, silage making, etc. A Rapid Rural Appraisal (RRA) conducted in the three main cassava producing provinces of Guangdong, Guangxi and Hainan in August 1994, obtained the following background information (Henry and Howeler, 1996):

Low yields of cassava during the 1990s (about 12 t/ha)
Serious problems of soil erosion in cassava fields
Increasing demand for cassava due to the rapid development of the processing industry. In 1996 China became a cassava importer, and currently the country imports annually at least 1.5 times its own domestic production
Increasing demand for cassava leaf silage and dry cassava root meal by farmers living in mountainous area for on-farm animal feeding
Much higher yields could be achieved from the adoption of high-yielding (or high-starch) varieties, as well as with more efficient cultivation practices, based on the research results obtained through the co-operation between CATAS, GSCRI and CIAT.

THE FPR PROJECT IN CHINA

The first phase (1993-1998) of the Nippon Foundation-funded project, entitled "Enhancing the Sustainability of Cassava-based Cropping Systems in Asia", in China was conducted only in Hainan province in collaboration with CATAS. Then, in the second phase (1999-2003) the project extended to Guangxi and Yunnan provinces, in collaboration with the Guangxi Subtropical Crops Research Institute (GSCRI) and the Honghe Regional Animal Husbandry Station of Yunnan province. The main objective during the first phase was to accelerate the development of improved cassava varieties and efficient cassava production practices to reduce erosion, maintain soil productivity and increase the income of cassava farmers in China through farmers' participation in research. Since the project was conducted mainly in mountainous areas (especially in Yunnan province), to accommodate the requirements of farmers in those areas some other technologies like silage making for animal feeding from cassava leaves, stems and root meal, were included as components of the project during the second phase (1999-2003) (Zhang Weite *et al.*, 1998; CATAS/CIAT, 1998; Howeler and Henry, 1998).

Project Objectives and Activities

A. The main objectives of the FPR project in China were:

1. To spread new varieties, characterized by high yield and/or high starch content, in rural areas
2. To extend high-yielding and cost-effective cassava production practices, such as balanced fertilization, the use of plastic mulch, or mulch of shredded stems, etc.

3. To extend erosion control measures, such as contour ridging, plastic mulching, planting contour vegetative hedgerows, etc.
4. To extend more efficient systems of intercropping
5. To extend technologies of silage making from cassava leaves, stems and roots.

Table 3 shows the number of counties, villages and farmers that were totally involved in the FPR project in China in 2003, funded by Nippon Foundation; also the number of farmers that were trained in cassava cultivation and silage making. From the information we can see the tendency that the new varieties that have high-yield and/or high starch content, as well effective cropping management practices are adopted very quickly once they have been tested by farmers.

Table 3. Number of farmers, villages and counties involved, and the number of farmers trained in the Nippon Foundation funded FPR project in three provinces in China in 2003.

	Counties	Villages	Farmers	Main technologies tested and disseminated	No. of farmers trained
Hainan	12	30	110	Varieties, erosion control and cropping management	742
Guangxi	10	18	120	Varieties, erosion control and cropping management	3,200
Yunnan	6	11	65	Varieties, erosion control, silage making	480
Total	**28**	**59**	**295**		**4,422**

B. The main activities of the FPR project in China were:

1. To select suitable pilot sites in the main cassava growing areas
2. To conduct a problem diagnosis (RRA) about cassava production with farmers
3. To identify the priority problems to be solved with farmers
4. To establish teams of interested farmers and enhance a good cooperative relationship between farmers and researchers
5. To provide technical support to farmers
6. To organize training courses and farmers' field days to evaluate the new technologies

C. The principal technology components that were being tested in the project were:

1. Cassava varieties with high yield potential and high starch content
2. Cassava fertilization
3. Cassava intercropping
4. Erosion control methods
5. Silage making from cassava leaves, stems and roots

METHODOLOGY

The steps in the process that we adopted were:

1. Contact the local Extension Station of the Bureau of Science and Technology
2. With local extension personnel select suitable pilot sites and discuss the objectives of the project with farmers
3. Identify farmers' needs for particular technology components
4. Set up demonstrations to provide technology options for farmers to evaluate and select for testing
5. Help farmers conduct FPR trials on their own fields
6. Provide technical support and training
7. Organize farmers' field days to evaluate and select new varieties and improved production practices
8. Provide the materials that are necessary for farmers to adopt the new technologies (according to local government requirements)

RESULTS

1. Adoption of new Varieties

Table 4 shows the varieties that were tested, selected and adopted in the three provinces, based on the favorable characteristics as perceived by farmers and processors. Among these varieties, SC 205 is the most favored by farmers and processing factories, while GR 911 is the best adapted to different soil conditions (both fertile and unfertile soils). SC 5 is generally found to do well in poor and sandy soils, but is not as good in fertile soil. These are the three most important varieties in China at present.

Table 4. Varieties released in the three cassava producing provinces of China.

	Varieties	Major characters	Farmers evaluation	Factory evaluation
Hainan	SC 5	HY*, HS*	Very good	Good
	SC 8	HY	Good	Not bad
Guangxi	SC 205	HY,HS	Very good	Very good
	SC 5	HY in south, HS	Good in sandy soil	Good
	GR 911	HY	Very good	Not bad
	NZ 199	HY, HS	Very good	Very good
	GR 891	HS	Good for eating	Very good
	SC 9	HY, HS	Good for eating	Low starch
Yunnan	SC 205	HY, HS	Good	Very good
	SC 124	HY	Good	Low starch
	GR 911	HY	Very good	Not bad
	GR 891	HS	Not bad	

*HY=high yield, HS=high starch content

2. Adoption of Erosion Control Practices

These practices are mainly adopted in upland, hilly and mountainous areas with steep slopes such as in cassava plantations in Yunnan province and in the western part of Guangxi province (**Table 5**).

3. Adoption of Other Management Practices

Unlike the past, farmers now like to make ridges when they grow cassava. In addition, they cover the soil with plastic sheets; this has become very popular in some areas in Guangxi province. Another new measure in Guangxi that farmers have adopted is to shred the stems after the cassava harvest; they use it as fuel for the fire and then return the ash to the field. This has been very effective in loosening the soil, and helps to maintain the soil's productivity, and increase yields (**Tables 6** and **7**).

Table 5. Erosion control management in three provinces.

	Measures	Farmers' evaluation
Hainan	Vetiver grass hedgerows	Good, but no income
	Contour ridging	Good, but easily damaged by heavy rainfall
	Intercropping with peanut	Very good, two incomes
Guangxi	Vetiver grass hedgerows	No income
	Contour ridging	Good
	Intercropping	Good, two incomes
	Soil covered with plastic	Very good, increase yields, control weeds
Yunnan	Vetiver grass hedgerows	No income, animals don't like to eat it
	Intercropping	Very good, two incomes
	Cassava planted as contour barriers and for leaf harvesting	Very good, solves the problem of lack of animal feed

Table 6. Main cultivation measures adopted in three provinces.

	Main cultivation measures adopted	Farmers' evaluation
Hainan	Ridging	Good
	Use of plastic mulch	Not tried
	Return shredded stems to the field	Not tried
Guangxi	Ridging	Good
	Use of plastic mulch	Very good, increases the yield, less weeding costs
	Return shredded stems to the field	Very good, easy to do and increases income
Yunnan	Ridging	Not bad
	Use of plastic mulch	Not tried
	Return shredded stems to the field	Not tried

Table 7. The effect of returning the shredded stems to the field and the use of plastic mulch on cassava yields (t/ha) in Wuming county, Guangxi province in 2007 (2nd year)[1)].

	Returning stems		Use of plastic mulch[2)]	
Farmer	With	Without	With	Without
Huang SH	32.00	26.36	31.06	18.04
Huang Q	23.94	24.12	21.67	17.11
Huang DS	25.87	24.52	23.80	18.80
Average	**27.27**	**25.00**	**25.51**	**17.98**

[1)] one hectare for each farmer
[2)] without ridging

4. Extension of Silage Making from Cassava Leaves, Stems and Roots

This project activity was mainly conducted in Yunnan province, because in these steep mountainous areas it is difficult to grow other crops for animal feed, while farmers have few other sources of income. Most farmers participating in the project were very interested in this technology; they call it "a technology which changes the crop (cassava) into cash". This is very welcomed by farmers and is now very popular in some areas of the province. Many farmers who used to be very poor have escaped poverty in three years since they joined the project.

In Guangxi and other provinces in the south, not many farmers make silage from cassava roots and leaves but many use the waste (wet pulp) of cassava starch processing for animal feeding. This is because it is comparatively easy for them to grow other crops for use in animal feeding as their land is less steep, and they have easy access to the waste from many starch factories.

Table 8 shows the results of a survey on the extent of adoption of new technologies for cassava production. In the early 1990's, very few farmers considered it possible to make a higher profit from cassava production by using more effective technologies (methodologies), but after ten years of the Project, they saw that this can happen, so they learned and adopted quickly.

Table 8. Survey of the extent of adoption of new technologies for cassava production in Taiping town of Wuming county, Guangxi province; and in Kongba village of Baisha county, Hainan province, China in 1994 and 2008.

Town/village	1994	2008
Taiping town, Guangxi	10%	85%
Kongba village, Hainan	0	95%

Table 9 shows the extent of adoption of new technologies in the project sites in the three provinces. In Guangxi province, land resources are not so scarce, so farmers have rather large land areas as compared with farmers in Yunnan province. They are not very interested in silage making, because they normally feed their animals with cassava processing waste (pulp). But in Yunnan province, the farm size is very small and farmers are short of animal feed resources, so they show very much interest in silage making.

Table 9. Extent of adoption of new technologies of cassava in the project areas of the three provinces in China in 2008.

Province	Area (ha)	No. of farmers	% of farmers making silage	Yield increase (%)
Guangxi	64,000	240,000	10	40
Hainan	15,000	30,000	2	50
Yunnan	1,500	30,000	85	30

Wuming county is one of the most successful counties where the project has been conducted in China. Since the start of the project, we can clearly see significant changes in the way cassava is produced and processed. In the past, farmers grew cassava as a auxiliary crop and with no or very little input; they didn't care about the cassava yield as they put more emphasis on the intercrop; this is partly because of the low price of cassava roots. They said that they can not see any benefits of high yields and more efficient production, so they preferred to find work outside after the crop was planted. Now it is different. Cassava is the No. 1 crop in many places, and farmers put a lot of time, money and labor into growing cassava, with the result that the yields in the county have increased very quickly (**Table 10**). We are also sure that the FPR methodologies that have been used for extending the improved cassava management measures have played a major role in this. When the project terminated in 2004 not only had farmers improved their livelihoods due to the project, but also scientist and extension workers as well as officials from the local governments had learned a lot from the methodologies used, which had changed some of their thinking. This is an indication that participatory research methodologies will replace some of the old methods of technology transfer. Actually, the FPR methodologies are now frequently being used in China when scientists and extensionists are both involved in the development and extension of new improved technologies.

Table 10. Cassava area, yield and production, and the number of farmers trained and those benefited from the Nippon Foundation project in Wuming county, Guangxi, China in 2004-2009[1)].

Year	Area ('000 ha)	Yield (t/ha)	Production ('000 t)	No. of farmers trained	Estimated no. of farmers benefited from the project
2004	19.9	26.5	527.4	5360	96,000
2005	22.5	27.7	623.0	6800	120,000
2006	24.6	31.9	783.7	7600	148,000
2007	25.6	32.4	827.8	8510	190,000
2008	24.8	34.0	842.0	8790	216,000
2009	25.3	33.6	850.0	9030	228,000

[1)] Wuming is the largest cassava producing and processing county in China.

CONCLUSIONS AND LESSONS LEARNED

1. As many farmers as possible should be involved in conducting FPR trials in order to achieve widespread adoption of new technologies.
2. Using FPR methodologies is more effective compared with the methods used previously; it is easy to get farmers involved if it is done through a close and friendly cooperation between extensionists and the farmers.
3. It is very important that extension people learn good interviewing skills to make the project successful; this in addition to knowing the technologies and having experience.
4. Getting farmers to express their ideas freely is important in making the project successful.
5. Exchanging experiences between farmers themselves is perhaps the most effective way for the technologies to spread widely.

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THE NIPPON FOUNDATION CASSAVA PROJECT IN LAO PDR

Tin Maung Aye[1], V. Phimphachanhvongsod[2] and Panthasin Kanthavong[2]

ABSTRACT

In Lao PDR cassava is traditionally one of the main food and feed crops for smallholder farmers living in upland areas. The crop has a highyield potential and can be grown under a very wide range of upland conditions. Recently, cassava has become a high-demand crop for either domestic use or for export because it has a multiplicity of industrial uses, including for animal feed, starch, sweeteners and ethanol. However, cassava yields in Laos are traditionally low (7.6 t/ha in 2006) and the crop is basically used only for direct human consumption after boiling.

With financial support from the Nippon Foundation in Japan, CIAT has conducted cassava research in Lao PDR since 2004, in collaboration with national research partners, mainly the National Agriculture and Forestry Research Institute (NAFRI), and with Provincial and District Agriculture and Forestry Offices. Farmer participatory research approaches are being used to evaluate new cassava varieties, fertilizers and integrated cropping systems, as well as the use of cassava roots and leaves for animal feeding, in order to enhance the adoption of improved cassava varieties and agronomic practices and its utilization, and thus increase farmers' income.

A recently harvested on-station variety evaluation trial showed that several introduced varieties produced the highest fresh root yields and had the highest starch contents (eg. Kasetsart 50, yield 41 t/ha with a starch content of 28% , and Rayong 72, yield 28 t/ha with a starch content of 24%), which were significantly higher than those of the local variety (Green Oudomxay, yield 10 t/ha with a starch content of 17%) at 11 months after planting. On-farm trials (2005-2008) showed that yields can be significantly increased by adoption of new, improved cassava varieties (eg. Kasetsart 50, KM 140, Rayong 72 and SC 205) and through the use of appropriate agronomic practices (eg. balanced fertilization and timely weeding).

Cassava roots and leaves can also be utilized as carbohydrate and protein sources, respectively. Drying or ensiling of roots and leaves can reduce the HCN content to a safe level of <50 ppm. Livestock can be fed approximately 10-30% of leaf silage or leaf meal in the feed ration.

In addition, locally fabricated appropriate tools are now available for harvesting cassava roots, for slicing roots and for chopping leaves. The harvesting tools can reduce farmers' labor 2-4 times as compared to harvesting by hoe, while the chipping tool increased the work efficiency 5-8 times as compared to chipping by knife.

It is expected that the use of farmer participatory research and extension approaches for specific agro-ecological areas will increase cassava yields as well as the long-term sustainability of cassava-based cropping systems in Laos.

Key words: Cassava, improved varieties, agronomic practices, productivity, sustainability, Lao PDR

INTRODUCTION

About 1 million ha of Laos' total land of 23.7 million ha are used for agriculture, which is mainly cereal-based. Rice *(Oryza sativa L.)*, maize (*Zea mays L.*) and sugarcane (*Saccharum officinarum L.*) are very important commodities of the agricultural production

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sector in which 80% of the country's labor is employed (NAFRI, 2004). The agricultural sector, which includes the crop, forestry, livestock and fisheries sub-sectors, is considered as the most important sector for national food security. The agricultural (crop) sub-sector is the backbone of the economy in Laos, contributing 50% of GDP (National Statistic Center, 2006). Laos has a population of 5.62 million people and more than 80% of the population resides in rural areas and is principally engaged in agriculture, livestock and fishery for their livelihood (National Statistic Center, 2006).

Cassava (*Manihot esculenta* Crantz) is a starchy root crop and an important food security crop for smallholder farmers in Laos. Cassava originated in Latin America (Brazil) and is known as '*Man Ton*' in Laos. Spanish merchants introduced it into Southeast Asia. It is a hardy crop that grows reasonably well on poor soils and in areas with low or unpredictable rainfall. This crop is also a popular crop among resource-poor farmers because it requires few inputs besides labor to produce a reasonable yield. Cassava can be utilized for human consumption and animal feed, but also for a multiplicity of other end-uses, including starch, sweeteners and ethanol. However, in Laos cassava roots and leaves are currently only used as energy and protein sources, respectively, for both humans and animals.

In 2006, 54% of cassava in the world was produced in Africa; 30% in Asia and 16% in Latin America. Yields were: 10.1 t/ha in Africa, 13.2 t/ha in Latin America and 18.2 t/ha in Asia. The average yield in Lao PDR was reported as 21.19 t/ha in 2007 (FAOSTAT, 2010). The crop has high yield potential and can produce great economic benefits. However, cassava productivity in Laos is still very low in traditional systems.

Recent research conducted by CIAT in collaboration with various national institutions has been supported by the Nippon Foundation with the aim of (a) improving the livelihoods of smallholders in the uplands; and (b) enhancing the sustainability of cassava-based cropping systems. The research partners in Lao PDR are the National Agricultural Research Institute (NAFRI), The Provincial Agriculture and Forestry Organization (PAFO) and the National University of Laos (NUOL). Research sites include Luang Prabang, Oudomxay, Xieng Khouang, Huaphanh and Saravanh provinces, and Vientiane municipality.

METHODOLOGY

In line with local and regional trends, introduced high-yielding cassava varieties and better agronomic practices were evaluated to show the effects of these alternative technologies on yields and income. Farmer participatory approaches were used to ensure that farmers were fully involved in the decision making process.

RESULTS

Improvements in Smallholder Cassava Production

Improved varieties

In Laos, local and improved varieties (more than 50 varieties) have been assessed

for adaptation to growing at high latitude and altitude, cold tolerance, and in poor soils; by determining their yield and utilization characteristics.

An on-station variety evaluation trial conducted at the Rice and Cash Crops Research Center (RCCRC) in Naphok, Vientiane, showed that the introduced Thai varieties (e.g. Rayong 72 and Kasetsart 50 = KU 50) produced the highest fresh root yields and had the highest starch contents, which were significantly higher than those of the local variety at 11 months after planting. These varieties showed a significant variation in hydrogen cyanide (HCN) content, which also affects their suitability for smallholder use as human food and animal feed (**Table 1**).

In on-farm trials conducted in various provinces root yields varied from 7 to 67 t/ha, depending on the fertility of the soil and climatic conditions. The results of these trials indicate that there are improved varieties which can yield well above the local variety. Even on very poor soil, and with cold and dry weather in winter in Xieng Khouang province, some improved varieties, such as Rayong 72 (40 t/ha), Rayong 90 (39.6 t/ha) and KU 50 (26.4 t/ha) had markedly higher yields than the local variety (4.0 t/ha) when harvested at 22 months after planting.

Table 1. Results of the cassava variety evaluation trial conducted at the Rice and Cash Crops Research Center (RCCRC) in Naphok, Vientiane in 2006/07 (11 months after planting).

Cassava variety	Roots yield (t/ha)	Starch content (%)	Starch yield (t/ha)	HCN (ppm)
KU 50	41	28	11.5	400
Rayong 90	28	25	7.0	200
Rayong 72	28	24	6.7	200
KM 140	26	22	5.7	-
Rayong 60	24	21	5.0	200
Rayong 2	21	18	3.8	50
NARC 48	19	20	3.8	30
Ba Trang	19	17	3.2	-
Hanatee	17	19	3.2	30
NARC 61	15	23	3.5	30
Vinh Phu	14	15	2.1	-
NARC 114	13	21	2.7	100
Nep	13	28	3.6	20
Green Oudomxay	10	17	1.7	-

Agronomic practices

Balanced fertilizer application

Long-term research on soil conservation and fertility management has indicated that the major challenges of agricultural production in Laos are soil erosion control and soil fertility maintenance or improvement (Sengtaheuanghoung, 2006). The application of balanced fertilizers is one strategy for restoring fertility and increasing crop yields (Wongwiwatchai *et al.*, 2007). Thus, in most of the trials, yields were significantly higher in the fertilized as compared to the unfertilized plots. Cassava responded particularly well to the application of P and K fertilizers in the highly acid and infertile soils of the Plain of Jars in Xieng Khouang province of Laos. But there was almost no response to the application of N, even a small negative response in case of KU 50 (**Table 1**). This is due to a high level of 4.8% OM in the soil, versus only 0.9 ppm P (Bray II) and 0.08 me K/100 g; the latter two are well below the critical levels of 4 ppm P and 0.15 me K/100 g (Howeler, 1996). It is expected that in future crop cycles, cassava will respond mainly to K, followed by P and with no or little response to N. In similar soils in Vietnam, the general fertilizer recommendations for cassava are: 40-80 kg N, 20-40 P_2O_5 and 40-80 K_2O/ha (Nguyen The Dang *et al.*, 2008). Application of P increased yield of local varieties from 3 t/ha to 19.4 t/ha and from 12 t/ha to 25.3 t/ha in the first 2-year crop cycle of cassava (2005/2007) (**Figure 1**). The average root yield of KU 50 was 23.3 t/ha and that of Xieng Khouang Red was 14.6 t/ha; thus, the average root yield of the introduced variety KU 50 was 60% higher than that of the local variety. Even without any fertilizers applied, KU 50 produced a reasonable yield of 12 t/ha versus 3 t/ha for the local variety. This experiment also clearly indicates that KU 50 has a much better tolerance to low-P conditions compared to the local variety (**Figure 1** and **Table 2**).

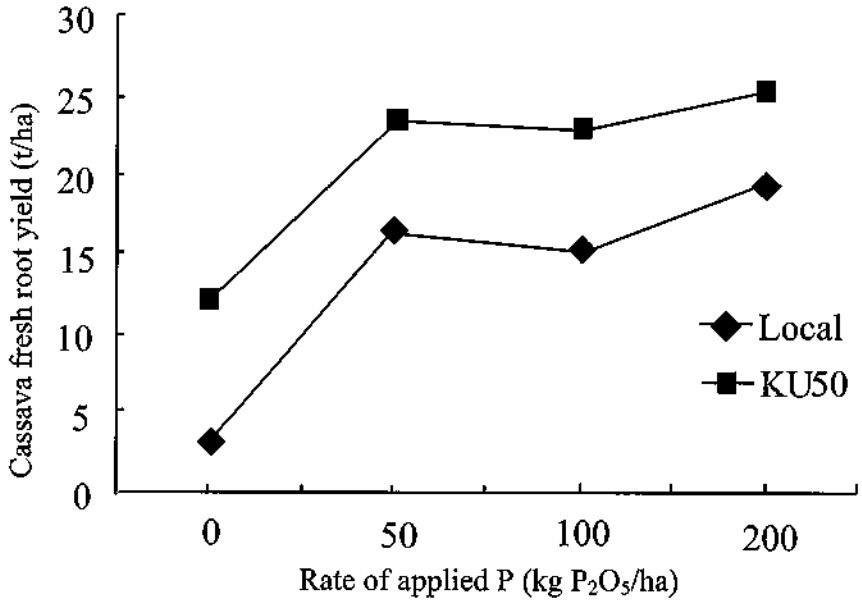

Figure 1. Effect of P fertilizer application on the root yields of two cassava varieties at the Cattle Bank in Phou Kout district of Xieng Khouang province of Lao PDR..

Table 2. Effect of biennial applications of various levels of N, P and K fertilizers on the root yields of two cassava varieties in Laos.

Treatments[1)]	Root yield (t/ha) 2005/07		Root yield (t/ha) 2007/09		Root yield (t/ha) Average	
	KU 50	Local	KU 50	Local	KU 50	Local
1. $N_0P_0K_0$	12.4	3.0	13.9	4.1	13.2	3.6
2. $N_0P_2K_2$	28.1	15.7	47.9	26.3	38.0	21.0
3. $N_1P_2K_2$	33.2	17.5	52.4	35.6	42.8	26.6
4. $N_2P_2K_2$	24.0	15.0	43.6	24.1	33.8	19.6
5. $N_3P_2K_2$	25.0	18.2	46.8	24.9	35.9	21.6
6. $N_2P_0K_2$	12.0	3.0	20.8	9.3	16.4	6.2
7. $N_2P_1K_2$	23.4	16.3	48.4	38.1	35.9	27.2
8. $N_2P_3K_2$	25.3	19.4	49.2	44.8	37.3	32.1
9. $N_2P_2K_0$	11.6	8.4	13.4	8.7	12.5	8.6
10. $N_2P_2K_1$	24.9	19.9	31.8	23.4	28.4	21.7
11. $N_2P_2K_3$	28.5	20.7	53.4	39.1	41.0	29.9
12. $N_3P_3K_3$	31.7	18.6	56.1	39.5	43.9	29.1
Average	**23.3**	**14.6**	**39.8**	**26.5**	**31.6**	**20.6**

[1)] N_0 = 0N; P_0 = 0P; K_0 = 0K
N_1 = 25 kg N/ha; P_1 = 50 kg P_2O_5/ha; K_1 = 50 kg K_2O/ha
N_2 = 50 kg N/ha; P_2 = 100 kg P_2O_5/ha; K_2 = 100 kg K_2O/ha
N_3 = 100 kg N/ha; P_3 = 200 kg P_2O_5/ha; K_3 = 200 kg K_2O/ha
all plots received 500 kg/ha of dolomitic lime in June 2005.

Intercropping

The sustainability of cassava production is an issue, both with respect to soil fertility maintenance and erosion control. Intercropping cassava with grain legumes has been considered to have many advantages for smallholder farmers, e.g. as a way to reduce the risk of crop failure, to provide diversity of crops, to have a positive effect on soil fertility and soil erosion, and to be able to harvest crops at different times of the year. Results of an intercropping cassava trial at RCCRC in 2006/07 are shown in **Table 3**. Many trials have indicated that intercropping with crops such as peanut (*Arachis hypogaea*) will provide farmers with better cash flow, and at the same time reduce soil erosion.

Table 3. Results of a cassava intercropping trial conducted at RCCRC in Naphok, Vientiane in 2006/07.

Treatment	Cassava root yield (t/ha)	Intercrop grain yield (t/ha)
Cassava (monocrop)	23.7	-
Cassava with soybean (*Glycine max*)	25.5	0.18
Cassava with peanut (*Arachis hypogaea*)	25.0	0.64
Cassava with mung bean (*Vigna radiata*)	22.8	0.32
Cassava with rice bean (*Vigna umbellata*)	20.5	0.13

Effective soil erosion control

Cassava cultivation can cause severe soil erosion if the crop is not properly managed, particularly on sloping lands. The slope of the land, soil composition, and extent of vegetative cover also influence the rate of soil erosion (Pimentel *et al.*, 1995).

Highest levels of erosion were measured in those plots that had up-down ridging even though the plot was fertilized. Most effective in reducing erosion were the use of various live barriers (hedgerows) and intercropping with peanut. Some of the hedgerow plants, such as pineapple, *Tephrosia candida and Paspalum atratum*, were growing better than others. Hedgerows planted with *Paspalum atratum* reduced soil erosion to about 40% of that in the check treatment, and to about 60% of that of the same treatment without hedgerows (**Table 4**). In addition, in the *Tephrosia candida* and *Paspalum atratum* hedgerow treatments, soil erosion was less than with vetiver grass or *Gliricidia sepium* hedgerows. The latter two species seem to be not as well adapted to the poor soil and cool climate of this site (**Figure 2**).

Opportunities from Improved Cassava Production

Improvements for smallholder farmers

There are now several suitable cassava varieties in Laos for the use as human food, animal feed or for starch production. Improved varieties such as NARC 61 and Ba Trang can increase the production of cassava as a food crops (19-20 t/ha). Other varieties, such as KU 50 and Rayong 72, are suitable for animal feeding and for starch production with yields that are 7-10 t/ha above the current yields.

Similarly, simple technologies for small-scale starch extraction or the processing and sale of various cassava-based snack foods can be adopted by farmers' groups to provide additional income during periods of low labor demand (mainly in the dry season), and to increase the demand for cassava roots.

Table 4. Results of the soil erosion control trial at the Extension and Improvement of livestock Systems Center in Xieng Khouang province, Laos (2007/8).

No.	Treatments	Dry soil loss (t/ha)
1.	Traditional practice: no fertilizer or lime, no hedgerows, 2 stakes/hill, no ridging, 0.9 m x 0.9 m	16.8
2.	No ridging, with fertilizers and lime; no hedgerows, 1 stake/hill; 0.9 x 0.9 m	11.0
3.	Intercrop with 2 rows of peanut; with fertilizers and lime; no hedgerows, 1 stake/hill; 0.9 x 0.9 m	8.5
4.	Hedgerow of pineapple; with fertilizers and lime; 1 stake/hill; 0.9 x 0.9 m	10.0
5.	Hedgerow of *Paspalum atratum*; with fertilizers and lime; 1 stake/hill; 0.9 x 0.9 m	6.6
6.	Hedgerow of *Tephrosia candida*; with fertilizers and lime; 1 stake/hill; 0.9 x 0.9 m	7.4
7.	Hedgerow of vetiver grass (Vietnam); with fertilizers and lime; 1 stake/hill; 0.9 x 0.9 m	8.0
8.	Closer plant spacing (0.7 m x 0.7 m); with fertilizers and lime; 1 stake/hill; no hedgerows	8.4
9.	Contour ridging, with fertilizers and lime; 1 stake/hill; 0.9 x 0.9 m, no hedgerows	8.1
10	Up-down ridging, with fertilizers and lime; 1 stake/hill; 0.9 x 0.9 m, no hedgerows	30.0

Demand for commercial cassava production

Demand for cassava roots is increasing very rapidly in the region; this is a great opportunity for resource-poor farmers to produce cassava commercially. In 2005 China imported 3,346 million tonnes of cassava dried chips and 0.82 million tonnes of starch; this represented about 70% of their total consumption of cassava in terms of fresh root equivalents. As such, the long-term utilization of cassava in the region is for (a) local food; (b) animal feed; (c) starch; (d) ethanol; and in the future (e) bio-degradable plastics. As a result, processors are eager to identify new areas of supply. Lao authorities are already being approached for that purpose by Chinese and Vietnamese companies. However, measures need to be taken to ensure that Lao farmers receive adequate compensation for producing cassava.

There are considerable price variations in the cassava market, not only in the region but also within a country. The market prices also depend on whether the crop is harvested in the off-season or peak-season. Currently, prices which Lao farmers receive for cassava are about 50% of what farmers in other countries in the region receive (**Figure 3**).

Figure 2. Contour hedgerows of Paspalum atratum markedly reduced soil loss by erosion on 10% slope in Xieng Khouang province of Laos.

Thus, for Lao farmers to benefit from the new opportunities of growing cassava as a cash crop, two additional factors will need to be taken into account:

a. the use of improved varieties and some inputs (fertilizer, etc.) to obtain higher yields, and agronomic practices that ensure the sustainability of production
b. establishing contractual arrangements between farmers and factories to ensure that factories have an adequate and timely supply of roots, and that farmers gain adequate benefits.

CONCLUSIONS

In Lao PDR, the prospects for increased cassava productivity in the immediate future are very bright. Improved cassava varieties such as KU 50 and Rayong 72 can be grown in many parts of Laos, and would be able to increase yields markedly above current yield levels. The application of balanced fertilizers significantly increases crop yields and improves soil fertility. Cassava intercropping with legume crops such as peanut will improve farm productivity and provide farmers with better cash flow. The use of contour hedgerows of grass or leguminous species will markedly reduce soil erosion.

There is a need to facilitate fairer pricing for cassava products in order to help farmers, and to ensure the availability of enough cassava supplies for both export and domestic processing factories. However, urgent steps are also necessary to improve yields and the sustainability of production, and to reduce production costs, which will all have

large income implications for smallholder farmers. Although there is an investment climate to establish new cassava processing factories in Lao PDR, the government must set policies and create an enabling environment for the development of new markets and for agro-industry to enhance rural development and poverty reduction.

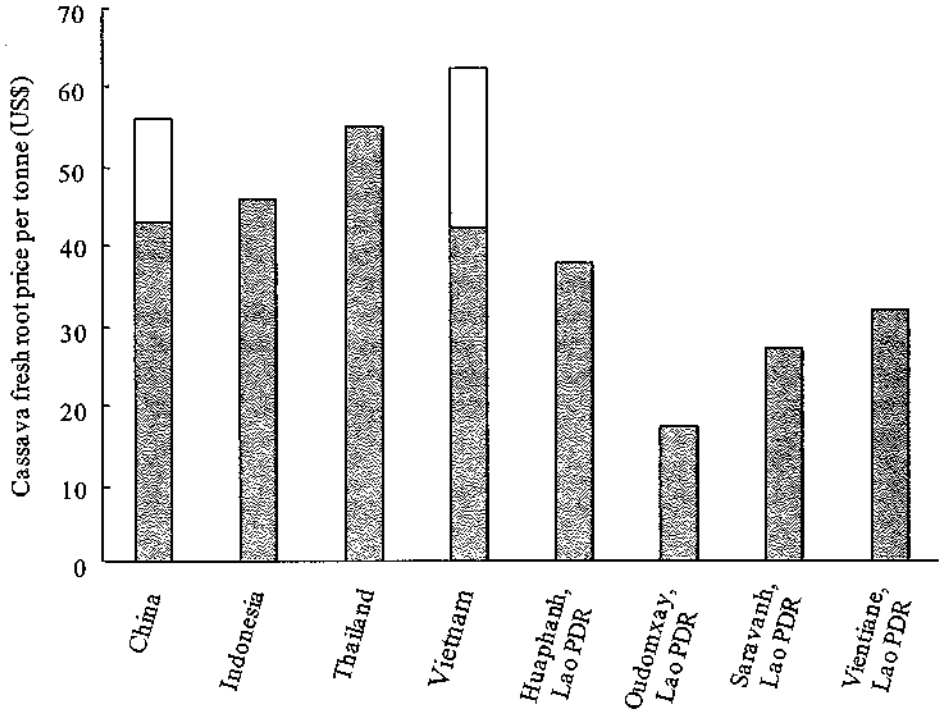

Figure 3. Price of fresh cassava roots that farmers received in various countries and in four provinces of Lao PDR in 2007 (grey bar = price variation between lowest and highest prices).

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RESULTS OF THE CASSAVA SURVEY IN LAO PDR

Thiphavong Boupha[1], Silinthone Sacklokham[2], Phosy Chanhming[3] and Tin Maung Aye[4]

ABSTRACT

Cassava has become a crop in high-demand in Lao PDR because of its many end-uses, such as for food, feed and starch, both for domestic use and for export. In order to identify and analyze the constraints and opportunities for cassava farmers in this country, a cassava baseline survey was conducted by CIAT in collaboration with the National University of Laos (NUoL) and the National Agriculture and Forestry Research Institute (NAFRI). The survey focused on cassava production, on-farm utilization and consumption. In December 2007 a questionnaire was developed and training of interviewers started. The survey interviewed 779 households, i.e. 20-25 households in each of 2-3 districts in each of 11 provinces, six in the north and north-east, three in the central part and two in the south.

Results of the survey indicate that most (90.6%) of the households surveyed grew cassava on sloping lands. The cassava production areas and agronomic practices used differed considerably between provinces. About 85% of surveyed farmers planted cassava permanently on the same land, and most used very little or no fertilizers. The average growing area per household was 0.31 ha with a yield of 14.76 t/ha. Most farmers preferred high-yielding cassava varieties with good taste for eating and with high starch content for feed and for sale. Most farmers grew cassava for home consumption. Cassava roots and leaves are mainly used as food or for feeding their animals. Only a few farmers (7.7%) sold their cassava.

Currently, cassava is one of the most important food and feed crops for smallholder farmers living in the uplands. High-yielding cassava varieties and better agronomic practices are still lacking. However, a tremendous potential exists for cassava production. This paper aims to present the rationalization of the cassava survey as part of a strategic plan for cassava research and development to improve food security and reduce poverty in the uplands of Lao PDR.

INTRODUCTION

Lao PDR is a land-locked and mountainous country with a total land area of 23.68 million ha, and a population of 5.7 million people; about 85% of those are working in agriculture. Nowadays, Lao PDR is trying to reduce poverty through a series of development goals. In this regards, the Ministry of Agriculture and Forestry (MAF) has identified four goals, including food security, market-oriented production, eradication of slash-and-burn upland cultivation, and sustainable forest management with a proper balance between its use and protection. Meanwhile, cassava is now considered as one of the main crops, after rice and maize.

The cultivation of cassava increased to a total area of 11,015 ha in 2008, with a total root production of 233,420 tonnes and an average yield of 21.19 t/ha, compared with a total area of 5,100 ha in 1998 (FAO, 2010). As the census data indicates, the FAO data may not be very accurate because cassava is grown by many households in small plots as a food security crop, with plants or even roots being harvested piecemeal and only when needed. This makes accurate data collection almost impossible. In many areas, yields are still low

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because most farmers grow only the local eating varieties which have low yields and low starch contents.

With the increasing demand for cassava products, cassava is likely to expand from being a crop for food security and animal feed to being a crop for cash income from sale as an industrial crop; this will encourage farmers to plant more cassava and shift from local eating varieties to high-yielding, high-starch industrial varieties, primarily some of the varieties developed in neighboring countries such as Thailand, Vietnam and China, and evaluated recently in Laos with CIAT and Lao collaboration. Thus, while cassava may continue in its role as a food security crop and a crop for animal feed, in the near future it is likely to become a very important industrial crop, as has already happened in many neighboring countries.

METHODOLOGY

A baseline survey was conducted to collect basic farm-level information on cassava production and utilization systems. The survey was conducted in 11 provinces across the country, of which six provinces were located in the north of the country (accounting for 61.10% of total households surveyed), where there is a high density of poverty; three provinces in the Central region, and two provinces in the South. The selected provinces represent the diversity of cassava area, ethnicity of the population, ecosystems, climatic, and geopolitical factors of the country.

The surveyed provinces and districts were selected in consultation with the NAFRI coordinator and other senior staff, PAFO/DAFO staff, and teachers from the National University of Laos (NUoL) to represent locally different conditions. Then, a random sampling method was used to select a representative sample. Villages and households were randomly selected from these districts. The household heads were interviewed with a structured questionnaire to collect quantitative and qualitative data.

The information was collected on cassava farming systems: on farm area, production, farming practices, cultivation of traditional and modern cassava varieties. Questions on agronomic practices such as cropping patterns, access to new technology, and farmers' perceptions of changes in general living standards were also included. A total of 779 households from 11 provinces, 38 districts, and about 20 households in each district were selected for the survey, which was conducted by students and staff of NUoL in December 2007. Detailed information on the number of households surveyed in each province and district is shown in **Table 1**. Six provinces in the north and northeastern part of the country were grouped together as belonging to the North, three provinces from the Central part and two provinces from the South of the country.

RESULTS

1. Demographics of Households Surveyed

Table 2 shows that male household heads were the dominant source of information, accounting for 91% of all households interviewed; the average age of farmers interviewed was 46 and the level of education was between traditional/religious and primary education. The average household size was 6.5 persons, with an average age of 26.

Table 1. Number of households in each district, province and region included in the cassava survey in Lao PDR.

Region	Province	District	No. of households surveyed in District	No. of households surveyed in Province
North	*6 provinces*	*23 districts*	*476*	*476*
	Houaphan	Samneua	19	64
		Samtai	15	
		Viengxai	15	
		Xiengkhor	15	
	Luang Namtha	Long	21	80
		LuangNamtha	18	
		Sing	20	
		Viengphoukha	21	
	Luang Prabang	Nambak	15	60
		Ngoy	15	
		PakOu	15	
		Viengkham	15	
	Oudomxay	Ghar	21	84
		Lar	21	
		Namor	21	
		Xai	21	
	Phongsali	Bountai	24	84
		Khua	30	
		Mai	30	
	Xieng Khouang	Nonghat	25	104
		Peak	28	
		Phaxai	25	
		Phoukood	26	
Central	*3 provinces*	*10 districts*	*196*	*196*
	Borikhamxay	Borlikhun	19	82
		Kamkerd	20	
		Pakading	20	
		Parksun	23	
	Khammouan	Hinboun	9	68
		Maharxai	18	
		Xebungfai	20	
		Yommalad	21	
	Vientiane	Hinherp	18	46
		Kasi	28	
South	*2 provinces*	*7 districts*	*107*	*107*
	Saravan	Khongsedone	15	62
		Lowgham	15	
		Saravan	17	
		Vapy	15	
	Sekong	Kaleum	15	45
		Lamam	16	
		Tharteng	14	
Total Country	*11 provinces*	*40 districts*	*779*	*779*

Table 2. Demographics of households surveyed.

Province	Total no. of households	Head of household			Average household		
		Male	Age	Education [1)]	Size	Age	Education
North	***476***	***426***	***45***	***2.90***	***6.5***	***26***	***2.69***
Houaphan	64	56	46	3.78	6.6	29	3.20
Luang Namtha	80	78	43	2.29	6.3	26	2.13
Luang Prabang	60	56	45	2.78	6.0	26	2.82
Oudomxay	84	81	45	2.87	6.9	25	2.64
Phongsali	84	64	45	2.88	5.9	27	2.69
Xieng Khouang	104	91	45	2.94	7.2	25	2.79
Central	***196***	***183***	***47***	***2.78***	***6.0***	***25***	***2.63***
Borikhamxay	82	79	46	2.65	6.0	25	2.63
Khammouan	68	58	49	2.93	5.3	30	2.73
Vientiane	46	46	47	2.80	6.2	27	2.57
South	***107***	***102***	***45***	***2.72***	***7.3***	***26***	***2.35***
Saravan	62	57	49	2.76	6.8	27	2.48
Sekong	45	45	47	2.67	7.8	24	2.17
Total Lao PDR	***779***	***711***	***46***	***2.85***	***6.5***	***26***	***2.64***

[1)] Level of education: 1 = none; 2 = traditional/religious; 3 = primary school

2. Agricultural Information

Table 3 shows that the average farm size of interviewed households was 2.59 ha, with farmers in the North having slightly less area than others, especially in Houaphan and Ponsali provinces. The average number of land plots was 3.0 across the country, with farmers in the North having more plots than those in the Central region and the South. Practically all farmers (92-100%) owned their land, while the rest was either borrowed or rented, or was rented out.

Practically all households seemed to have enough land (1.8-3.4 ha) for their agricultural and livestock activities; of this 94.6% was used for cropping, 0.6% for livestock and 4.9% for homes and gardens. In particular in Houaphan, Luang Prabang, Xieng Khouang, Vientiane and Sekong 100% of land was used for cropping, while only 73.2% of farm land owned in Oudomxay was used for cropping **(Table 4)**.

During the wet season of 2007, about 50.7% of surveyed households cultivated upland rice with the average area of 0.83 ha per household **(Table 5)**.

Some cash crops were also planted; the most common ones are maize, cassava, soybean, sweetpotatoes, sesame, job tears and vegetables. Among those, maize was planted on average by 40.3% of the surveyed households with an average area of 0.5 ha per household. Cassava is also becoming a more and more popular cash crop. Out of 779 households surveyed, 90.6% were involved in growing cassava, with an average area of

0.31 ha, while the average cost of inputs was about 59,000 kip (about US$ 6.-) per household (**Table 6**).

Table 3. Agricultural and livestock activities of households surveyed.

Province	Number of laborers for Agriculture	Number of laborers for Livestock	Farm size (ha)	Number of Plots	Land owned (%)
North	***2.96***	***2.73***	***2.41***	***3.3***	***96.22***
Houaphan	1.39	0.83	1.81	3.3	96.88
Luang Namtha	1.56	1.25	3.28	2.9	100.00
Luang Prabang	4.20	4.15	2.71	3.9	91.67
Oudomxay	3.08	3.01	2.53	4.3	95.24
Phongsali	2.98	2.96	1.93	3.5	95.24
Xieng Khouang	4.18	3.79	2.21	2.1	97.12
Central	***4.01***	***3.79***	***2.91***	***2.6***	***95.41***
Borikhamxay	4.96	4.74	3.14	2.8	92.68
Khammouan	2.88	2.72	2.53	2.6	97.06
Vientiane	4.00	3.67	3.08	2.3	97.83
South	***4.60***	***4.02***	***2.80***	***2.8***	***99.07***
Saravan	3.76	2.94	2.35	2.2	100.00
Sekong	5.76	5.51	3.43	3.5	97.78
Total Lao PDR	***3.45***	***3.17***	***2.59***	***3.0***	***96.41***

Table 4. Land use and land type.

Province	Farm size (ha)	% Land used for: Cropping	Livestock	Garden	% Land type is: Very Steep	Steep	Sloping	Flat
North	***2.41***	***94.02***	***0.46***	***5.52***	***3.26***	***21.52***	***56.09***	***19.13***
Houaphan	1.81	100.00	0.00	0.00	9.38	28.13	51.56	10.94
Luang Namtha	3.28	100.00	0.00	0.00	3.90	16.88	55.84	23.38
Luang Prabang	2.71	89.47	1.75	8.77	3.64	18.18	60.00	18.18
Oudomxay	2.53	73.24	1.41	25.35	0.00	7.59	78.48	13.92
Phongsali	1.93	98.80	0.00	1.20	0.00	9.64	81.93	8.43
Xieng Khouang	2.21	100.00	0.00	0.00	3.92	43.14	18.63	34.31
Central	***2.91***	***93.30***	***0.56***	***6.15***	***4.92***	***5.46***	***28.42***	***61.20***
Borikhamxay	3.14	92.86	1.43	5.71	5.71	8.57	34.29	51.43
Khammouan	2.53	88.89	0.00	11.11	0.00	1.49	14.93	83.58
Vientiane	3.08	100.00	0.00	0.00	10.87	6.52	39.13	43.48
South	***2.80***	***99.04***	***0.96***	***0.00***	***0.00***	***5.71***	***43.81***	***50.48***
Saravan	2.35	98.39	1.61	0.00	0.00	6.45	43.55	50.00
Sekong	3.43	100.00	0.00	0.00	0.00	4.65	44.19	51.16
Total Lao PDR	***2.59***	***94.57***	***0.56***	***4.87***	***3.21***	***15.37***	***47.59***	***33.82***

Table 5. Staple crops planted during the wet (WS) and dry season (DS) of 2007.

Province	Upland Rice			Paddy Rice (WS)			Paddy Rice (DS)		
	HHs (No.)	Area (ha)	Cost (kip)	HHs (No.)	Area (ha)	Cost (kip)	HHs (No.)	Area (ha)	Cost (kip)
North	***243***	***0.82***	***45,147***	***340***	***0.82***	***227,974***	***20***	***0.52***	***208,000***
Houaphan	35	0.50	79,431	56	0.59	73,768	4	0.54	0
Luang Namtha	47	1.01	43,564	66	1.06	623,455	2	0.90	135,000
Luang Prabang	28	0.76	37,717	31	0.72	159,677	7	0.47	331,429
Oudomxay	49	0.80	4,020	67	0.73	125,552	2	0.54	150,000
Phongsali	48	0.97	101,875	47	0.71	117,660	5	0.41	254,000
Xieng Khouang	36	0.76	0	73	0.95	182,740	0		
Central	***93***	***0.93***	***63,656***	***169***	***1.52***	***868,580***	***22***	***0.36***	***419,864***
Borikhamxay	33	0.79	86,364	73	1.67	1,141,781	1	0.32	900,000
Khammouan	45	0.96	58,444	56	1.64	526,429	20	0.35	391,850
Vientiane	15	1.14	29,333	40	1.10	849,000	1	0.56	500,000
South	***59***	***0.74***	***0***	***87***	***1.28***	***5,402***	***9***	***0.79***	***62,222***
Saravan	26	0.29	0	53	1.36	8,868	3	0.90	186,667
Sekong	33	0.57	0	34	1.16	0	6	0.73	0
Total Lao PDR	***395***	***0.83***	***42,761***	***596***	***1.08***	***377,133***	***51***	***0.50***	***273,667***

Table 6. Cash crops planted during 2007.

Province	Maize			Cassava			Soybean		
	HHs (%)	Area (ha)	Cost (kip)	HHs (%)	Area (ha)	Cost (kip)	HHs (%)	Area (ha)	Cost (kip)
North	***52.31***	***0.57***	***59,985***	***92.86***	***0.28***	***21,799***	***2.31***	***0.38***	***3,636***
Houaphan	75.00	0.55	26,854	96.88	0.25	2,419	12.50	0.47	0
Luang Namtha	45.00	0.63	145,444	98.75	0.35	7,595	0.00		
Luang Prabang	45.00	0.30	25,926	61.67	0.12	0	1.67	0.40	0
Oudomxay	51.19	0.69	143,791	96.43	0.35	0	0.00		
Phongsali	29.76	0.60	56,960	98.81	0.50	105,482	1.19	0.01	40,000
Xieng Khouang	67.31	0.57	1,491	96.15	0.25	1,300	0.96	0.05	0
Central	***12.76***	***0.35***	***16,400***	***93.37***	***0.42***	***174,243***	***1.53***	***0.16***	***0***
Borikhamxay	19.51	0.34	15,625	97.56	0.70	236,769	3.66	0.16	0
Khammouan	4.41	0.28	0	88.24	0.20	194,083	0.00		0
Vientiane	13.04	0.41	26,667	93.48	0.32	30,233	0.00		0
South	***37.38***	***0.17***	***0***	***75.70***	***0.29***	***0***	***5.61***	***0.09***	***0***
Saravan	16.13	0.21	0	58.06	0.36	0	1.61	0.10	0
Sekong	66.67	0.16	0	100.00	0.18	0	11.11	0.09	0
Total Lao PDR	***40.31***	***0.50***	***48,874***	***90.63***	***0.31***	***58,812***	***2.57***	***0.26***	***2,000***

[1] 1 US$ = 10,000 kip in Dec 2007.

CASSAVA PRODUCTION

1. Land Use and Cropping Systems

With regards to the land use, on average 85.1% of households surveyed grew cassava permanently on the same piece of land and only 14.9% practiced slash-and- burn rotations for planting cassava. Most farmers in the North, about 85%, planted cassava permanently on the same land, especially in Houaphan and Xieng Khouang provinces, but in Luang Namtha about 47% of farmers planted cassava in slash-and-burn rotation systems. In contrast, more farmers in the South rotated the land, while only 30% used the land for permanent cropping. Growing cassava in rotation was particularly prevalent in Saravan province. On average for the whole country, about 65% of farmers grew cassava in monoculture while 35% practiced intercropping. Intercropping was particularly prevalent in Sekong, Vientiane and Oudomxay provinces **(Table 7)**. The most common intercrops were rice, fruits, cash crops and vegetables.

Table 7. Information about cassava cultivation.

		Area for (%)		Land use (%)	
Province	**Cassava area (ha)**	**Monocropping**	**Intercropping**	**Permanent cropping**	**Slash/burn rotation**
North	***0.28***	***72.18***	***27.82***	***84.21***	***15.79***
Houaphan	0.25	77.88	22.12	96.88	3.13
Luang Namtha	0.35	40.87	59.13	53.25	46.75
Luang Prabang	0.12	70.47	29.53	86.11	13.89
Oudomxay	0.35	21.45	78.55	89.87	10.13
Phongsali	0.50	74.80	25.20	81.93	18.07
Xieng Khouang	0.25	100.00	0.00	96.94	3.06
Central	***0.42***	***52.95***	***47.05***	***90.32***	***9.68***
Borikhamxay	0.70	52.92	47.08	80.77	19.23
Khammouan	0.20	100.00	0.00	100.00	0.00
Vientiane	0.32	11.06	88.94	92.86	7.14
South	***0.29***	***76.87***	***23.13***	***30.00***	***70.00***
Saravan	0.36	91.03	8.97	14.29	85.71
Sekong	0.18	0.00	100.00	66.67	33.33
Total Lao PDR	***0.31***	***65.65***	***34.35***	***85.15***	***14.85***

2. Cassava Soils

There are about four types of soil in Lao PDR that are being used to grow cassava, such as sandy, loamy, clayey and rocky soils. Results from the survey indicate that on average about 21% of soils used for growing cassava have a sandy texture, 25% are loamy, 32% are clayey and 22% are rocky. The soil color is also different from place to place across the country, but on average about 41% of cassava soils are red, 15% are grey, 34% are black, and about 10% are white **(Table 8)**.

Table 8. Soil types used for cassava cultivation.

	Soil types (% of area)				Soil color (% of area)			
Province	**Sandy**	**Loamy**	**Clayey**	**Rocky**	**Red**	**Grey**	**Black**	**White**
North	***16.74***	***23.70***	***35.00***	***24.57***	***48.18***	***8.64***	***35.91***	***7.27***
Houaphan	21.88	12.50	37.50	28.13	48.44	17.19	34.38	0.00
Luang Namtha	27.50	15.00	51.25	6.25	46.84	15.19	26.58	11.39
Luang Prabang	15.91	22.73	36.36	25.00	45.71	0.00	25.71	28.57
Oudomxay	21.43	3.57	60.71	14.29	54.43	10.13	24.05	11.39
Phongsali	4.76	2.38	28.57	64.29	67.47	3.61	24.10	4.82
Xieng Khouang	11.54	71.15	4.81	12.50	29.00	4.00	67.00	0.00
Central	***36.07***	***33.33***	***23.50***	***7.10***	***27.27***	***11.69***	***32.47***	***28.57***
Borikhamxay	61.73	12.50	37.50	28.13	27.27	11.69	32.47	28.57
Khammouan	20.59	15.00	51.25	6.25	11.94	61.19	23.88	2.99
Vientiane	5.88	22.73	36.36	25.00	35.71	9.52	35.71	19.05
South	***11.11***	***11.11***	***37.04***	***40.74***	***55.56***	***11.11***	***33.33***	***0.00***
Saravan	2.78	0.00	5.56	91.67	50.00	16.67	33.33	0.00
Sekong	17.78	20.00	62.22	0.00	66.67	0.00	33.33	0.00
Total Lao PDR	***20.99***	***24.72***	***32.32***	***21.96***	***41.10***	***14.65***	***34.17***	***10.08***

3. Land Preparation

Most surveyed households in the country (57%) prepared the land used for cassava cultivation by hoe, while only 0.32% used animals, 3.15% used a hand tractor, 2.5% used a 4-wheel tractor, and 37% planted cassava without any tillage **(Table 9)**.

Table 9. Land preparation for cassava cultivation.

	Land preparation (% of households)				
Province	Hoe	Animals	Hand tractor	4-W tractor	No tillage
North	***46.59***	***0.45***	***2.50***	***0.91***	***49.55***
Houaphan	1.56	0.00	0.00	0.00	98.44
Luang Namtha	68.35	0.00	2.53	2.53	26.58
Luang Prabang	77.14	0.00	0.00	2.86	20.00
Oudomxay	100.00	0.00	0.00	0.00	0.00
Phongsali	7.23	0.00	0.00	0.00	92.77
Xieng Khouang	38.00	2.00	9.00	1.00	50.00
Central	***79.35***	***0.00***	***4.89***	***5.98***	***9.78***
Borikhamxay	76.32	0.00	11.84	10.53	1.32
Khammouan	75.76	0.00	0.00	4.55	19.70
Vientiane	90.48	0.00	0.00	0.00	9.52
South		***0.00***	***0.00***	***10.00***	***0.00***
Saravan	100.00	0.00	0.00	0.00	0.00
Sekong	66.67	0.00	0.00	33.33	0.00
Total Lao PDR	***56.78***	***0.32***	***3.15***	***2.52***	***37.22***

Among 779 households surveyed, only 25 made ridges before planting cassava and that was mainly in Borikhamxay province. In total, the percentage of households making ridges was only about 4%. Among those farmers that made ridges for cassava, on average about 58% made the ridges along contour lines, 32% up-and-down the slope, and about 10% parallel to plot borders. Nearly all farmers planted cassava on top of the ridges **(Table 10)**.

Table 10. Ridge characteristics.

	% of households		Ridge type (% of households)		
Province	Making ridges	Plant on top of ridges	Up-down slope	Along Contours	Parallel to plot borders
North	***0.48***	***100.00***	***33.33***	***66.67***	***0.00***
Houaphan	0.00	0.00	0.00	0.00	0.00
Luang Namtha	2.53	100.00	0.00	100.00	0.00
Luang Prabang	0.00	0.00	50.00	50.00	0.00
Oudomxay	0.00	0.00	0.00	0.00	0.00
Phongsali	0.00	0.00	0.00	0.00	0.00
Xieng Khouang	0.00	0.00	0.00	0.00	0.00
Central	***12.23***	***79.41***	***32.35***	***55.88***	***11.76***
Borikhamxay	22.78	78.13	33.33	56.67	10.00
Khammouan	7.46	100.00	50.00	50.00	0.00
Vientiane	0.00	0.00	0.00	50.00	50.00
South	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***
Saravan	0.00	0.00	0.00	0.00	0.00
Sekong	0.00	0.00	0.00	0.00	0.00
Total Lao PDR	***4.06***	***80.56***	***32.50***	***57.50***	***10.00***

4. Time of Planting

Table 11 shows that on average for the whole country about 80% of households surveyed plant their cassava from April to June, particularly farmers in the Central part of the country. But in both the North and South about 22% of surveyed farmers plant in the period from January to March, particularly in Houaphan (86%) and Sekong (50%) provinces. Very few farmers plant cassava in other months of the year.

5. Source and Storage of Planting Material

There are several sources of cassava stakes for planting, but the most common is the use of stems from the farmers' own fields (accounting for 63% of total households surveyed), followed by getting from neighbors or friends (24%) and buying (13.%) **(Table 12)**.

Table 13 shows that after getting cassava stakes, most farmers (85%) will plant cassava within two weeks; only about 9.5%, 4.0% and 1.7% of households surveyed store cassava stems for about 3 to 4 weeks; 5 to 12 weeks, and longer than 12 weeks,

respectively. Only in Sekong province the majority of farmers (67%) store cassava stems for 5-12 weeks, while 33% will store the stems for more than 12 weeks.

Table 11. Period for planting cassava (% of households).

Province	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
North	***21.77***	***74.64***	***3.59***	***0.00***
Houaphan	85.94	14.06	0.00	0.00
Luang Namtha	19.74	77.63	2.63	0.00
Luang Prabang	28.57	68.57	2.86	0.00
Oudomxay	6.33	78.48	15.19	0.00
Phongsali	6.02	93.98	0.00	0.00
Xieng Khouang	1.23	98.77	0.00	0.00
Central	***2.16***	***95.14***	***2.16***	***0.54***
Borikhamxay	1.32	96.05	1.32	1.32
Khammouan	2.99	92.54	4.48	0.00
Vientiane	2.38	97.62	0.00	0.00
South	***22.22***	***11.11***	***66.67***	***0.00***
Saravan	14.29	0.00	85.71	0.00
Sekong	50.00	50.00	0.00	0.00
Total Lao PDR	***15.85***	***79.90***	***4.08***	***0.16***

Table 12. Source of cassava stakes for planting (% of households).

Province	From own Field	From neighbors	Buy
North	***60.33***	***23.75***	***15.91***
Houaphan	78.13	21.88	0.00
Luang Namtha	10.53	3.95	85.53
Luang Prabang	75.00	25.00	0.00
Oudomxay	43.55	54.84	1.61
Phongsali	59.04	40.96	0.00
Xieng Khouang	93.00	6.00	1.00
Central	***69.71***	***22.86***	***7.43***
Borikhamxay	67.95	23.08	8.97
Khammouan	88.71	6.45	4.84
Vientiane	40.00	51.43	8.57
South	***50.00***	***40.00***	***10.00***
Saravan	57.14	42.86	0.00
Sekong	33.33	33.33	33.33
Total Lao PDR	***62.87***	***23.76***	***13.37***

About 67% of the 779 households surveyed stored cassava stems in the shade, particularly in Khammouan and Luang Namtha provinces, while 38% stored cassava stems in open fields, especially in the Phongsali province. Only about 5% of farmers stored the

stems in a shed. In all cases, cassava stems were mainly stored in a horizontal position **(Table 14)**.

Table 13. Storage period for cassava stems before planting (% of households).

Province	<2 weeks	3-4 weeks	5-12 weeks	>12 weeks
North	***87.17***	***8.64***	***3.14***	***1.05***
Houaphan	95.45	4.55	0.00	0.00
Luang Namtha	57.69	28.21	12.82	1.28
Luang Prabang	94.12	0.00	5.88	0.00
Oudomxay	84.21	11.84	0.00	3.95
Phongsali	100.00	0.00	0.00	0.00
Xieng Khouang	98.88	1.12	0.00	0.00
Central	***78.57***	***12.70***	***5.56***	***3.17***
Borikhamxay	58.49	28.30	11.32	1.89
Khammouan	93.75	3.13	3.13	0.00
Vientiane	92.68	0.00	0.00	7.32
South	***70.00***	***0.00***	***20.00***	***10.00***
Saravan	100.00	0.00	0.00	0.00
Sekong	0.00	0.00	66.67	33.33
Total Lao PDR	***84.75***	***9.46***	***4.05***	***1.74***

Table 14. Storage place of cassava stems (% of households).

	In open field		In shade		In shed	
Province	**Total**	**Horizontal**	**Total**	**Horizontal**	**Total**	**Horizontal**
North	***32.75***	***60.61***	***63.03***	***78.35***	***4.22***	***17.65***
Houaphan	71.43	20.00	28.57	16.67	0.00	0.00
Luang Namtha	9.09	85.71	84.42	72.31	6.49	40.00
Luang Prabang	25.00	55.56	72.22	57.69	2.78	0.00
Oudomxay	24.36	78.95	74.36	68.97	1.28	0.00
Phongsali	95.12	62.82	4.88	50.00	0.00	0.00
Xieng Khouang	3.67	50.00	87.16	98.95	9.17	10.00
Central	***13.48***	***36.84***	***80.85***	***28.95***	***5.67***	***12.50***
Borikhamxay	13.04	33.33	79.71	38.18	7.25	20.00
Khammouan	6.45	50.00	93.55	17.24	0.00	0.00
Vientiane	19.51	37.50	73.17	23.33	7.32	0.00
South	***33.33***	***0.00***	***58.33***	***0.00***	***8.33***	***0.00***
Saravan	37.50	0.00	62.50	0.00	0.00	0.00
Sekong	25.00	0.00	50.00	0.00	25.00	0.00
Total Lao PDR	***27.88***	***56.13***	***67.45***	***61.87***	***4.68***	***15.38***

6. Cassava Varieties

According to results of the survey, about 96% of farmers prefer high yielding varieties, followed by easy growing varieties (78%), those that have good taste (76%), and high starch content varieties (71%). Interestingly, farmers in Luang Namtha province consider the four criteria for selecting cassava varieties of equal importance, while high-starch content is considered of least importance in Houaphan and in the two southern provinces **(Table 15).**

Table 15. Criteria for selecting cassava varieties (% of households).

Province	High Yield	High Starch	Good Taste	Easy Growing
North	***94.86***	***71.79***	***78.95***	***73.44***
Houaphan	94.12	0.00	50.00	100.00
Luang Namtha	100.00	100.00	100.00	100.00
Luang Prabang	95.65	45.45	16.67	100.00
Oudomxay	78.72	100.00	100.00	100.00
Phongsali	97.37	75.00	89.66	3.03
Xieng Khouang	98.57	80.00	62.50	90.48
Central	***99.25***	***82.61***	***80.00***	***97.30***
Borikhamxay	100.00	75.00	100.00	100.00
Khammouan	98.28	66.67	60.00	87.50
Vientiane	100.00	87.50	100.00	100.00
South	***77.78***	***0.00***	***25.00***	***25.00***
Saravan	100.00	0.00	0.00	50.00
Sekong	33.33	0.00	33.33	0.00
Total Lao PDR	***95.85***	***71.21***	***76.06***	***77.51***

Cassava yields and production per household are rather similar among regions and provinces. Averaged over the whole country, surveyed farmers estimated a yield of 14.8 t/ha, with those in the North estimating the highest yield of about 15.2 t/ha. In the Central and South, the expected yield is a little lower at 13.5 t/ha, and 14.0 t/ha, respectively. Most of the surveyed farmers (86%) would like to continue planting cassava, with those in the Central part and the South being the most interested in continuing to grow cassava (**Table 16**).

7. Method of Planting

About 82% of farmers plant cassava stakes horizontally, 13% in a slanted position and only 4% plant vertically.

The number of stakes planted per hill is also different from province to province. In the North, farmers plant mostly one stake per hill (average of 58%), except for Xieng Kouang where farmers plant mostly two stakes per hill. In the Central part, farmers usually plant two stakes per hill, particularly in Khammouan. Farmers in the South also plant mostly two stakes per hill **(Table 17).**

Table 16. Farmer estimated cassava area, production and yield.

Province	Area (ha/HH)	Production (t/HH)	Yield (t/ha)	Like to continue (%)
North	***0.28***	***4.29***	***15.20***	***78.99***
Houaphan	0.25	3.23	12.92	100.00
Luang Namtha	0.35	3.45	9.93	27.03
Luang Prabang	0.12	2.65	22.16	96.15
Oudomxay	0.35	5.11	14.76	66.10
Phongsali	0.50	6.32	12.53	75.00
Xieng Khouang	0.25	4.15	16.58	98.67
Central	***0.42***	***5.67***	***13.50***	***92.06***
Borikhamxay	0.70	9.44	13.41	97.96
Khammouan	0.20	3.07	15.28	85.48
Vientiane	0.32	3.35	10.43	100.00
South	***0.29***	***4.01***	***13.96***	***100.00***
Saravan	0.36	6.10	16.88	100.00
Sekong	0.18	2.38	12.90	100.00
Total Lao PDR	***0.31***	***4.63***	***14.76***	***85.65***

Table 17. Cassava planting methods used (% of households).

	Planting position			No. of stakes/hill	
Province	Vertical	Horizontal	Slanted	1 stake/hill	2 stakes/hill
North	***1.54***	***83.04***	***15.42***	***58.41***	***41.59***
Houaphan	0.00	98.44	1.56	65.63	34.38
Luang Namtha	1.25	60.00	38.75	81.01	18.99
Luang Prabang	7.50	90.00	2.50	77.50	22.50
Oudomxay	2.44	53.66	43.90	76.54	23.46
Phongsali	0.00	98.81	1.19	69.05	30.95
Xieng Khouang	0.96	99.04	0.00	6.73	93.27
Central	***11.40***	***78.24***	***10.36***	***19.79***	***80.21***
Borikhamxay	18.75	58.75	22.50	30.00	70.00
Khammouan	4.41	95.59	0.00	4.41	95.59
Vientiane	8.89	86.67	4.44	25.00	75.00
South	***2.67***	***89.33***	***8.00***	***31.08***	***68.92***
Saravan	0.00	90.00	10.00	53.33	46.67
Sekong	4.44	88.89	6.67	15.91	84.09
Total Lao PDR	***4.29***	***82.41***	***13.30***	***45.26***	***54.74***

8. Plant Spacing

About 43% of surveyed households planted cassava at a row spacing of 80-100 cm, while about 22% planted at 60-80 cm, and 34% planted at more than 100 cm. This was very

similar for the spacing between plants in the rows **(Table 18)**. In the North the plant spacing tended to be a little closer than in the Central part and in the South, especially in Xieng Khouang province.

Table 18. Spacing between plants and rows (% of households).

	Plant spacing in the row (cm)				Spacing between rows (cm)			
Province	**60-80**	**80-100**	**100-120**	**>120**	**60-80**	**80-100**	**100-120**	**>120**
North	***31.10***	***42.06***	***17.67***	***9.17***	***31.42***	***42.70***	***16.81***	***9.07***
Houaphan	1.59	39.68	23.81	34.92	1.56	34.38	32.81	31.25
Luang Namtha	51.28	34.62	12.82	1.28	50.00	36.25	12.50	1.25
Luang Prabang	2.56	48.72	38.46	10.26	2.50	50.00	37.50	10.00
Oudomxay	9.64	72.29	14.46	3.61	8.64	72.84	14.81	3.70
Phongsali	1.19	57.14	28.57	13.10	2.38	65.48	16.67	15.48
Xieng Khouang	88.00	9.00	3.00	0.00	88.35	7.77	3.88	0.00
Central	***6.45***	***47.31***	***18.82***	***27.42***	***3.70***	***43.92***	***20.63***	***31.75***
Borikhamxay	10.13	68.35	16.46	5.06	5.00	63.75	20.00	11.25
Khammouan	1.61	37.10	20.97	40.32	0.00	31.82	21.21	46.97
Vientiane	6.67	24.44	20.00	48.89	6.98	25.58	20.93	46.51
South	***7.58***	***39.39***	***13.64***	***39.39***	***12.77***	***44.68***	***21.28***	***21.28***
Saravan	16.67	63.33	16.67	3.33	16.67	63.33	16.67	3.33
Sekong	0.00	19.44	11.11	69.44	5.88	11.76	29.41	52.94
Total Lao PDR	***22.32***	***43.20***	***17.60***	***16.88***	***22.53***	***43.17***	***18.17***	***16.13***

9. Intercropping in Cassava

As indicated in **Table 7**, on average about 34% of the surveyed farmers intercrop cassava with other crops. The most common intercrops are upland rice, fruits, cash crops and vegetables. **Table 19** shows that about 41% of farmers across the country intercrop cassava with rice, 28% with cash crops, 26% with fruit trees and about 6% with vegetables. Farmers in the Central part and the South intercrop cassava with rice more than farmers in the North, where it accounts for only 7.1%.

Banana, pineapple and oranges are the most popular fruit crops intercropped with cassava, accounting for 48, 25, and 11% in the North, Central and South, respectively. On average about 28% of surveyed farmers intercrop their cassava with cash crops. The most popular cash crops are maize, beans, sugarcane, etc. Farmers in the North and South intercrop with cash crops more than farmers in the Central part. **Table 19** also shows that, on average, about 6% of households intercropped their cassava with vegetables such as chili, eggplant, cucumber, pumpkin, etc. Most intercrops are planted either two weeks before or 1-2 weeks after cassava.

10. Fertilization and Weeding

Fertilizer and manure application is very rare for cassava cultivation in Lao PDR. Across the country, an average of only 1.7% of households surveyed applied fertilizers to

cassava. About 0.86% of farmers in the North, 3.9% in the Central part and no farmers in the South applied fertilizers **(Table 20)**. The results also showed that no manures were applied to cassava in the 11 provinces included in the survey.

Table 19. Intercrops planted with cassava (% of households).

Province	Fruits	Cash Crops	Vegetables	Rice
North	***48.21***	***39.29***	***5.36***	***7.14***
Houaphan	85.71	0.00	14.29	0.00
Luang Namtha	66.67	33.33	0.00	0.00
Luang Prabang	0.00	66.67	0.00	33.33
Oudomxay	50.00	33.33	5.56	11.11
Phongsali	71.43	0.00	14.29	14.29
Xieng Khouang	27.78	72.22	0.00	0.00
Central	***25.00***	***5.36***	***10.71***	***58.93***
Borikhamxay	40.00	0.00	0.00	60.00
Khammouan	24.39	2.44	7.32	65.85
Vientiane	20.00	20.00	30.00	30.00
South	***10.98***	***35.37***	***2.44***	***51.22***
Saravan	6.90	55.17	3.45	34.48
Sekong	13.21	24.53	1.89	60.38
Total Lao PDR	***25.77***	***27.84***	***5.67***	***40.72***

Table 20. Fertilization and weeding (% of households).

		Weeding with		Weeding times			Weeding Stage		
Province	Fertilizer application	Hoe	Knife	1	2	>3	1 MAP	2 MAP	>3 MAP
North	***0.86***	***68.85***	***31.15***	***16.78***	***63.80***	***17.66***	***88.77***	***10.35***	***0.88***
Houaphan	0.00	88.89	11.11	7.81	78.13	10.94	100.00	0.00	0.00
Luang Namtha	0.00	50.00	50.00	39.24	53.16	6.33	97.50	1.25	1.25
Luang Prabang	7.14	75.68	24.32	2.44	51.22	41.46	100.00	0.00	0.00
Oudomxay	0.00	67.07	32.93	24.39	46.34	26.83	92.86	7.14	0.00
Phongsali	0.00	48.19	51.81	3.57	69.05	26.19	83.33	13.10	3.57
Xieng Khouang	2.02	87.00	13.00	15.53	77.67	6.80	72.12	27.88	0.00
Central	***3.95***	***60.53***	***39.47***	***13.99***	***65.28***	***16.58***	***87.18***	***9.23***	***3.59***
Borikhamxay	10.14	53.75	46.25	30.00	62.50	7.50	83.95	9.88	6.17
Khammouan	0.00	92.19	7.81	1.49	70.15	17.91	94.12	4.41	1.47
Vientiane	0.00	28.26	71.74	4.35	63.04	30.43	82.61	15.22	2.17
South	***0.00***	***36.71***	***63.29***	***2.56***	***29.49***	***44.87***	***79.75***	***16.46***	***3.80***
Saravan	0.00	2.86	97.14	0.00	20.00	37.14	94.12	0.00	5.88
Sekong	0.00	63.64	36.36	2.56	29.49	44.87	68.89	28.89	2.22
Total Lao PDR	***1.67***	***63.06***	***36.94***	***14.50***	***60.50***	***20.30***	***87.36***	***10.71***	***1.92***

On average, 93% of farmers surveyed weeded their cassava. But this was more common among farmers in the Central part and in the North than in the South. For those who weeded, 14% did so only once, 61% twice and 20% weeded three times or more after planting cassava. Hoe and knife are the most common tools used for weeding. **Table 20** also shows that on average about 63% weeded with hoe and 37% with knife, but no animals were used for weeding. The use of a knife for weeding is more common in the South, especially in Saravan, than in the North or Central part. Most farmers started weeding at one month after planting while only 12% started at two months or later.

11. Cassava Pests and Diseases

Farmers have observed some pests and diseases in their cassava fields. About 37% of households surveyed have seen pests and about 4% have seen some diseases. The most common problems were pigs and rats, encountered by 96% of farmers surveyed. However, farmers did not know the names of the diseases found **(Table 21)**.

Table 21. Pests and diseases (% of households).

Province	Pests (%)	Diseases (%)	Pigs and rats
North	***39.22***	***4.05***	***97.55***
Houaphan	32.81	4.84	100.00
Luang Namtha	57.53	0.00	97.67
Luang Prabang	32.35	2.86	100.00
Oudomxay	51.25	0.00	100.00
Phongsali	50.00	1.25	95.92
Xieng Khouang	13.86	12.24	0.00
Central	***22.63***	***5.49***	***95.83***
Borikhamxay	11.25	6.67	100.00
Khammouan	2.94	0.00	0.00
Vientiane	76.19	11.63	97.06
South	***61.84***	***0.00***	***89.58***
Saravan	17.65	0.00	25.00
Sekong	97.62	0.00	95.45
Total Lao PDR	***37.18***	***3.97***	***95.75***

12. Soil Erosion

Most farmers do not think that soil erosion is a problem on their cassava farm; only 7% of farmers surveyed considered soil erosion a serious problem. An average of 3.6% of farmers in the North, 1.9% in the Central part and 2.5% in the South try to reduce or stop soil erosion by making bunds through planting trees, placing wood or stones across the slope or by replanting cassava in their field. About 97% of farmers either do not know how, or do nothing to solve the soil erosion problem in their cassava fields **(Table 22)**.

Table 22. Soil erosion and solutions (% of households).

	Problem		Solve problem	
Province	**No**	**Serious**	**Yes**	**No**
North	***91.69***	***8.31***	***3.65***	***96.35***
Houaphan	93.55	6.45	0.00	100.00
Luang Namtha	92.41	7.59	0.00	100.00
Luang Prabang	79.49	20.51	26.67	73.33
Oudomxay	85.37	14.63	4.76	95.24
Phongsali	93.90	6.10	14.29	85.71
Xieng Khouang	98.02	1.98	0.00	100.00
Central	***95.98***	***4.02***	***1.90***	***98.10***
Borikhamxay	90.67	9.33	2.99	97.01
Khammouan	100.00	0.00	0.00	100.00
Vientiane	100.00	0.00	0.00	100.00
South	***94.87***	***5.13***	***0.00***	***100.00***
Saravan	94.29	5.71	0.00	100.00
Sekong	95.35	4.65	0.00	100.00
Total Lao PDR	***93.11***	***6.89***	***2.54***	***97.46***

13. Cassava Harvest Time and Methods

The results of the survey indicate that 62% of farmers harvest their cassava when the roots are more or less mature. About 65% of farmers use cassava for home consumption, 11% to sell for cash, and 24% to feed their animals. Most farmers harvest cassava between nine and twelve months, but about 6% harvest at less than six months and 26% at more than 12 months. Tools used for harvesting are hoes (68%), digging sticks (31%), and other tools (4%) **(Table 23)**.

14. Labor Requirements for Cassava Production

On average for the whole country, the total labor requirement for growing cassava is about 98 man-days/ha, including 16 man-days for land preparation, 15 for planting, 16 for weeding, and 34 for harvesting, and 17 for transport and post-harvest handling **(Table 24)**. Fertilizer and manure applications are very rare for cassava. Labor requirements are considerably higher in the North than in the Central part, which in turn is much higher than in the South. The lowest labor requirements were reported in Saravan province because little weeding is done.

CASSAVA UTILIZATION

Cassava is used in many ways; both cassava roots and leaves are food for home consumption in many rural areas in the Lao PDR. Some extra production of cassava is used for raising livestock such as pigs, goats, cattle, chickens, etc. In addition, cassava is also a source of income for households through the sale of roots, as well as that of the intercrops.

Table 23. Purpose and methods used for harvesting cassava roots (% of households).

	Purpose of harvest			Harvest Time (months)				Harvest by		
Province	Home consumption	Need cash	Feed animals	<6	9 (Jun)	12 (Sep)	>12	Hoe	Digging stick	Other
North	*59.82*	***10.40***	***28.32***	***5.09***	***32.08***	***27.88***	***34.96***	***68.14***	***30.75***	***1.11***
Houaphan	-	1.56	68.75	3.13	1.56	6.25	89.06	15.87	84.13	0.00
L. Namtha		5.19	2.60	0.00	3.80	89.87	6.33	96.25	1.25	2.50
L. Prabang	78.05	4.88	68.29	2.44	65.85	21.95	9.76	21.95	78.05	0.00
Oudomxay	-	46.34	46.34	14.63	56.10	25.61	3.66	84.52	14.29	1.19
Phongsali	88.10	2.38	8.33	2.38	80.95	16.67	0.00	60.00	37.50	2.50
X. Khouang		0.00	8.65	5.88	0.00	6.86	87.25	89.42	10.58	0.00
Central	*77.95*	***7.73***	***12.89***	***6.22***	***36.27***	***48.70***	***8.81***	***75.92***	***21.47***	***2.62***
Borikhamxay	-	18.52	11.11	9.88	41.98	39.51	8.64	91.36	6.17	2.47
Khammouan	-	0.00	1.49	2.99	1.49	83.58	11.94	82.81	12.50	4.69
Vientiane	-	0.00	32.61	4.44	77.78	13.33	4.44	39.13	60.87	0.00
South	*55.70*	***25.00***	***26.25***	***8.75***	***26.25***	***47.50***	***17.50***	***23.75***	***55.00***	***21.25***
Saravan	-	57.14	5.71	0.00	40.00	48.57	11.43	5.71	57.14	37.14
Sekong	-	0.00	42.22	15.56	15.56	46.67	22.22	37.78	53.33	8.89
Total Lao PDR	*64.50*	***11.29***	***23.97***	***5.79***	***32.55***	***35.59***	***26.07***	***65.28***	***30.98***	***3.73***

Table 24. Labor required for various activities in cassava plots (man-days/ha).

	Labor required (md/ha)								
Province	Land prep	Stake cut	Plant -ing	Fert. applic.	Weed-ing	Harvest	Carry	Post-harvest	Total
North	***18.45***	***5.43***	***10.70***	***0.07***	***17.57***	***43.31***	***19.32***	***0.45***	***115.31***
Houaphan	17.68	9.11	5.85	0.00	9.13	0.00	0.00	0.00	41.77
L. Namtha	12.95	7.77	14.24	0.00	10.36	28.48	6.47	0.00	80.27
L. Prabang	35.63	11.95	19.54	1.21	30.46	40.48	42.11	4.49	185.88
Oudomxay	27.34	4.60	18.54	0.00	22.77	36.15	19.42	0.64	129.46
Phongsali	14.75	2.55	10.31	0.00	26.09	35.38	43.82	0.00	132.89
X. Khouang	10.98	4.70	5.69	0.00	6.23	4.84	0.21	0.27	32.93
Central	***13.25***	***6.02***	***7.64***	***0.06***	***14.41***	***22.64***	***15.90***	***0.28***	***80.19***
Borikhamxay	6.38	6.43	7.94	0.10	6.48	25.17	26.93	0.26	79.70
Khammouan	57.22	10.27	14.50	0.10	60.41	44.76	10.07	1.10	198.42
Vientiane	14.50	7.31	8.91	0.00	18.35	20.75	3.19	0.00	73.01
South	***9.99***	***2.51***	***6.31***	***0.13***	***9.22***	***8.38***	***2.91***	***0.57***	***40.02***
Saravan	7.50	1.18	4.68	0.00	4.92	5.17	1.58	0.25	25.27
Sekong	15.49	6.64	9.66	0.60	21.93	17.10	6.84	1.61	79.88
Total Lao PDR	***16.09***	***5.37***	***9.34***	***0.07***	***15.84***	***33.60***	***16.77***	***0.41***	***97.49***

The majority of farmers (64%) grow cassava for family consumption. In the North, for example, an average of 60% of farmers grow cassava for eating, with the highest percentage in Phongsali (88%) and Luang Prabang (78%) provinces. In the Central part and South, an average of 78 and 56% of households use cassava roots for eating, respectively. Some cassava roots are also used for feeding animals, the highest percentage for this use was in Houaphan (52%), Sekong (29%) and Luang Prabang (22%), while the lowest percentages were found in Saravan (3%) and Luang Namtha (4%) provinces.

The results of the survey also indicate that on average about 19% of households sell cassava roots. This is the case for about 20% of surveyed households in the North, 15% in the Central region, and 27% in the South. The provinces that produce most cassava for sale are Luang Namtha (81%), Saravan (59%) and Oudomxay (32%). In the other four provinces in the North farmers do not sell their cassava.

Among the 64% of farmers across the country who use cassava roots for eating, 14% prepare the roots first by drying the root pieces, 56% through boiling fresh roots, 20% through roasting the roots in the fire, and about 10% is through other kinds of preparation **(Table 25)**.

Table 25. Utilization of cassava roots (% of households).

	Use of roots			Preparation of cassava roots for eating			
Province	Eating	Animal feeding	Sale	Drying	Boiling	Roasting	Others
North	***59.82***	***20.09***	***20.09***	***14.24***	***54.80***	***20.12***	***10.84***
Houaphan	48.44	51.56	0.00	2.63	76.32	15.79	5.26
Luang Namtha	15.00	3.75	81.25	2.63	76.32	18.42	2.63
Luang Prabang	78.05	21.95	0.00	0.00	39.47	42.11	18.42
Oudomxay	53.66	14.63	31.71	2.04	40.82	42.86	14.29
Phongsali	88.10	11.90	0.00	0.00	66.27	12.05	21.69
Xieng Khouang	76.47	23.53	0.00	55.84	37.66	6.49	0.00
Central	***77.95***	***7.18***	***14.87***	***3.85***	***73.72***	***17.95***	***4.49***
Borikhamxay	61.73	7.41	30.86	5.56	81.48	9.26	3.70
Khammouan	86.76	8.82	4.41	1.67	63.33	33.33	1.67
Vientiane	93.48	4.35	2.17	4.76	78.57	7.14	9.52
South	***55.70***	***17.72***	***26.58***	***41.82***	***9.09***	***29.09***	***20.00***
Saravan	38.24	2.94	58.82	0.00	0.00	83.33	16.67
Sekong	68.89	28.89	2.22	62.16	13.51	2.70	21.62
Total Lao PDR	***64.24***	***16.37***	***19.39***	***14.04***	***55.62***	***20.41***	***9.93***

Among the 16% of surveyed farmers who feed cassava roots to their animals, most feed the roots to pigs (84%), followed by cattle (7%) and chickens (6%). The highest percentage of farmers feeding cassava roots to their pigs was found in Luang Prabang, and Saravan provinces, and the lowest in Borikhamxay, Xieng Khouang and Sekong provinces. Some farmers also feed cassava roots to other animals including fish (1.14%), buffaloes (0.95%), goats and ducks (both 0.38% **(Table 26)**.

Table 26. Animals fed with cassava roots (% of households).

Province	Cattle	Buffaloes	Pigs	Goats	Chickens	Ducks	Fish
North	***7.44***	***0.55***	***86.78***	***0.28***	***4.41***	***0.28***	***0.28***
Houaphan	0.00	0.00	94.92	0.00	3.39	1.69	0.00
Luang Namtha	4.17	0.00	87.50	0.00	8.33	0.00	0.00
Luang Prabang	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Oudomxay	0.00	1.85	81.48	0.00	14.81	0.00	1.85
Phongsali	1.19	0.00	94.05	1.19	3.57	0.00	0.00
Xieng Khouang	24.04	0.96	74.04	0.00	0.96	0.00	0.00
Central	***7.44***	***0.83***	***77.69***	***0.83***	***11.57***	***0.83***	***0.83***
Borikhamxay	19.15	2.13	70.21	2.13	6.38	0.00	0.00
Khammouan	0.00	0.00	83.33	0.00	13.89	2.78	0.00
Vientiane	0.00	0.00	81.58	0.00	15.79	0.00	2.63
South	***4.76***	***4.76***	***78.57***	***0.00***	***2.38***	***0.00***	***9.52***
Saravan	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Sekong	5.26	5.26	76.32	0.00	2.63	0.00	10.53
Total Lao PDR	***7.22***	***0.95***	***84.03***	***0.38***	***5.89***	***0.38***	***1.14***

According to the results of the survey, an average of 54% of farmers feed cassava roots to their animals in the form of fresh root pieces, and about 32% after boiling. Some farmers feed cassava to their animals after chipping and drying (8%), after silage making (0.8%) and by other methods (4.6%) **(Table 27).**

Table 27. Methods of feeding cassava roots to animals (% of households).

Province	Fresh	Boiled	Chipped/Dried	Silage	Other
North	***56.03***	***30.17***	***10.34***	***0.86***	***2.59***
Houaphan	85.96	14.04	0.00	0.00	0.00
Luang Namtha	22.73	72.73	4.55	0.00	0.00
Luang Prabang	44.74	18.42	21.05	7.89	7.89
Oudomxay	10.20	55.10	24.49	0.00	10.20
Phongsali	73.81	23.81	1.19	0.00	1.19
Xieng Khouang	58.16	27.55	14.29	0.00	0.00
Central	***52.68***	***33.04***	***4.46***	***0.89***	***8.93***
Borikhamxay	36.96	54.35	6.52	2.17	0.00
Khammouan	82.35	17.65	0.00	0.00	0.00
Vientiane	43.75	18.75	6.25	0.00	31.25
South	***45.24***	***42.86***	***2.38***	***0.00***	***9.52***
Saravan	75.00	0.00	25.00	0.00	0.00
Sekong	42.11	47.37	0.00	0.00	10.53
Total Lao PDR	***54.38***	***31.87***	***8.37***	***0.80***	***4.58***

Compared with cassava roots, cassava leaves are seldom used in all provinces across the country. Households surveyed indicated that only about 10% of farmers use cassava leaves for either eating or feeding to livestock. More farmers use cassava leaves in Vientiane (65%) and Houaphan (26%) than in any other provinces across the country. At the same time, an average of 12% of farmers surveyed have never used cassava leaves before, particularly farmers in Saravan (58%), and Luang Namtha (37%). **Table 28** also shows that cassava leaves were mainly used for eating (average of 90%), while only 10% of farmers indicated that cassava leaves were used for feeding animals.

Table 28. Utilization of cassava leaves (% of households).

	Use of cassava leaves (%)			Use leaves for (%)	
Province	**Often**	**Seldom**	**Never**	**Eating**	**Animal feeding**
North	***8.25***	***81.37***	***10.38***	***88.54***	***11.46***
Houaphan	25.81	59.68	14.52	52.50	47.50
Luang Namtha	2.82	60.56	36.62	97.62	2.38
Luang Prabang	2.78	75.00	22.22	73.33	26.67
Oudomxay	9.21	89.47	1.32	100.00	0.00
Phongsali	2.53	97.47	0.00	93.59	6.41
Xieng Khouang	7.00	93.00	0.00	92.31	7.69
Central	***19.43***	***69.14***	***11.43***	***94.84***	***5.16***
Borikhamxay	4.00	77.33	18.67	91.23	8.77
Khammouan	5.26	94.74	0.00	98.36	1.64
Vientiane	65.12	20.93	13.95	94.59	5.41
South	***2.63***	***71.05***	***26.32***	***85.71***	***14.29***
Saravan	3.03	39.39	57.58	92.86	7.14
Sekong	2.33	95.35	2.33	83.33	16.67
Total Lao PDR	***10.52***	***77.04***	***12.44***	***90.00***	***10.00***

Among those farmers that feed cassava leaves to their animals an average of about 13% feed the leaves to their cattle, 28% to buffaloes, 12% to pigs, 13% to goats, and about 19% feed cassava leaves to their chickens **(Table 29)**.

Cassava leaves are fed to animals by several different ways, such as fresh, after wilting several hours, after cooking, after drying and after silage making. Results of the survey shows that most farmers feed cassava leaves fresh to their animals (68%), followed by feeding after cooking (26%) and after drying (3%) **(Table 30)**.

Farmers surveyed also indicated the different types of cassava varieties they fed to their animals. On average about 82% of farmers said that cassava leaves fed to their animals were of sweet varieties, about 13% of farmers fed both sweet and bitter varieties, about 1.4% fed some bitter varieties, and 3.1% fed only bitter varieties to their animals **(Table 31)**.

Table 29. Animals fed with cassava leaves (% of those that feed cassava leaves to animals).

	Cassava leaves are fed to					
Province	**Cattle**	**Buffalos**	**Pigs**	**Goats**	**Chickens**	**Others**
North	***19.54***	***28.15***	***17.65***	***16.60***	***22.69***	***16.60***
Houaphan	1.56	1.56	1.56	56.25	0.00	56.25
Luang Namtha	0.00	11.25	0.00	0.00	2.50	0.00
Luang Prabang	0.00	31.67	6.67	5.00	20.00	5.00
Oudomxay	1.19	4.76	0.00	3.57	4.76	3.57
Phongsali	1.19	1.19	0.00	28.57	0.00	28.57
Xieng Khouang	86.54	96.15	75.96	12.50	86.54	12.50
Central	***3.57***	***33.16***	***2.55***	***5.10***	***18.37***	***5.10***
Borikhamxay	4.88	37.80	3.66	4.88	29.27	4.88
Khammouan	1.47	36.76	1.47	2.94	5.88	2.94
Vientiane	4.35	19.57	2.17	8.70	17.39	8.70
South	***3.74***	***18.69***	***1.87***	***8.41***	***6.54***	***8.41***
Saravan	0.00	4.84	0.00	1.61	1.61	1.61
Sekong	8.89	37.78	4.44	17.78	13.33	17.78
Total Lao PDR	***13.35***	***28.11***	***11.68***	***12.58***	***19.38***	***12.58***

Table 30. Methods of feeding cassava leaves to animals (% of those that feed cassava leaves to animals).

Province	**Fresh**	**After wilting**	**After cooking**	**After drying**	**As silage**
North	***81.97***	***1.64***	***12.02***	***3.83***	***0.55***
Houaphan	94.12	5.88	0.00	0.00	0.00
Luang Namtha	20.00	0.00	80.00	0.00	0.00
Luang Prabang	33.33	0.00	8.33	50.00	8.33
Oudomxay	50.00	0.00	33.33	16.67	0.00
Phongsali	92.86	3.57	3.57	0.00	0.00
Xieng Khouang	85.71	0.00	14.29	0.00	0.00
Central	***46.55***	***1.72***	***48.28***	***1.72***	***1.72***
Borikhamxay	43.75	0.00	50.00	3.13	3.13
Khammouan	27.78	5.56	66.67	0.00	0.00
Vientiane	100.00	0.00	0.00	0.00	0.00
South	***16.67***	***0.00***	***83.33***	***0.00***	***0.00***
Saravan	0.00	0.00	100.00	0.00	0.00
Sekong	18.18	0.00	81.82	0.00	0.00
Total Lao PDR	***68.30***	***1.51***	***26.42***	***3.02***	***0.75***

Table 31. Type of cassava varieties used for feeding leaves to animals (% of farmers who feed cassava leaves to animals).

Province	Sweet	Sweet and bitter	Some bitter	Bitter only
North	***83.37***	***15.63***	***0.99***	***0.00***
Houaphan	87.30	9.52	3.17	0.00
Luang Namtha	92.73	7.27	0.00	0.00
Luang Prabang	87.80	12.20	0.00	0.00
Oudomxay	96.55	1.72	1.72	0.00
Phongsali	42.17	56.63	1.20	0.00
Xieng Khouang	100.00	0.00	0.00	0.00
Central	***83.65***	***13.84***	***1.89***	***0.63***
Borikhamxay	97.44	1.28	1.28	0.00
Khammouan	58.14	39.53	2.33	0.00
Vientiane	84.21	10.53	2.63	2.63
South	***73.42***	***0.00***	***2.53***	***24.05***
Saravan	41.18	0.00	2.94	55.88
Sekong	97.78	0.00	2.22	0.00
Total Lao PDR	***82.22***	***13.26***	***1.40***	***3.12***

Table 32 shows that on average 7.7% of farmers often sell their cassava roots, with the highest percentage of this in Luang Namtha (54%) and Saravan (25%) provinces. About 22% of surveyed farmers across the country sell their cassava a few times, and an average of 70% of farmers has never sold their cassava roots before.

Table 32. Sale of cassava roots (% of households).

Province	Never	A few times	Often
North	***84.20***	***25.00***	***12.64***
Houaphan	95.16	4.84	0.00
Luang Namtha	13.51	32.43	54.05
Luang Prabang	91.67	8.33	0.00
Oudomxay	41.89	54.05	4.05
Phongsali	92.68	7.32	0.00
Xieng Khouang	87.50	11.46	1.04
Central	***64.84***	***31.87***	***3.30***
Borikhamxay	41.33	53.33	5.33
Khammouan	73.44	26.56	0.00
Vientiane	93.02	2.33	4.65
South	***89.04***	***8.22***	***2.74***
Saravan	85.29	100.00	25.00
Sekong	92.31	5.13	2.56
Total Lao PDR	***70.10***	***22.24***	***7.66***

LIVESTOCK AND FAMILY INCOME

Income from raising livestock plays an increasingly important role in livelihood improvement in rural areas of Lao PDR. Most farmers surveyed raise animals such as cattle, buffaloes, pigs, goats, chickens, ducks, birds, fish, etc. Results of the survey indicate that, across the country, one household keeps on average 1.83 adult cattle on their farm. Farmers who owned the highest number of cattle were in Xieng Khouang (5.81 head of cattle) and Saravan (2.08 cattle), while those having the lowest number of cattle were in Sekong (0.38) and Phongsali (0.29). The average number of young cattle per household across the country was 0.82 heads. The number of buffaloes kept was a little lower, on average 1.24 adult buffaloes and 0.48 young buffaloes per household. The most buffaloes were owned by farmers in Xieng Khouang (2.78) and in Houaphan (2.11).

Pig raising is also very common (an average of 1.78 adult pigs and 1.41 young pigs kept per household). Farmers in Luang Namtha and Luang Prabang keep pigs on their farms more than in any other province surveyed. The number of goats kept is lower compared with pigs, an average of 0.58 adult goats and 0.17 young goats per household. Chickens and ducks are also kept on farms, an average of 16.9 adults, and 12 young chicks or ducklings **(Table 33)**.

Table 33. Number of various livestock kept on the farm.

	Cattle		Buffaloes		Pigs		Goats		Poultry	
Province	**Adult**	**Young**	**Adult**	**Young**	**Adult**	**Young**	**Adult**	**Young**	**Adult**	**Young**
North	***2.02***	***0.89***	***1.41***	***0.57***	***2.11***	***1.51***	***0.45***	***0.13***	***20.19***	***14.25***
Houaphan	1.80	1.05	2.11	0.84	2.03	1.97	0.27	0.05	14.48	16.81
L. Namtha	1.14	0.46	1.06	0.35	3.01	1.85	0.55	0.16	35.53	16.68
L. Prabang	1.28	0.60	0.48	0.27	2.77	2.12	1.32	0.38	22.60	15.25
Oudomxay	0.58	0.39	0.62	0.40	1.15	1.15	0.08	0.04	11.61	18.32
Phongsali	0.29	0.13	0.99	0.56	1.82	1.44	0.00	0.00	8.99	6.95
X. Khouang	5.81	2.29	2.78	0.88	2.07	0.98	0.63	0.17	26.50	12.82
Central	***1.62***	***0.74***	***0.83***	***0.29***	***1.35***	***1.68***	***0.62***	***0.19***	***11.73***	***11.94***
Borikhamxay	1.88	0.79	0.71	0.26	1.90	2.21	0.33	0.20	8.28	7.76
Khammouan	1.37	0.72	1.10	0.43	0.81	0.74	1.40	0.31	12.06	11.35
Vientiane	1.54	0.70	0.63	0.13	1.15	2.13	0.00	0.00	17.39	20.28
South	***1.36***	***0.69***	***1.25***	***0.47***	***1.14***	***0.47***	***1.09***	***0.36***	***11.79***	***2.36***
Saravan	2.08	1.16	1.19	0.65	0.79	0.44	0.95	0.52	7.42	2.40
Sekong	0.38	0.04	1.33	0.22	1.62	0.51	1.29	0.16	17.82	2.29
Total Lao PDR	***1.83***	***0.82***	***1.24***	***0.48***	***1.78***	***1.41***	***0.58***	***0.17***	***16.91***	***12.03***

Across the country, on average about 50% of farmers surveyed earned less than 1 million kip from selling crops over the past 12 months. About 33% earned between 1 and 3 million kip, and only 17% earned more than 3 million kip through selling crops. The highest number of households with an income of over 3 million kip from crops were in Saravan (30%), Vientiane (25%) and Borikhamxay (24%), while the lowest numbers are in Luang Prabang, Oudomxay and Pongsali **(Table 34)**.

Table 34. Family income from selling crops and livestock (% of households)

	Crop sale			Sale of pigs and piglets			Other animals		
Province	**<1 M**	**1-3 M**	**>3 M**	**<1 M**	**1-3 M**	**>3 M**	**<1 M**	**1-3 M**	**>3 M**
North	***54.09***	***30.70***	***15.20***	***47.59***	***44.14***	***8.28***	***42.32***	***19.48***	***38.20***
Houaphan	68.63	27.45	3.92	43.48	45.65	10.87	23.68	18.42	57.89
Luang Namtha	35.29	0.46	1.06	74.36	23.08	2.56	15.00	45.00	40.00
Luang Prabang	54.35	0.60	0.48	31.43	45.71	22.86	58.54	12.20	29.27
Oudomxay	33.33	0.39	0.62	40.91	45.45	13.64	66.67	13.89	19.44
Phongsali	67.31	0.13	0.99	63.79	36.21	0.00	90.57	7.55	1.89
Xieng Khouang	85.11	2.29	2.78	33.82	60.29	5.88	6.33	27.85	65.82
Central	***44.20***	***36.23***	***19.57***	***48.21***	***41.07***	***10.71***	***48.31***	***24.72***	***26.97***
Borikhamxay	33.82	42.65	23.53	50.00	33.33	16.67	40.63	18.75	40.63
Khammouan	81.58	10.53	7.89	57.14	42.86	0.00	52.50	22.50	25.00
Vientiane	21.88	53.13	25.00	42.11	52.63	5.26	52.94	41.18	5.88
South	***40.24***	***40.24***	***19.51***	***83.33***	***16.67***	***0.00***	***44.74***	***23.68***	***31.58***
Saravan	18.00	52.00	30.00	78.57	21.43	0.00	42.31	26.92	30.77
Sekong	75.00	21.88	3.13	86.36	13.64	0.00	50.00	16.67	33.33
Total Lao PDR	***49.64***	***33.45***	***16.90***	***51.05***	***41.10***	***7.85***	***43.91***	***21.07***	***35.03***

Selling pigs is another main source of family income; however, only 7.8% of households surveyed earned an income of more than 3 million kip. On average 41% earned between 1 and 3 million kip and about 51% earned less than 1 million kip. Provinces that earn more income from selling pigs are Luang Prabang, Borikhamxay and Oudomxay, and those earning less are Sekong, Saravan and Luang Namtha.

Table 34 also shows the family income earned from selling other kinds of livestock. On average 44% earned less than 1 million kip, 21% earned between 1 and 3 million kip and about 35% earned more than 3 million kip in the last 12 months. Besides selling crops and livestock, households surveyed also earned income from family members working with the government, wages from farm work and non-farm work, selling NTFPs, handicraft, trading and remittance, etc.

CONCLUSIONS

Cassava is one of the most important food and feed crops for smallholder farmers, especially in the uplands of Lao PDR. More than 90% of surveyed farmers cultivate cassava with an average area of 0.31 ha per household. However, high-yielding cassava varieties, better agronomic practices, and appropriate utilization technologies are still lacking. A great potential exists for cassava production and utilization. Therefore, there is an urgent need for a strategy for cassava research and development to improve food security and poverty reduction in the uplands of Lao PDR.

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ENHANCING CASSAVA PRODUCTION AND UTILIZATION THROUGH THE NIPPON FOUNDATION PROJECT IN CAMBODIA

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ABSTRACT

Research on cassava has only recently commenced in Cambodia as part of the CIAT coordinated Nippon Foundation Cassava Project, focusing mainly on varietal improvement, nutrient management and planting methods. To identify high-yielding varieties that are suitable for Cambodian conditions, many introduced varieties, mainly from Thailand, were tested in replicated and non-replicated trials in four provinces from 2005 to 2008. Different planting methods (vertical, horizontal, inclined, with either one stake or two stakes per hill) and different combinations of NPK fertilizers were also tested in both replicated and non-replicated trials, conducted on farmers fields in 13 sites in four provinces.

Preliminary results indicate that four genotypes, i.e. Rayong 72, Rayong 60, Rayong 5, and KU 50, performed very well in terms of fresh root yield and starch content across the various environments. Applying NPK fertilizers generally increased root yields of cassava and there was a significant difference among the fertilizer treatments. However, the root yield increase due to the application of NPK fertilizer was found to be greater in lower yielding than in the higher yielding environments. This indicates that the application of fertilizer is primarily needed in those areas where cassava is grown on poor soils. There was no consistent effect of planting method, spacing and planting method-by-spacing interaction for root yield of cassava in both replicated and non-replicated trials. The most economic planting method is horizontal planting with 1.0 x 1.0 m spacing.

Key words: Cassava, varietal selection, nutrient management, planting method, economics.

INTRODUCTION

Presently, farmers in Cambodia are interested in growing cassava because cassava has become a high-value crop, while the crop tolerates long dry periods and poor soils, and produces reasonable yields. Moreover, cassava roots currently have a high price. Most Cambodian farmers grow cassava in upland areas where the crop can be grown under rainfed conditions and on low-fertility soils; under these conditions cassava produces better than most other field crops. The national average yield was 20.49 t/ha in 2007 (MAFF, 2007). Cassava is normally planted in the early rainy season between May and June, while some farmers plant in the late rainy season, between October and November. The crop is usually harvested within 8-12 months after planting. The most important planting area is in Kampong Cham province, in northeastern Cambodia, but now other large planting areas are found in Battambang province in northwestern Cambodia.

In Cambodia cassava is the second most important crop, after rice. Recently, cassava has rapidly changed its role from being a food crop to an industrial crop, with a

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high rate of growth during the past several years. Cassava could be a high-demand crop for either domestic use or for export because it has a multiplicity of end-uses, including as human feed, animal feed, starch, sweeteners and ethanol.

Most of the cassava roots are processed into starch, especially those of industrial varieties, and most of the starch produced is used as food for human consumption. The remainder of the starch produced is exported to Vietnam.

In Cambodia, the cassava project started officially on April, 2005, with financial support from the Nippon Foundation in Japan. The project is coordinated by the CIAT Cassava Office in Bangkok. However, the institutional arrangements were already explored in 2004 and a few preliminary variety trials were initiated in July and August of 2004, using small amounts of planting material introduced from Thailand, with the idea of multiplying this material during these initial trials. The project is being implemented by the Cambodian Agricultural Research and Development Institute (CARDI), and involves mainly four CARDI research divisions, i.e. Plant Breeding, Soil and Water Science, Agronomy and Farming Systems, and Socio-Economics.

THE NIPPON FOUNDATION CASSAVA PROJECT IN CAMBODIA (2004-2008)

1. Objectives of the Project

The project has the following objectives:

1. To support national institutions in conducting strategic and applied research in cassava production and on-farm utilization, and to identify constraints at the farm level
2. To develop, with farmers, improved cassava varieties, crop and nutrient management and cassava-based cropping systems that increase cassava productivity and farm income
3. To disseminate new cassava-based technologies at the local, district, provincial, and national levels
4. To strengthen the research capacity, knowledge about good agricultural practices and FPR methodologies in national institutions
5. To strengthen partnerships and networks for conducting more effectively collaborative cassava production and utilization research and development activities.

2. Activities and Outcomes of the Project

The first phase of the cassava project in Cambodia was conducted from 2005/06 to 2008/09. Cassava production aspects of the project were executed in collaboration with the Cambodian Agricultural Research and Development Institute (CARDI), while various aspects about the use of cassava roots and leaves for on-farm animal feeding were studied in collaboration with CelAgrid. Three departments of CARDI were actively involved with the project. The Plant Breeding Department was responsible for varietal testing; the Soil and Water Science Department took responsibility for integrated nutrient management, while the Agronomy and Farming Systems Department was in charge of agronomic trials. In addition, the Socio-economic Department conducted a survey on various aspects of cassava production in Cambodia. Some experiments were conducted on the research station, but most were on-farm trials conducted with farmer participation in the provinces of Kampong Cham, Kampong Speu, Battambang and Preah Vihear.

The on-farm trials were conducted on farmers' fields in target areas of the project. Researchers, extension workers at the provincial and district level, and farmers worked

together to identify the best varieties and practices. The objective of these trials is to develop, together with the farmers, the best practices. At the time of harvest, a farmers field day was organized. Farmers could evaluate the various treatments tested through participatory methods and discuss these among themselves, sharing ideas and experiences. This is an effective way of technology transfer from one farmer to others using these participatory approaches.

3. Project Training Courses

Two training courses on cassava production and FPR methodologies were conducted in Cambodia in 2006 and 2008. This introduction course on FPR aimed to train the project researchers and extension workers from 18 institutions in the country, 14 institutions from various provincial departments of agriculture and another four researchers at the national level. About 60-70 researchers and agricultural extension workers from various provinces and research institutions were trained. After the course, the training of trainers will transfer their skills and the knowledge gained from the course to their staff and local farmers in their region.

4. Project Implementation

During the first phase of the project (2005/06-2008/09), 91 experiments, including FPR trials and replicated experiments, were conducted in four provinces. Out of the 91 experiments, 71 were FPR trials conducted in farmers' fields and 19 were replicated experiments conducted on both research stations and farmers' fields. About 34 different varieties introduced from Thailand, Vietnam, China, and Indonesia were multiplied at CARDI near Phnom Penh and conserved in the cassava germplasm collection (**Table 1**). The varieties were evaluated in replicated experiments conducted in 2005 and 2006 in Kampong Cham, Kampong Speu and Battambang provinces, as shown in **Table 2**.

RESULTS AND DISCUSSION

5.1. Replicated variety experiments

In 2005/06 four replicated experiments were conducted in Kampong Cham, Battambang and Kampong Speu provinces. Nine genotypes were tested in Kampong Cham, ten in Battambang, and eight in Kampong Speu (**Table 2**). The objective of these experiments was to evaluate cassava varieties for root yield, root starch content and eating quality in various agro-ecosystems of Cambodia. These experiments were conducted using a randomized complete block (RCB) design comprising 8-10 treatments with 3 replications. Fertilizers were applied at the rate of 200 kg of 15-15-15/ha at one month after planting and placed about 20 cm from the plants. The plant spacing was 1x1 m, and a horizontal planting position was used in these experiments. The results show that in all four locations there were marked differences among the varieties tested in terms of root yield and root starch contents. In these experiments Rayong 60, Rayong 5, KU 50, KM 94 and Rayong 72 produced high yields and had high starch contents, varying from 22.2 to 33.6 t/ha, and starch contents from 26.2 to 28.6% (**Table 2**).

Table 1. Number and type of trials conducted in Cambodia from 2005 to 2008.

	Cassava project implementation						
	2005/06	2006/07		2007/08	2008/09		
Experiments	Replic. expt	On-farm	Replic. expt	On-farm	Replic. expt	On-farm	**Total**
1. Germplasm collection							**1**
2. Varietal testing	4	6	2	14	1	7	**34**
3. Fertilization	3	6	2	10	2	5	**28**
4. Planting distance & stake position	2	6		10	1	7	**26**
5. Intercropping			2				**2**
Total	**9**	**18**	**6**	**34**	**4**	**19**	**91**

Table 2. Results of four on-farm cassava variety trials conducted in Battambang, Kampong Speu and Kampong Cham provinces of Cambodia in 2005/06.

	Root yield (t/ha)					Root starch content (%)		
	Battambang	Kampong Speu		Kampong		Battambang	Kampong Speu	
Varieties	Thmor Prous	Chamcar Chek Leu	Trapeang Saray	Cham Sre Leu	**Average**	Thmor Prous	Trapeang Saray	**Average**
1. Hanatee	19.2	7.6[2)]	39.5	5.2	**17.9**	22.5	22.4	**22.4**
2. Rayong 2	34.7	25.3	41.3	18.0	**29.8**	18.8	21.7	**20.2**
3. Rayong 3	28.7	-	-	8.8	-	27.9	-	-
4. Rayong 5	36.3	40.9	38.3	19.0	**33.6**	28.3	27.0	**27.6**
5. Rayong 60	37.6	6.4[2)]	23.7	21.3	**22.2**	26.6	25.8	**26.2**
6. Rayong 72	27.1[2)]	-	37.7	14.5	**26.4**	27.0	25.7	**26.4**
7. Rayong 90	24.5[2)]	6.1[2)]	20.4	14.8	**16.4**	27.3	29.0	**28.1**
8. KU 50	41.7	21.2	35.5	18.0	**29.1**	28.1	29.2	**28.6**
9. KM 94[3)]	45.0[1)]	18.3	-	29.5	**30.9**	23.7	-	-
10. Damlong Kor[3)]	22.3	32.4	24.7	-	**26.5**	27.2	23.9	**25.6**

[1)] border row plants in plots of Hanatee
[2)] low yields due to poor plant stand
[3)] high yields due to fresh, locally cut planting material; KM 94 = KU 50

5.2 FPR variety trials

In 2006/07, five FPR trials were conducted in different locations in three provinces. Two trials were conducted in Battambang (BB) province, one trial in Kampong Speu (KS) and another two trials in Kampong Cham (KC), while in 2007/08, two trials were conducted in Battambang and two in Kampong Cham provinces. The trials were planted in the early rainy season in May or June and harvested in December or January. The planting distance was 1x1m with one stake per hill. Fertilizers were applied at 200 kg of 15-15-15/ha one month after planting.

In 2006/07 the yields in Kampong Speu were very low due to heavy rain and poorly drained soils. In 2007/08 many varieties germinated poorly due to dehydration of planting stakes, except those of KU 50, Rayong 60 and Damlong Slek Toch.

The result, shown in **Table 3,** indicate that KU 50, KM 94 and Rayong 60 on average produced high fresh root yields; these were followed by Damlong Slek Toch, Rayong 90, Rayong 72, Rayong 2 and Rayong 5. The Thai eating varieties Hanatee and Rayong 2 had lower yields compared with the other varieties.

Table 3. Cassava fresh root yields and standard deviation (SD) in nine on-farm variety trials conducted in 2006 and 2007.

Variety	Cassava root yield (t/ha)										
	Year 2006/07						Year 2007/08				
	BB1	BB2	KS	KC1	KC2	Ave.	BB1	BB2	KC1	KC2	Ave.
Kasetsart 50	29.2	22.1	14.4	31.7	33.3	**26.1**	23.9	52.5	29.2	31.7	**34.3**
Rayong 5	32.5	27.5	13.4	38.3	-	**27.9**	-	-	-	-	-
Rayong 72	33.8	30.8	15.5	35.8	-	**29.0**	-	-	-	-	-
Rayong 2	17.5	31.7	24.9	-	-	**24.7**	-	-	-	-	-
Hanatee	16.7	20.8	15.8	-	-	**17.8**	-	-	-	-	-
Rayong 90	-	-	-	35.4	21.2	**28.3**	-	-	-	-	-
KM 94	-	-	-	32.9	32.5	**32.7**	-	-	-	-	-
Rayong 60	-	-	-	-	-	-	18.7	45.2	-	20.3	**28.1**
Damlong ST[1)]	-	-	-	-	-	-	17.9	40.4	26.7	9.6	**23.6**

[1)] Damlong Slek Toch = narrow-leaved Damlong

Note: BB1: Battambang site 1
BB2: Battambang site 2
KC1: Kampong Cham site 1
KC2: Kampong Cham site 2
KS : Kampong Speu

5.2 Cassava fertilizer experiments

In 2005/06 three fertilizer experiments were conducted, one each in Kampong Cham, Battambang and Kampong Speu provinces. The objective of these experiments was to determine the response of cassava to the application of various combinations of N, P and K, in order to find the best and most economic fertilizer rate to obtain and maintain high cassava yields. Two varieties, Rayong 5 and KM 94, were used in the experiments in Kampong Cham and Kampong Speu, and the local variety Damlong Kor was used in Battambang province. The experiments were arranged in a split-plot design with 12 fertilizer treatments in main plots, and two varieties in subplots, with four replications. The results of these experiments, shown in **Table 4,** indicate that there was only a response to P in Battambang, mainly a response to N in Kampong Speu and a good response to N and K

in the poor sandy soil in Kampong Cham. While the application of 160-80-160 and 160-40-80 produced the highest average yields, the application of 80-80-80 and 80-40-80 produced the highest net income.

Table 4. Results of on-farm NPK experiments conducted in Battambang, Kampong Speu and Kampong Cham provinces of Cambodia in 2005/06.

Treatments[1]	Battambang Thmor Prous[2]	K. Speu Chamcar Leu[3]	K. Cham Am Pok[4]	Average	Gross income[6]	Fertilizer costs[6]	Product. costs[6]	Net income
					(US $/ha)			
1. $N_0P_0K_0$	18.40	27.98	12.58	**19.65**	393	0	250	143
2. $N_0P_2K_2$	27.06	32.79	11.38	**23.74**	475	64	314	161
3. $N_1P_2K_2$	24.83	35.17	18.92	**26.31**	526	85	335	191
4. $N_2P_2K_2$	31.04	36.81	26.46	**31.44**	629	106	356	273
5. $N_3P_2K_2$	28.65	38.90	31.84	**33.13**	663	149	399	264
6. $N_2P_0K_2$	20.45	36.63	26.88	**27.99**	560	83	333	227
7. $N_2P_1K_2$	27.19	34.29	29.34	**30.27**	605	94	344	261
8. $N_2P_3K_2$	30.29	40.02	28.04	**32.78**	656	130	380	276
9. $N_2P_2K_0$	28.79	34.06	14.50	**25.78**	516	66	316	200
10. $N_2P_2K_1$	24.67	40.79	18.96	**28.14**	563	86	336	227
11. $N_2P_2K_3$	25.52	31.85[5]	29.92	**29.10**	582	146	396	186
12. $N_3P_3K_3$	27.89	41.88	33.25	**34.34**	686	212	462	224
Average	**26.23**	**35.93**	**23.50**	**28.56**				

[1] N_0 = 0N; P_0 = 0P; K_0 = 0K
N_1 = 40 kg N/ha; P_1 = 20 kg P_2O_5/ha; K_1 = 40 kg K_2O/ha
N_2 = 80 kg N/ha; P_2 = 40 kg P_2O_5/ha; K_2 = 80 kg K_2O/ha
N_3 = 160 kg N/ha; P_3 = 80 kg P_2O_5/ha; K_3 = 160 kg K_2O/ha

[2] Variety Damlong Kor

[3] Average of two varieties: KM 94 and Rayong 5

[4] Variety KM 94

[5] Low yield due to poor plant stand in Rep. I of Rayong 5

[6] Prices:

	US $
cassava	20 /t fresh roots
urea (45% N)	0.24 /kg
SSP (17% P_2O_5)	0.10 /kg
KCl (60% K_2O)	0.30 /kg
cassava production without fertilizer	$ 250 /ha

Six similar experiments but with only eight treatments of various combinations of N, P and K, were conducted in 2006/07 on red soils in Thbong Khmom district of Kampong Cham and on black clay soils in Battambang provinces using Rayong 5 or KM 94 as the test varieties. Highest yields of 33-35 t/ha were obtained with the application of 0-40-80, 80-40-80 and 80-40-40, while the check plots without fertilizers produced 29.3 t/ha. Thus, even in the relatively fertile red soils of Kampong Cham, adequate and balanced fertilizer applications are necessary to obtain and maintain high yields. In Battambang province the highest yields of 35-36 t/ha were obtained with 80-40-0 and 80-40-80 and 80-0-80, while the check plot produced 29.0 t/ha **(Table 5).**

Table 5. Result of six experiments conducted in 2006 using Rayong 5 and KM 94.

Fertilizer rate $N-P_2O_5-K_2O$ (kg/ha)	Fresh root yield (t/ha)							
	Rayong 5				KM 94			
	L1	L2	L3	**Mean**	L1	L2	L3	**Mean**
N0P0K0	14.60	47.93	25.28	**29.27**	23.01	37.26	26.61	**28.96**
N0P40K80	25.42	46.06	33.89	**35.12**	28.26	41.20	33.17	**34.21**
N40P40K80	22.66	34.19	23.75	**26.87**	28.82	43.90	27.17	**33.29**
N80P40K80	27.12	37.72	35.83	**33.56**	30.67	42.00	32.75	**35.14**
N80P0K80	21.79	38.95	22.36	**27.70**	35.07	41.37	29.11	**35.18**
N80P20K80	21.78	37.79	29.31	**29.63**	35.18	38.57	29.72	**34.49**
N80P40K0	17.78	35.22	29.44	**27.48**	32.76	43.10	34.42	**36.76**
N80P40K40	24.02	41.52	34.44	**33.33**	28.22	42.14	33.92	**34.76**
Mean	**21.90**	**39.92**	**29.29**	**30.37**	**30.25**	**41.19**	**30.86**	**34.10**
Environment (E)	12.86*				8.86*			
Fertilizer rate (FR)	4.62**				4.15*			
FT x E	8.01*				ns			

5.4 FPR fertilizer trials

In 2006/07 FPR fertilizer trials were conducted at five locations in Battambang, Kampong Cham and Kampong Speu provinces using either Rayong 5 or KM 94 as the test varieties. Five combinations of different levels of N, P and K, with or without 5 t/ha of cow manure, were used in these trials. Results are presented in **Table 6**.

In 2007/08, six similar FPR trials were conducted, four in Kampong Cham, one in Battambang, and one in Preah Vihear provinces. Six rates of fertilizer were used in these trials. The results of these trials (**Table 7**) indicate that the use of chemical fertilizers resulted in higher fresh root yields than using organic fertilizers.

5.5 Replicated planting methods experiment

In 2005/06 a replicated experiment on cassava planting methods was conducted in Kampong Speu province using planting material of KM 94 (=Malay=KU 50) from Kampong Cham. The objective of this experiment was to determine the best planting distance and stake position for the soil and climatic conditions in Cambodia. The fertilizer application was 200 kg/ha of 15-15-15 applied in short bands near the stake at one month after first emergence.

The experiment had a spit plot design with two planting distances in main plots and four stake positions in sub-plots with four replications. The results from the experiment (**Table 8**) show that there were no significant differences between the various planting methods or plant spacings used and also no significant interaction between planting method and planting distance.

Table 6. Results of FPR fertilizer trials conducted in five farmers' fields in 2006/07 using Rayong 5 and KM 94.

Fertilizer rate $N\text{-}P_2O_5\text{-}K_2O$ (kg/ha)	Root yield (t/ha) at five sites					Average
	Rayong 5			KM94		
	BB	KC	KS	BB	KC	
$N_0P_0K_0$	29.17	35.83	14.58	24.17	30.00	**26.75**
$N_0P_{40}K_0$	35.00	43.33	13.75	33.33	33.33	**31.75**
$N_{60}P_0K_{60}$	32.50	30.42	17.83	26.67	39.17	**29.32**
$N_{60}P_{40}K_{60}$	33.33	38.50	24.58	30.00	33.33	**31.95**
$N_{60}P_{40}K_{60}$ + CM 5t/ha	31.67	39.58	12.00[2)]	30.83	39.17	**30.65**
Average	**32.33**	**37.53**	**16.55**	**29.00**	**35.00**	**30.08**

[1)] BB = Battambang, KC = Kampong Cham, KS = Kampong Speu, CM = cow manure
[2)] low yield due to waterlogging

Table 7. Results of FPR fertilizer trials conducted in six farmers' field in 2007/08 using KM 94.

Fertilizer rate $N\text{-}P_2O_5\text{-}K_2O$ (kg/ha)	Fresh root yield (t/ha)						**Mean±SD**
	KC1[1)]	KC2	KC3	KC4	BB	PV	
$N_0P_0K_0$	30.00	28.33	12.50	16.67	40.42	41.25	**28.19 ±11.85**
$N_{80}P_{40}K_{80}$	31.67	30.00	14.17	20.42	33.75	65.83	**32.64 ±17.90**
$N_{15}P_{15}K_{15}$	30.83	31.67	16.67	21.67	58.33	49.17	**34.72 ±16.04**
$N_{45}P_{45}K_{45}$	31.67	31.67	17.92	22.92	68.00	75.42	**41.26 ±24.28**
$N_{15}P_{15}K_{15}$ + CM 10 t/ha	35.00	33.33	19.17	24.17	28.33	46.67	**31.11 ± 9.60**
CM 10 t/ha	29.17	20.83	13.75	19.17	26.67	42.50	**25.35 ± 10.04**
Mean	**31.39**	**29.31**	**15.69**	**20.83**	**42.58**	**53.47**	**32.21 ± 13.94**

[1)] KC = Kampong Cham (4 sites); BB = Battambang; PV = Preah Vihear

Table 8. Results of a replicated planting method experiment conducted in Kampong Speu in 2005/06 using KM 94 variety.

Planting method and spacing	Cassava root yield (t/ha)		
	1.0 x 1.0 m	0.8 x 0.8 m	Average
Vertical	42.3	40.0	**41.2**
Horizontal	44.4	36.6	**40.5**
Inclined with one stake	43.6	44.8	**44.2**
Inclined with two stakes	40.3	33.6	**37.0**
Average	**42.7**	**38.8**	
Level of significance	NS	NS	
Spacing (S)	NS		
Planting method (PM)	NS		
PM x S	NS		

5.6 FPR planting method trials

In 2006/07 and 2007/08 twelve FPR trials on planting methods were conducted in several provinces in Cambodia using KM 94. The planting distance was 1x1 m and fertilizers were applied at the rate of 200 kg/ha of 15-15-15 at one month after planting. The result of these trials indicate that vertical, horizontal or inclined planting with one stake per hill gave similar yields which varied from 26.1 to 28.5 t/ha, but the planting with two stakes per hill resulted in lower yields of only 20.7 t/ha (**Table 9**).

Table 9. Effect of planting methods on cassava root yields (t/ha) in 12 FPR trials conducted by farmers in 2006/07 and 2007/08 using KM 94 variety.

Planting method	Year 2006					Year 2007							
	BB1	BB2	KC1	KC2	KS	BB1	BB2	KC1	KC2	KC3	KS	PV	Average
Vertical	30.0	34.2	25.0	35.0	19.5	13.3	55.0	21.3	20.0	33.3	6.7	19.6	**26.1**
Horizontal	36.7	28.8	30.0	37.5	35.9	10.8	46.0	22.5	19.6	36.7	4.6	23.8	**27.7**
Inclined +one stake	25.0	27.5	42.5	35.8	14.7	20.8	63.0	22.1	18.8	31.7	7.5	32.5	**28.5**
Inclined +two stakes	27.5	23.3	25.0	25.8	11.8	7.5	42.1	20.7	16.7	30.8	5.0	12.1	**20.7**

Note: BB = Battambang (4 sites); KC = Kampong Cham (5 sites); KS = Kampong Speu (2 sites); PV = Preah Vihear .

CONCLUSIONS

Based on the results of the experiments on varietal testing, nutrient management and planting distance and stake position, we can conclude that of the ten genotypes that were evaluated in different environments four varieties, Rayong 60, Rayong 5, KU 50 and

Rayong 72 gave the highest yields in practically all locations, and that these high-yielding varieties are suitable for animal feeding and industrial uses in Cambodia.

With respect, to plant distance and stake position, the results show that there were no significant differences between horizontal, vertical or inclined planting, nor between the planting distances of 1x1 m and 0.8 x0.8 m. However, both the replicated experiment and the FPR trials indicate that planting one stake per hill produced higher yields than planting two stakes per hill, which is a traditional planting method in many parts of Cambodia. Therefore, we can recommend that farmers should plant only one stake per hill as this produces higher yields and also saves labor.

The application of NPK fertilizers normally increased the cassava fresh root yields and there were significant differences among the various fertilizer treatments. In poor sandy soils of Kampong Speu province and in Ponia Krek district of Kampong Cham province, cassava responded markedly to applications of high rates of N, P and K, while in the more fertile soils of Battambang province there was mainly a response to the application of P, and in red clay soils of Kampong Cham to application of P and K.

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RESULTS OF THE CASSAVA SURVEY IN CAMBODIA

El Sotheary [1]

ABSTRACT

The survey on cassava production and utilization in Cambodia was conducted in 2008 by the Socio-Economics Division of the Cambodian Agricultural Research and Development Institute (CARDI), with funding from the Nippon Foundation through the Centro Internacional de Agricultura Tropical (CIAT). Individual interviews were conducted with 427 cassava growers in nine communes in eight provinces throughout the country using random sampling and a snowball sampling technique.

The survey found that the average farm size per household was 3.89 ha while the average number of parcels was 3.94 plots. The average cassava growing area in the northwest was 3.89 ha and 1.13 ha in the southeast. The land for growing cassava in the northwest tended to be slightly steeper than in the southeast region. However, in the country as a whole, cassava was grown mainly on flat land, accounting for 53.71% of the total. Two main types of soil were found in cassava growing areas, i.e. loamy (38.68%) and sandy (37.45%). In the country, cassava farms were found to be much more mechanized than other farms. More than 50% of the respondents were using 4-wheel tractors to prepare their land. About half of the respondents made ridges for growing cassava while the other 50% did not. The most common ridging method was parallel with plot borders followed by ridging along contour lines. Most farmers used cassava stems from their own fields from the previous harvest to plant a new crop. But, about 37% of farmers also bought cassava planting material from others. KM 94 (also known as "Malaysia"), various unknown cassava varieties, and Damlong Slek Toch (also known as "Damlong Chin") were found to be the dominant varieties in the cassava growing areas in the country, accounting for 34, 24 and 22%, respectively. The surveyed average fresh yield of cassava was 23.28 t/ha, while the dry yield of cassava was 10.93 t/ha. The most common planting position of cassava stakes is slanted, followed by the vertical and horizontal positions. Although land preparation for cassava was mostly mechanized, this was not the case for cassava harvesting. More than 50% of surveyed cassava growers were harvesting their cassava manually or were using a *ngam* (a Cambodian traditional cassava harvesting tool). Only about 38% of cassava growers in Cambodia have used chemical fertilizer to improve their soil fertility and increase cassava yields. Urea was by far the most widely used fertilizer, while some DAP, mixed single-element as well as compound NPK fertilizers were also used. Those farmers that used fertilizers applied on average about 170 kg/ha, which cost approximately US$ 84. The use of cassava leaves in Cambodia is very rare, while roots were mainly sold (77.7%), used for household consumption (21.0%) or for animal feeding (1.3%).

SURVEY METHODOLOGY

The survey was conducted from April to November 2008 by the Socio-Economics Division of the Cambodian Agricultural Research and Development Institute (CARDI).

Survey Location

The survey was conducted in eight provinces in Cambodia, namely: Battambang, Banteay Meanchey, Siem Reap, Kampong Speu, Takeo, Kampong Cham, Prey Veng and

[1] Cambodian Agricultural Research and Development Institute (CARDI), National Road No 3, Prateah Lang Commune, Dongkor District, Phnom Penh, Cambodia.

Svay Rieng. **Table 1** shows the number of farm households interviewed in each commune, district and province where the survey was conducted.

The selection of the provinces was based on the annual statistical review published by the Ministry of Agriculture, Forestry and Fisheries (MAFF). These are the provinces that have the largest cassava production areas and highest cassava production. The selection of the districts and communes to be included in the survey was decided after consultation with the Director of the Provincial Department of Agriculture (PDA) or with PDA officers.

The map in **Figure 1** shows that the provinces can be grouped into two main regions: the Northwestern region consisting of Battambang, Banteay Meanchey and Siem Reap provinces; and the Southeastern region consisting of Kampong Speu, Takeo, Kampong Cham, Prey Veng and Svay Rieng provinces.

Survey Method

Altogether, 427 cassava farmers from the eight provinces were interviewed using a questionnaire that was slightly modified from the Farmer Questionnaire for Monitoring and Evaluation of Cassava Production and Utilization in Lao PDR. The questionnaire was translated into Khmer (Cambodian language) and was tested before the survey started.

Table 1. Number of households in each commune, district, province and region included in the cassava survey in Cambodia.

Region	Province	District	Commune	No. of households surveyed in		
				Commune	District	Province
Northwest	Battambang	Kamreng	Kamreng	48	70	70
			Odar	22		
	Banteay Meanchey	Malay	Boeng Beng	8	16	16
			O Sampor	8		
	Siem Reap	Banteay Srey	Preah Dak	17	18	18
			Khna Sanday	1		
Total Northwest	**3 provinces**	**3 districts**	**6 communes**	**104**	**104**	**104**
Southeast	Kampong Speu	Phnom Srouch	Or	8	8	8
	Takeo	Kiri Vong	Kiri Chongkoh	112	112	112
	Kampong Cham	Dambe	Dambe	56	75	152
			Kok Srok	19		
		Tbong Khmom	Kor	19	77	
			Lng'eang	58		
	Prey Veng	Kamchay Mear	Cheach	20	20	20
	Svay Rieng	Romeas Heak	Dong	15	31	31
			Tras	16		
Total Southeast	**5 provinces**	**6 districts**	**9 communes**	**323**	**323**	**323**
Total Cambodia	**8 provinces**	**9 districts**	**15 communes**	**427**	**427**	**427**

The information was collected from the respondents using structured face to face interviews. Because not every farmer is involved in cassava production, it was decided to use a simple and snowball sampling method[2] to identify the respondents. Besides that, the survey team always contacted the local authorities ahead of the survey, so that the local people were well aware of the objective of the study, and some assistance could be provided to the survey team regarding mobilizing respondents for the interview.

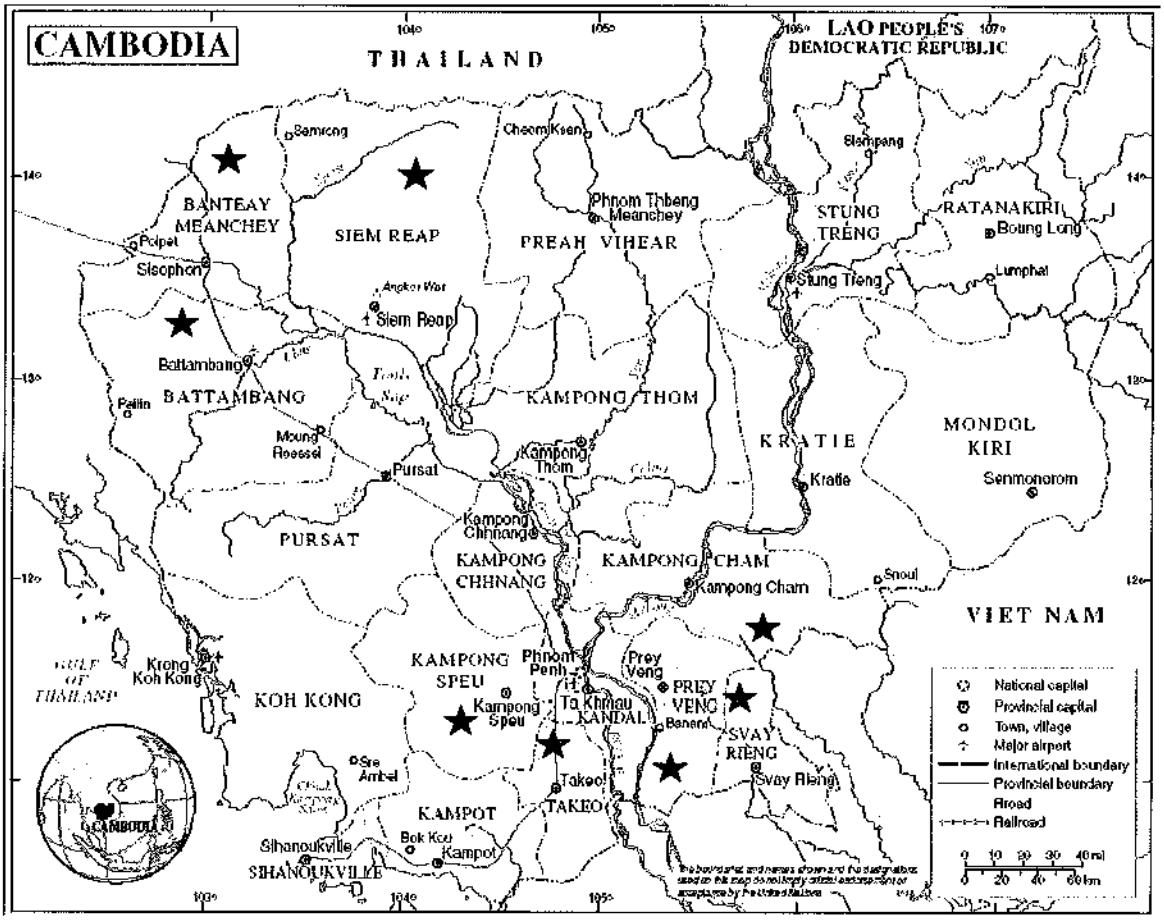

Figure 1. Target area for the survey on Cassava Production and Utilization in Cambodia. Target provinces are marked by a red star.

[2] In the snowball sampling method the researcher asks respondents to give referrals to other respondents

RESULTS OF THE SURVEY

General Information

Crop and Animal Production

Most of the respondents in the eight selected provinces were involved in both crop and animal production. As seen in **Table 2,** in Kampong Speu province the proportion reached up to 100% of crop and animal involvement.

Table 2. Percentage of farmers involved in crop and animal production.

Province	Crop and animal involvement (%)	
	Crop involvement	Animal involvement
Battambang	97.10	68.60
B. Meanchey	93.80	81.30
Siem Reap	94.40	72.20
Northwest	**96.20**	**71.20**
Kampong Speu	100.00	100.00
Takeo	97.30	65.20
Kampong Cham	98.00	73.40
Prey Veng	100.00	96.80
Svay Rieng	100.00	95.00
Southeast	**98.10**	**74.80**
Total Cambodia	**97.70**	**73.90**

Total Farm Size, Number of Parcels and Land Characteristics

The average farm size of farmers in Banteay Meanchey province was the highest at 9.81 ha/household, while the average number of parcels owned by farmers was highest in Takeo province at 4.27 parcels/household. More information about farm size and number of parcels is shown in **Table 3**.

In each province, the land has different slope characteristics. The general slope of the land was divided into four categories, i.e. very steep, steep, gently sloping and flat. The percentage of land in these different categories is shown in **Table 4**.

Crops Grown in the Wet Season of 2007

In the wet season of 2007, farmers in the selected eight provinces grew the following crops, listed in decreasing order according to the frequency of responses.

Cassava
Wet season rice
Dry season rice
Maize
Upland rice
Other crops such as mango, cashew, rubber, banana, watermelon, soybean, string bean etc.

Table 3. Average farm size and number of parcels per household in each province.

Province	Farm size (ha)			Number of parcels per household		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Battambang	0.52	36.56	7.87	1	8	3.52
B. Meanchey	1.02	25.20	9.81	3	7	4.06
Siem Reap	0.17	3.73	1.14	1	6	3.61
Northwest	**0.17**	**36.56**	**7.52**	**1**	**8**	**3.62**
Kampong Speu	0.19	3.75	1.69	2	6	4.00
Takeo	0.13	13.20	1.65	1	11	4.27
Kampong Cham	0.10	22.60	3.51	2	10	3.94
Prey Veng	0.90	9.80	2.80	3	7	4.00
Svay Rieng	0.56	6.90	2.44	1	8	3.70
Southeast	**0.10**	**22.60**	**2.72**	**1**	**11**	**4.04**
Total Cambodia	**0.10**	**36.56**	**3.89**	**1**	**11**	**3.94**

Table 4. Slope of cassava fields.

Province	Total area (ha)	Very steep (%)	Steep (%)	Gently sloping (%)	Flat (%)
Battambang	375.90	4.00	6.00	51.00	39.00
B. Meanchey	27.84	0.00	6.00	69.00	25.00
Siem Reap	3.78	0.00	24.00	43.00	33.00
Northwest	**407.52**	**2.41**	**9.35**	**52.46**	**36.05**
Kampong Speu	0.72	0.00	19.00	13.00	68.00
Takeo	41.44	3.00	19.00	16.00	62.00
Kampong Cham	273.60	2.00	11.00	25.00	62.00
Prey Veng	34.60	3.00	19.00	16.00	62.00
Svay Rieng	27.28	3.00	25.00	25.00	47.00
Southeast	**377.64**	**2.49**	**16.17**	**21.99**	**59.38**
Total Cambodia	**785.16**	**2.47**	**14.51**	**29.45**	**53.71**

Table 5 provides additional information regarding the principal crops being grown in each province.

Cassava Area and the Area Planted in Monoculture and in Intercropping Systems

Because we used the simple and snowball sampling method to identify those farmers growing cassava, we found that the highest proportion of crops grown in the wet season of 2007 was cassava, i.e. all respondents grew cassava during that year. **Table 6** provides more information about the average size of land used for cassava, and also the average area of cassava grown in monoculture and in intercropping systems.

Table 5. Principal crops grown in each province.

Province	Principal crops
Battambang	Cassava, wet season rice, maize, upland rice, soybean and other crops
B. Meanchey	Cassava, wet season rice, maize, soybean and other crops
Siem Reap	Cassava, wet season rice, water melon, cashew nuts and other crops
Northwest	**Cassava, wet season rice, maize, soybean and other crops**
Kampong Speu	Cassava, wet season rice, maize, dry season rice, vegetables and other crops
Takeo	Cassava, wet season rice, dry season rice, maize, water melon and other crops
Kampong Cham	Cassava, wet season rice, maize, cashew nut, vegetables and other crops
Prey Veng	Cassava, wet season rice and cashew nut
Svay Rieng	Cassava, wet season rice, maize, dry season rice and other crops
Southeast	**Cassava, wet season rice, maize, cashew nut and other crops**
Total Cambodia	**Cassava, wet season rice, maize, cashew nut and other crops**

Table 6. Average cassava area per household and the cassava area planted in monoculture and in intercropping systems.

Province	Cassava area (ha)			Monoculture (ha)			Intercropped (ha)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Battambang	0.24	32.00	5.37	0.24	32.00	5.29	0.00	3.00	0.08
B. Meanchey	0.16	8.00	1.74	0.16	8.00	1.74	0.00	0.00	0.00
Siem Reap	0.02	0.50	0.21	0.00	0.50	0.16	0.00	0.40	0.05
Northwest	**0.02**	**32.00**	**3.89**	**0.00**	**32.00**	**3.84**	**0.00**	**3.00**	**0.05**
Kampong Speu	0.03	0.25	0.09	0.00	0.18	0.05	0.00	0.25	0.04
Takeo	0.06	2.00	0.37	0.00	1.88	0.29	0.00	2.00	0.08
Kampong Cham	0.50	10.00	1.80	0.00	10.00	1.60	0.00	3.00	0.20
Prey Veng	0.10	7.00	1.73	0.10	7.00	1.21	0.50	7.00	0.52
Svay Rieng	0.16	3.50	0.88	0.16	3.50	0.82	0.00	2.00	0.06
Southeast	**0.03**	**10.00**	**1.13**	**0.00**	**10.00**	**0.93**	**0.00**	**7.00**	**0.21**
Total Cambodia	**0.02**	**32.00**	**1.80**	**0.00**	**32.00**	**1.73**	**0.00**	**7.00**	**0.16**

In practically all provinces, cassava was permanently cropped on the same land for more than one year. In Siem Reap, however, about 40% of farmers had planted their cassava in rotation with other vegetables. In that case, the cassava varieties grown were the local eating varieties, mostly the one known as "Damlong Kor", which is usually grown in relatively small areas as compared to the area used to grow the modern industrial cassava varieties.

Cassava Soil Types and Colors

The soils used for planting cassava can be divided into five different types, namely sandy, loamy, clayey, sandy clay, rocky and sediment. The proportions of different soil types and colors used for growing cassava in the eight provinces are shown in **Tables 7** and **8**, respectively.

Table 7. Type of soils on which cassava is grown.

Province	Total area (ha)	Soil type (% of cassava area)					
		Sandy	Loamy	Clay	Rocky	Sandy clay	Sediment
Battambang	375.90	0.00	55.56	4.94	17.28	0.00	22.22
B. Meanchey	27.84	0.00	62.50	0.00	12.50	0.00	25.00
Siem Reap	3.78	27.78	55.56	0.00	0.00	11.11	5.56
Northwest	**407.52**	**4.35**	**56.52**	**3.48**	**13.91**	**1.74**	**20.00**
Kampong Speu	0.72	63.64	18.18	0.00	18.18	0.00	0.00
Takeo	41.44	86.51	3.97	1.59	6.35	0.79	0.79
Kampong Cham	273.60	18.24	48.82	12.35	20.59	0.00	0.00
Prey Veng	34.60	57.69	42.31	0.00	0.00	0.00	0.00
Svay Rieng	27.28	39.47	57.89	2.63	0.00	0.00	0.00
Southeast	**377.64**	**47.71**	**33.15**	**6.47**	**12.13**	**0.27**	**0.27**
Total Cambodia	**785.16**	**37.45**	**38.68**	**5.76**	**12.55**	**0.62**	**4.94**

Table 8. Color of soils on which cassava is grown.

Province	Total area (ha)	Soil color (% of cassava area)			
		Red	Grey	Black	White
Battambang	375.90	64.30	7.10	28.60	0.00
B. Meanchey	27.84	37.50	12.50	50.00	0.00
Siem Reap	3.78	0.00	72.20	16.70	11.10
Northwest	**407.52**	**35.70**	**14.70**	**44.80**	**4.90**
Kampong Speu	0.72	62.50	37.50	0.00	0.00
Takeo	41.44	3.60	35.10	3.60	57.70
Kampong Cham	273.60	33.10	11.30	33.10	22.50
Prey Veng	34.60	40.00	45.00	5.00	10.00
Svay Rieng	27.28	10.00	56.70	10.00	23.30
Southeast	**377.64**	**18.00**	**24.40**	**20.50**	**37.00**
Total Cambodia	**785.16**	**22.60**	**21.90**	**26.80**	**28.60**

Table 7 shows that the dominant soil types in Kampong Speu, Battambang, Takeo and Prey Veng are sandy soils; in the remaining provinces, Battambang, Banteay Meanchey, Siem Reap, Svay Rieng and Kampong Cham, the loamy soils are dominant.

Method of Land Preparation for Cassava

Various tools are used for preparing land before planting cassava. The preference of any tool depends on local traditions and on what farmers can afford. However, for most crops the most common way to prepare the land is by hoe, followed by animal-drawn plow, by hand-tractor, by four-wheel tractor or not to till the soil at all. More information about the way land is prepared for cassava in each province is shown in **Table 9**. The percentage of cassava growers using four-wheel tractors for land preparation was highest in Battambang, Banteay Meanchey, Prey Veng and Kampong Cham provinces where farmers own larger land areas for growing cassava. **Figure 2** (at the end of the paper) shows a commonly used disk plow.

Table 9. Methods of land preparation for cassava.

Province	No. of house holds	Land preparation method (% of households)				
		Manual (hoe)	Animal-drawn plow	2-wheel tractor	4-wheel tractor	No tillage
Battambang	70	1.40	0.00	0.00	97.10	1.50
B. Meanchey	16	0.00	0.00	0.00	100.00	0.00
Siem Reap	18	33.30	61.10	0.00	5.60	0.00
Northwest	**104**	**6.40**	**15.50**	**0.00**	**77.30**	**0.90**
Kampong Speu	8	12.50	75.00	12.50	0.00	0.00
Takeo	112	9.00	34.20	37.00	19.80	0.00
Kampong Cham	152	5.90	2.00	17.10	70.40	4.60
Prey Veng	20	5.00	0.00	15.00	80.00	0.00
Svay Rieng	31	56.70	13.30	6.70	23.30	0.00
Southeast	**323**	**10.50**	**15.60**	**23.40**	**48.70**	**1.90**
Total Cambodia	**427**	**9.50**	**15.60**	**18.00**	**55.20**	**1.70**

About half of the interviewed farmers made ridges for planting cassava. The others did not build any ridges but planted cassava on flat land. However, the latter method was used mainly for planting local eating varieties, such as Damlong Kor, which are usually grown near the house. **Table 10** shows the proportion of farmers who made ridges for planting cassava.

More than 95% of the farmers who built ridges planted cassava on top of the ridge **(Figure 3)**, whereas the remaining 5% planted in the furrow. Moreover, among those making ridges, nearly 70% build the ridges parallel with plot borders, followed by ridging along the contour line, and about 9% in the up-down direction. **Table 11** provides more information on ridging methods for each province.

Cassava Planting Material

The most common period for growing cassava is between April and June, which accounts for more than 70%. This means that it happens during the early wet season. **Table 12** provides three main sources of planting materials adopted by farmers in each province.

Table 10. Proportion of farmers who made ridges for planting their cassava.

Province	Total area (ha)	No. of households	Percentage of farmers who made ridges	
			Yes	No
Battambang	375.90	70	97.10	2.90
B. Meanchey	27.84	16	100.00	0.00
Siem Reap	3.78	18	0.00	100.00
Northwest	**407.52**	**104**	**80.80**	**19.20**
Kampong Speu	0.72	8	0.00	100.00
Takeo	41.44	112	100	0.00
Kampong Cham	273.60	152	2.60	97.40
Prey Veng	34.60	20	10.00	90.00
Svay Rieng	27.28	31	50.00	50.00
Southeast	**377.64**	**323**	**41.30**	**58.80**
Total Cambodia	**785.16**	**427**	**50.90**	**49.10**

Table 11. Ridging methods.

Province	No. of households	Ridging methods (% of households)		
		Up-down direction	Along contour lines	Parallel with plot borders
Battambang	70	19.20	37.00	43.80
B. Meanchey	16	0.00	62.50	37.50
Siem Reap	18	-	-	-
Northwest	**104**	**15.70**	**41.60**	**42.70**
Kampong Speu	8	-	-	-
Takeo	112	1.20	3.70	95.10
Kampong Cham	152	100.00	0.00	0.00
Prey Veng	20	0.00	0.00	100.00
Svay Rieng	31	0.00	0.00	100.00
Southeast	**323**	**2.20**	**3.30**	**94.60**
Total Cambodia	**427**	**8.80**	**22.10**	**69.10**

In general, cassava stakes used as planting material were cut from stems collected during the harvest of the previous crop, or were bought from other villagers. Farmers have their own judgment to select good, healthy cassava stems to use as planting material. These criteria are:

The cassava stems should look greener and bigger than average
The cassava stems should be nice and straight
The bark of the cassava stem should be as smooth as possible
The stems should only be taken from fields which do not have any insect or disease problems

The stems should be stored in the shade
The stems should only be cut into stakes just before planting

Table 12. Sources of planting materials.

Province	No. of households	Sources of planting materials (% of households)		
		Own field, previous season	From neighbors or friends	Buy from others
Battambang	70	53.50	8.10	38.40
B. Meanchey	16	16.70	0.00	83.30
Siem Reap	18	44.40	27.80	27.80
Northwest	**104**	**46.70**	**9.80**	**43.50**
Kampong Speu	8	75.00	25.00	0.00
Takeo	112	48.10	15.00	36.80
Kampong Cham	152	66.90	13.50	14.60
Prey Veng	20	13.60	0.00	86.40
Svay Rieng	31	3.20	3.20	93.50
Southeast	**323**	**51.00**	**14.80**	**34.20**
Total Cambodia	**427**	**49.90**	**13.50**	**36.60**

However, cassava planting materials are oftentimes stored in open fields because it is rather difficult for cassava growers to find a more suitable place for storing the stems in the shade. Another reason is that cassava growers prefer to use the planting materials available from the previous season and grown in the same field. In doing so, they tie the cassava stems together into bundles and store them vertically, sometimes burying the lower ends of the stems in the soil if they need to store the stems for a long time. In general, cassava stems were stored for more than five weeks before planting. The time stored can vary from one season to another, or from one location to another depending on the availability of the planting material.

Cassava Varieties

The criteria used by cassava growers for selecting the variety to grow are listed in their order of importance as follows:

High yield
Easy to grow
High starch content
Good taste
Other criteria are: high market demand, good selling price, good availability of planting material, and tolerance to unfavorable weather.

Because every cassava farmer has different perceptions or understanding about the quality of different cassava varieties, there are a number of varieties of cassava which were grown in the eight selected provinces. **Tables 13 and 14** show the distribution of the most common cassava varieties grown, the average area used for growing each variety, and the average fresh and dry root yields.

Table 13. Total number of households and area planted to different cassava varieties.

Varieties	Number of households		Total planted area (ha)	
	Number	(%)	Area	(%)
KM 94 (= Malaysia)	134	35.83	234.50	33.98
Damlong Kor (local)	95	25.40	71.25	10.32
Damlong Mi Sandorng	40	10.70	12.80	1.86
Don't know the name	40	10.70	163.60	23.71
Damlong Slek Toch	30	8.02	148.50	21.52
Rayong 5	12	3.21	35.16	5.10
Damlong Mi Moay	9	2.41	3.51	0.51
Si Soon	8	2.14	18.40	2.67
Damlong Mi Choeu	2	0.53	1.00	0.14
Huay Bong 60	2	0.53	0.64	0.09
Damlong Mi Sak	1	0.27	0.13	0.02
Damlong Mi Sun	1	0.27	0.52	0.08
Total	374	100.00	690.01	100.00

Table 14. Cassava varieties most planted in each province.

Province	Most planted cassava varieties
Battambang	Damlong Slek Toch, Damlong Mi, Damlong Kor (local)
Banteay Meanchey	Damlong Mi, Si Soon, Huay Bong 60
Siem Reap	Damlong Kor
Northwest	**Damlong Mi, Damlong Kor, Damlong Slek Toch**
Kampong Speu	Damlong Mi Sandorng, Damlong Kor
Takeo	Damlong Mi Sandorng, Damlong Kor
Kampong Cham	KM 94 (Malaysia), Damlong Mi
Prey Veng	Damlong Mi
Svay Rieng	Damlong Mi
Southeast	**KM 94 (Malaysia), Damlong Mi, Damlong Kor**
Total Cambodia	**KM 94, Damlong Mi, Damlong Kor, Damlong Slek Toch**

KM94 (also known as "Malaysia") was found to be the variety grown by the largest number of respondents, accounting for 35.83%. This is the main variety grown in Kampong Cham province. Following KM 94, the local variety Damlong Kor is also popular among farmers. This variety, however, is mainly used for home consumption, either as steamed or boiled cassava, or as cassava cake. **Table 14** is a summary of the popular cassava varieties most planted in each province of the country.

While Damlong Slek Toch (narrow-leaved Damlong) is not a variety very well-known among cassava farmers in the country, it is planted by many farmers in Battambang province on large areas. The average plot area allocated for growing this variety was 4.95 ha, while the average plot size of KM 94 was 1.75 ha (**Table 15**).

Table 15. Average area per household planted with different cassava varieties and their fresh and dry root yields.

Variety	Area/household (ha)			Fresh root yield (t/ha)			Dry root yield (t/ha)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Damlong Slek Toch	0.24	32.00	4.95	23.43	62.50	37.06	6.50	21.87	14.38
Don't know the name	0.22	27.20	4.09	24.00	66.66	40.88	3.13	26.56	12.57
Rayong 5	0.24	9.87	2.93	23.43	62.50	45.61	15.38	22.12	17.76
Si Soon	0.48	8.00	2.30	18.75	60.00	34.20	-	-	-
KM 94	0.50	10.00	1.75	12.00	35.00	22.48	4.50	17.00	7.91
Damlong Kor	0.02	28.00	0.75	1.25	31.25	9.90	-	-	-
Damlong Mi Sun	0.52	0.52	0.52	-	-	-	-	-	-
Damlong Mi Choeu	0.50	0.50	0.50	-	-	-	-	-	-
Damlong Mi Moay	0.06	0.97	0.39	5.79	14.64	9.48	-	-	-
Huay Bong 60	0.16	0.48	0.32	15.00	31.25	23.13	-	-	-
Damlong Mi Sandorng	0.04	2.00	0.32	3.86	66.60	16.79	-	-	-
Damlong Mi Sak	0.13	0.13	0.13	-	-	-	-	-	
Overall	**0.02**	**32.00**	**1.85**	**1.25**	**66.66**	**23.28**	**3.13**	**26.56**	**10.93**

According to the farmers interviewed, Rayong 5 is the highest yielding variety which produced a mean fresh root yield of 45.61 t/ha and a dry root yield of 17.76 t/ha (**Table 15**). One of the reasons that this variety produces such high yields is because it is mainly grown in Battambang province in areas that are recently cleared of forests and where the soil is much more fertile than in other areas. Also, farmers in these border areas are able to buy good quality planting material directly from Thai traders or from processing factories in Thailand.

Cassava Planting Method and Plant Spacing

Cassava stakes are most commonly planted in a slanted position followed by the vertical and horizontal planting methods (**Table 16**).

About 73% of interviewed farmers said that they planted only one cassava stake per hill.

The most common plant spacing between rows was 75 cm and between plants in the row 50 cm. However, for the local variety (Damlong Kor) the plant spacing was usually closer.

Farmers usually harvest their cassava when the crop is mature (between 9 to 12 months). However, some farmers decide to harvest their cassava whenever there is good demand and a high price in the market.

Although some farmers are able to purchase or hire tractors to harvest their cassava, most do this manually using tools such as hoes.

Soil Fertility Maintenance and Erosion Control for Cassava

About 40% of the respondents said that the fertility of their soils used for growing cassava is decreasing year after year. In response to this problem, some measures are taken to reduce or prevent soil erosion and improve soil fertility:

Table 16. Cassava planting positions.

Province	Total area (ha)	No. of households	Cassava planting position		
			Vertical	Horizontal	Slanted
Battambang	375.90	70	100.00	0.00	0.00
B. Meanchey	27.84	16	100.00	0.00	0.00
Siem Reap	3.78	18	5.60	72.20	22.20
Northwest	**407.52**	**104**	**83.70**	**12.50**	**3.80**
Kampong Speu	0.72	8	12.50	87.50	0.00
Takeo	41.44	112	0.00	10.80	89.20
Kampong Cham	273.60	152	22.40	43.40	34.20
Prey Veng	34.60	20	0.00	80.00	20.00
Svay Rieng	27.28	31	0.00	0.00	100.00
Southeast	**377.64**	**323**	**10.90**	**31.50**	**57.60**
Total Cambodia	**785.16**	**427**	**28.70**	**26.80**	**44.50**

Build contour ridges
Add more fertile soil to the ridges (using the soil from surrounding fields)
Build small moats around the plot so that the plot can be kept wet and more fertile
Intercropping with other crops
Use banana tree trunks to stop erosion. The trunks of banana can decrease the amount of soil being washed from higher to lower levels
Apply land leveling techniques or terracing. However, this technique doesn't seem to be affordable for cassava growers in Cambodia
Add more organic matter to the ridges

However, these methods are practiced only in some provinces such as in Takeo, Prey Veng and Svay Rieng where soil fertility is generally poor.

Table 17 shows the percentage of farmers who use or don't use fertilizers to improve the soil fertility of their land, as well as the types of fertilizers used in each province. Only about 38% of the cassava growers in Cambodia have used chemical fertilizers to improve the fertility of their soils. This was most common in Takeo province where cassava farmers used inorganic fertilizers, mainly urea and NPK compound fertilizers, to improve the fertility of their soils. The average fertilizer cost is about 350,000 Riels (approximately US$ 84) per hectare.

There are a number of different fertilizers used by cassava growers in Cambodia. Urea was by far the most common fertilizer used for cassava. Besides urea, some farmers also used di-ammonium phosphate (DAP), NPK compound, and mixed elemental fertilizers. The last type of fertilizer is mainly used in Prey Veng and Svay Rieng provinces.

Table 17. Fertilizer use for cassava.

Province	Fertilizer use (%)		Types of fertilizers used (% of households)			
	Yes	No	Urea	NPK	DAP	Mixed
Battambang	0.00	100.00	N/A	N/A	N/A	N/A
B. Meanchey	6.20	93.80	0.00	0.00	100	0.00
Siem Reap	0.00	100.00	N/A	N/A	N/A	N/A
Northwest	**1.00**	**99.00**	**0.00**	**0.00**	**100**	**0.00**
Kampong Speu	25.00	75.00	50.00	0.00	50.00	0.00
Takeo	98.20	1.80	95.50	4.50	0.00	0.00
Kampong Cham	13.20	86.80	15.00	30.00	55.00	0.00
Prey Veng	75.00	25.00	13.30	6.70	13.30	66.70
Svay Rieng	43.30	56.70	15.40	15.40	23.00	46.20
Southeast	**50.30**	**49.70**	**70.60**	**8.80**	**10.60**	**10.00**
Total Cambodia	**37.80**	**62.20**	**70.20**	**8.70**	**11.20**	**9.90**

Table 18 shows that approximately 2.5 bags (125 kg) of fertilizer are used per hectare of cassava. The cost of fertilizer inputs is quite similar in Kampong Cham and Takeo provinces where cassava has been planted for many years resulting in a decrease in soil fertility as compared to the other two provinces, Banteay Meanchey and Kampong Speu. In the latter provinces cassava has been planted for only a few years and the soil fertility has not deteriorated as much. As a result, the spending on fertilizer in Banteay Meanchey and Kampong Speu provinces is less.

Table 18. Cost of fertilizer input in each province.

Province	Amount of fertilizer used (kg/ha)	Cost of fertilizers (R/kg)	Total cost of fertilizers (R/ha)	Total cost of fertilizers (US$/ha)
Battambang	N/A	N/A	N/A	N/A
B. Meanchey	146	2,000	292,000	73
Siem Reap	N/A	N/A	N/A	N/A
Northwest	**146**	**2,000**	**292,000**	**73**
Kampong Speu	140	2,000	280,000	70
Takeo	250	1,800	450,000	112.5
Kampong Cham	250	1,900	475,000	118.75
Prey Veng	N/A	N/A	N/A	N/A
Svay Rieng	N/A	N/A	N/A	N/A
Southeast	**210**	**1,900**	**400,000**	**100**
Total Cambodia	**170**	**2,000**	**350,000**	**84**

Cassava Harvesting

Table 19 indicates that more than 30% of farmers harvest their cassava by pulling the roots up by using their hands. The reasons for harvesting by hand are:

Cassava roots are often damaged when harvested by tractor

Manual harvesting can be done on a piecemeal basis

Harvesting cassava manually can be done using family labor.

Table 19. Harvesting tools used by farmers in each province.

Province	No. of house-holds	Harvesting tools (% of households)						
		Hoe	Digging stick	By hand	Tractor	Ngam [1)]	Knife	Buyer responsible
Battambang	70	1.16	2.33	0.00	17.44	75.58	1.16	2.33
B. Meanchey	16	0.00	0.00	11.76	35.29	52.94	0.00	0.00
Siem Reap	18	24.14	48.28	27.59	0.00	0.00	0.00	0.00
Northwest	**104**	**6.10**	**12.10**	**7.60**	**15.90**	**56.10**	**0.80**	**1.50**
K. Speu	8	8.33	8.33	50.00	0.00	0.00	16.67	16.67
Takeo	112	5.11	0.73	55.47	0.00	0.00	10.22	28.47
K. Cham	152	36.84	0.00	31.58	0.00	16.45	13.49	1.64
Prey Veng	20	41.18	11.76	44.12	0.00	0.00	2.94	0.00
Svay Rieng	31	45.45	2.27	47.73	0.00	0.00	4.55	0.00
Southeast	**323**	**29.00**	**1.30**	**40.30**	**0.00**	**9.40**	**11.30**	**8.70**
Total Cambodia	**427**	**24.40**	**3.50**	**33.80**	**3.20**	**18.70**	**9.20**	**7.20**

[1)] Ngam is a Cambodian traditional cassava harvesting tool (**Figure 4** at end of paper).

Major Problems Faced by Cassava Farmers and Processors

While farmers reported some problems with pests and diseases in cassava in some areas, it does not appear that the yield of cassava was seriously affected. The following list provides information about the main problems faced by farmers in Cambodia in cassava production.

Shortage of capital investment. Although cassava is a good cash crop, it requires a lot of money. The greatest costs are for land preparation, buying planting materials, and for planting, weeding and harvesting.

High labor costs. Currently, the cost of labor in Cambodia is increasing quite fast. The cost of farm labor per day increased from 5,000 Riels (US$ 1.25) in 2000 to about 12,000 Riels (US$ 3) in 2008. **Table 20** shows the average number of man-days used and the average labor spent on different activities in cassava production.

Unstable price. It is common now to read or hear the news about the price of agricultural products. Fluctuations in the gasoline price have a large effect on the cassava price, as a large proportion of cassava roots is now being used for ethanol production since the recent establishment of MH-Bio-Energy Co. in Cambodia.

Unstable market demand. Similar to the cassava price, the demand for cassava roots is changing year to year. This makes it difficult for farmers to decide which crops to grow.

Labor unavailability. Besides the cost of labor being quite high, it is also becoming difficult for farmers to find available labor because the labor demand for cassava varies depending on the season. For example, labor is more difficult to find during the time of planting and harvesting.

Unreliable weather. This is mainly a problem during the harvesting time when the crop is harvested and the roots are being sun-dried; when unexpectedly it starts raining, this lowers the quality of the cassava chips.

Pests and diseases. Although not many farmers reported problems with pests and diseases in cassava, the most common pests found in Cambodia were whiteflies and mealybugs.

Rules, policies and regulations by various authorities. Cambodia is now having a border conflict with Thailand. Crop growers have complained about the closure of the border passes between the two countries. Sometimes the problem happens during the harvest time of cassava. Unlike other crops such as beans and nuts, cassava can't be stored for very long before the roots start rotting.

Soil degradation. Farmers started observing problems of soil fertility decline resulting in a decrease of their cassava yields.

Table 20. Labor input and cost of various activities in cassava production.

Activities	Man-days/ha	Cost of labor (R/ha) [1)]	Cost of labor (US$/ha)
Land preparation	7.42	89,040	22.26
Cutting stakes	8.29	99,480	24.87
Planting	15.18	182,160	45.54
Fertilizer application	2.80	33,600	8.40
Manure application	3.68	44,160	11.04
Weeding	41.47	497,640	124.41
Harvesting	76.65	919,800	229.95
Carrying roots	9.83	117,960	29.49
Drying	60.00	720,000	180.00
Others	10.00	120,000	30.00
Total	235.32	2,823,840	705.96

[1)] Labor cost: R 12,000/man-day (=US$ 3/man-day).

Cassava Utilization

Cassava roots are used mainly for three purposes:

1. For income generation from selling cassava roots
2. For food consumption at home
3. For animal feeding

More detailed information about the use of cassava roots is shown in **Table 21**.

Table 21. Cassava root utilization.

Province	Cassava root use (% of households)		
	For selling	For food consumption	For animal feeding
Battambang	71.40	26.50	2.10
B. Meanchey	75.00	25.00	0.00
Siem Reap	50.00	47.20	2.80
Northwest	**66.90**	**31.20**	**1.90**
Kampong Speu	46.70	46.70	6.60
Takeo	64.70	34.10	1.20
Kampong Cham	99.30	0.00	0.70
Prey Veng	100.00	0.00	0.00
Svay Rieng	100.00	0.00	0.00
Southeast	**82.00**	**17.00**	**1.00**
Total Cambodia	**77.70**	**21.00**	**1.30**

Although some varieties produce higher yields than others, almost all of the respondents have indicated their tendency to grow the same cassava varieties they had planted before. However, this tendency will only continue as long as there is a stable demand and they receive a good price for the variety in the market.

By far the highest proportion of cassava farmers used the roots for income generation, while only a small number of farmers used the crop for household consumption. Almost none of the cassava growers used cassava roots to feed animals. The most common way of consuming fresh cassava roots in Cambodia is by boiling or roasting the roots, or for making some desserts. Usually, the local cassava variety "Damlong Kor" is used for these purposes.

Cassava leaves are seldom used in Cambodia, neither for feeding animals nor for human consumption. In a few cases, fresh cassava leaves are used to feed cattle, pigs and poultry. Besides that, some people also eat cooked young cassava leaves as a vegetable. However, a few farmers reported about the bad effect of feeding their animals with fresh cassava leaves, especially after the early rains at the end of the dry season. HCN toxicity caused their animals to become sick for a few days.

Cassava Price

In 2007, the average price of fresh cassava roots in Cambodia was around 290 Riels/kg (US$ 70/t), while the average price of dry cassava roots was about 600 Riels/kg (US$ 150/t). However, the price of cassava roots decreased very fast together with the decrease in the gasoline price and the decline of the global economy. In October 2008, the price of dry cassava roots was down to about 200 Riels/kg (US$ 50/t), and it continued to decrease till less than 100 Riels/kg (US$ 25/t) for fresh cassava roots in early 2009. This decrease in the cassava price has resulted in great capital losses for cassava growers as they had invested more money to increase their production.

Cassava Value Chain

There are several different types of traders who buy directly from cassava growers in Cambodia, such as:

Traders from inside the villages (who are usually the rich people in the village)
Cambodian traders from outside the villages
Traders from Thailand
Traders from Vietnam
Local processing factories
Traders from local markets (who usually buy the local variety, Damlong Kor, to process and sell at the market)
Agents of local companies
End consumers

The utilization patterns have changed for cassava growers in the Northwestern provinces since they now have more options to sell their crops at the drying floors. In most cases, farmers can take out a loan from the owners of drying floors in order to pay for the cost of their crop production, since they could not make a profit in 2008 or have some savings for the next cropping cycle in 2009. **Table 22** shows the sources of income of cassava growers in Cambodia who were included in the survey.

There are many sources of income for cassava growers in Cambodia, such as from growing crops, from raising pigs or other animals, selling non-timber forest products (NTFPs) and so on. Among farmers who were able to earn income from crop production, more than 70% of them could earn more than 3 million Riels from this source of income, while income from pig raising contributed less than 1 million Riels to the household. Besides that, trading is considered a good source of income for the community. Almost half of the trader-farmers earned more than 3 million Riels per year from their business.

Table 22. Percent of surveyed farmers who earned less than 1 million, 1-3 million, or over 3 million Riels per year from different sources of income in Cambodia.

Sources of income	Less than 1 million Riels	1-3 million Riels	Over 3 million Riels
Crops	9.80	14.60	75.60
Pigs	46.40	39.30	14.30
Other animals	44.61	30.40	23.90
NTFPs	100.00	-	-
Government position	50.00	37.50	12.50
Farm jobs	70.80	19.50	9.70
Non-farm jobs	42.60	37.70	19.70
Trading	29.70	25.00	45.30
Gifts	66.70	33.30	-
Handicrafts	40.00	40.00	20.00
Land rentals	45.50	27.29	27.30

SIGNIFICANCE OF THE FINDINGS

There are some significant findings from this survey on cassava production and utilization in Cambodia, which could lead to additional research or to a refocus of the cassava project in the country.

During the survey, farmers mentioned many cassava varieties using their local names. Most of these were hard to identify exactly by the researchers. It is possible that many of these varieties are actually the same but have different names in different areas. We would suggest that CARDI tries to collect these varieties in a cassava germplasm bank to see which ones have the same morphological characters. Subsequently, DNA fingerprinting may help to decide whether or not they are duplicates of the same variety.

The other important finding is that some local or unnamed varieties had very high yields (according to the farmers). It would be useful if CARDI, or another relevant institution, would collect and evaluate these varieties in well-managed replicated experiments to see whether the farmers' perceptions are actually correct.

In Cambodia now, most farmers cannot make use of their cassava leaves and unmarketable cassava roots. Although various organizations may have provided some knowledge to farmers regarding the value-addition to their cassava products and by-products, farmers are still not well aware of these techniques. We should provide more information and training to help farmers gain additional benefits from their cassava plantations.

Finally, farmers mentioned that soil fertility has declined, and that they are using mainly urea and di-ammonium phosphate (DAP) as a fertilizer. A similar situation existed in other countries such as Vietnam. But once farmers there conducted some FPR fertilizer trials on their own fields and saw that other types of fertilizers are more suitable for cassava, they started using these fertilizers; their yields increased and fertilizer use became more profitable and more widespread. This indicates that there is a great potential for further increasing cassava yields by conducting simple on-farm fertilizer trials in many locations to let farmers see with their own eyes that urea and DAP are not the right kind of fertilizers for cassava, but that they can increase their yields a lot more by using a mixed or compound fertilizer which will provide something like 80-100 kg N, 20-40 kg P_2O_5 and 80-120 kg of K_2O per ha..

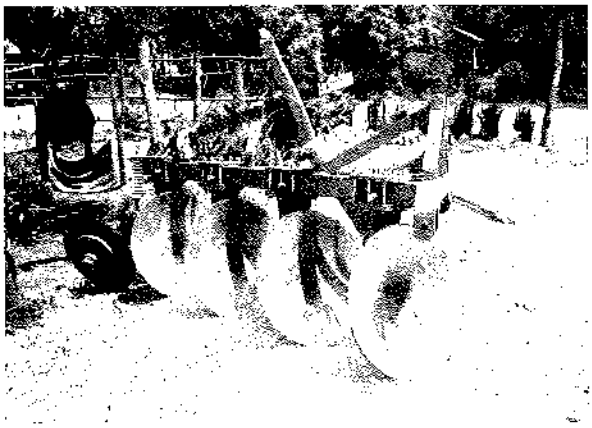

Figure 2: Tractor disks for plowing

Figure 3: Cassava planted on ridges.

Figure 4. *Ngam*, a traditional cassava harvesting tool in Cambodia.

ENHANCING THE ADOPTION OF IMPROVED CASSAVA PRODUCTION AND UTILIZATION SYSTEMS IN INDONESIA (The ACIAR Cassava Project in Indonesia)

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ABSTRACT

In order to improve food security, protect the soil from degradation and contribute to poverty alleviation, a research project was implemented by CIAT in close collaboration with several government and non-government agencies in Indonesia, and funded by ACIAR in Australia. The project was part of a larger project entitled "Enhancing the Adoption of Improved Cassava Production and Utilization Systems in Indonesia and East Timor". The general objective of the project was to increase the productivity of cassava-based cropping systems through the widespread adoption of higher yielding cassava varieties and improved cultural practices that increase yields and protect the soil from erosion and nutrient depletion.

This was achieved by conducting collaborative experiments on varieties and some agronomic aspects in experiment stations and on-farm. The project was executed in East Java, Central Java,Yogyakarta, West Java, and Lampung provinces. A farmer participatory approach was used with the objective to include farmers in all the project activities in order to enhance adoption of improved practices. Both on-station and on-farm trials were conducted on appropriate and economic fertilizer and manure inputs, on cassava leaf production, and on the effect of supplementing the diet of sheep and dairy cattle with cassava leaf silage. To increase the market demand for cassava, in Malang district of East Java farmers were also encouraged to develop simple tools and methods for on-farm processing of fresh cassava roots into a variety of products. These groups visited similar processing groups in Kediri, Gunung Kidul and Pati districts to learn to make more cassava-based dishes and products for sale.

The main achievements of this 3-year project were the identification of several high-yielding, high-starches and/or tasty cassava varieties, that are suitable for industrial processing, animal feeding and for human consumption, respectively, as well as more economic and sustainable cassava production practices. Highly promising varieties identified and preferred by farmers include UJ-5, UJ-3, Markonah, Malang 6, UB 447-2, UB ½, Faroka, Bandung, Manggu and Adira 1. The last three varieties, i.e. Bandung, Manggu and Adira 1, are mainly used for direct human consumption or processing into snacks such as *kripik* or *krupuk*.

Many new varieties and improved technologies were tested in FPR trials by farmers. Some of these have now been adopted commercially by the collaborating farmers. In Malang district of East Java, three farmer groups of cassava processors have been established. They are now producing and selling a variety of products, such as *kripik, krupuk,* wafers and cakes made from fresh cassava roots. They have produced a recipe book for 32 different cassava-based products or dishes.

It is still too early to have achieved widespread adoption and impact. However, observing the enthusiasm of the collaborating farmers and some of their neighbors in the village, it is likely that the dissemination methodology used in this project has a good prospect to be continued in order to enhance more widespread adoption and achieve real impact in the future.

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1. INTRODUCTION

Together with Nigeria, Brazil and Thailand, Indonesia is one of the largest cassava producing countries in the world. In Indonesia cassava is the third most important food crop, after rice and maize. From about 1.6 million tones of fresh roots produced, about 53% is used for food and the other 47% for the production of starch, modified starch, sorbitol, fuel-ethanol and other industries based on cassava (CBS, 2007). However, cassava has never been considered a high priority crop, either by the government or by researchers. National responsibility for cassava research rests with the Indonesian Legume and Tuber Crops Research Institute (ILETRI) in Malang, E. Java, but very few researchers are actually working full-time on the crop. Brawijaya University used to have an active cassava breeding and agronomy program, but both have practically disappeared. Similarly, the national, provincial and district extension offices concentrate their limited resources mainly on rice, maize and soybean, with very little attention paid to cassava. With a population of over 200 million people and an estimated 5-10 million cassava producing households, Indonesia has now only 2-3 full-time cassava researchers and no more than ten part-time researchers.

Most varieties presently grown are local cultivars developed and selected by farmers. An exception is Lampung province in the southern part of Sumatra island where cassava is grown mainly as a commercial crop for starch processing. Here the private sector, particularly the Great Giant Pineapple Co., has conducted it own research at Umas Jaya Farm, and has first selected and widely disseminated the high-yielding variety Adira 4, which was later replaced by two varieties introduced from Thailand, which have now been officially released as UJ-3 (= Rayong 60, locally known as "Thai") and UJ-5 (= KU 50, locally known as "Kasetsart"). The latter variety is now estimated to be grown in about 65% of the cassava area or 160,000 ha in Lampung province. Locally developed and officially released varieties such as Adira 1, Adira 4, Malang 1, Malang 4, Malang 6 and Kaspro, and some highly promising breeding lines such as UB ½ and UB 477-2, are not yet widely adopted, as many farmers are not even aware of their existence, and no planting material has ever been widely distributed.

During the 1970s and 80s Indonesia made a major effort to upgrade its cassava research. At least 19 researchers received training in CIAT-Colombia, and since the establishment of the CIAT Cassava Office in Asia in 1983 there has been a close working relationship between researchers in various Indonesian institutions, notably Brawijaya University, ILETRI, CRIFC and Umas Jaya Farm, with the CIAT breeder and agronomists stationed in Bangkok. Being the second largest cassava growing country in Asia, Indonesia has actively participated in the Asian Cassava Research Network, especially in the seven Regional Cassava Workshops that have been held every three years in different countries in the region. Unfortunately, during the 1990s and the first decade of the 21 century, economic crises and budget cuts resulted in a marked reduction in funding for cassava research, both at CIAT and in the Indonesian institutions.

In spite of these reduced efforts, Indonesia has made steady progress in cassava research and development, partially driven by increasing demand for cheap food, especially since the economic crisis of 1987, as well as for starch and starch-derived products, such as instant noodles, MSG, sorbitol, and modified starches; the latter is used mainly in the paper

and textile industry. During the past ten years the cassava area in Indonesia declined, especially in Java, due to competition from other, more valuable, crops, but total production increased at an annual rate of 1.4% due to a steady increase in yield, from 12.0 t/ha in 1996 to 15.9 t/ha in 2005, corresponding to a remarkable annual increase of 3.2%. Increases in yields were greatest in Lampung province where many farmers started planting the two high-yielding Thai varieties, "Kasetsart" and "Thai", while also intensifying production by planting cassava more and more in monoculture and with increasing use of chemical fertilizers. Average yields in Lampung have now reached 19 t/ha, which is similar to yields in Thailand, but still much below the yields of 26-28 t/ha obtained on average on 2,000-3,000 ha of cassava at Umas Jaya Farm in Lampung.

Because cassava has many alternative uses as food, feed and for many industrial purposes – while it can also grow well in many unfavorable environments – it is an ideal crop to initiate rural development through the commercialization and processing of cassava roots and dry chips, thus allowing farmers to earn money to buy inputs to further intensify their agricultural activities, whether in food crops, horticultural crops, fruit trees, aquaculture or livestock production. This also creates on- and off-farm jobs for an ever increasing and restless young generation. Thus, besides improving the productivity of cassava as a food crop, it is an opportunity to enhance its use in animal feeding, in small-scale processing into a variety of dishes and products for sale, and eventually for production of starch and fuel-ethanol, both for domestic use and export. The current, seemingly insatiable need for cassava dry chips, starch and ethanol in China, has resulted in marked increases in the price of these cassava products, thus providing an opportunity for cassava farmers in Asia to expand their area and intensify their production, to benefit from new markets and improve their income and livelihood. This has been the key issue that the ACIAR-funded cassava project intended to address.

2. OBJECTIVES

The general objective of the ACIAR-funded cassava project was to increase the productivity of cassava-based cropping systems through the widespread adoption of higher yielding cassava varieties of superior nutritional quality, and improved cultural practices that increase yields while protecting the soil from erosion and nutrient depletion.

The specific objectives of the project were:

1. To support national institutions in conducting strategic and applied research in cassava production and on-farm utilization that will overcome important constraints identified at the farm level.
2. To strengthen inter-institutional as well as inter-disciplinary collaboration and the capacity for farmer participatory research in national institutes and in selected farm communities.
3. To develop, with farmers, new high-yielding cassava varieties of superior nutritional quality, improved crop management practices that increase yields and maintain the soil resource, and better utilization through small-scale processing and on-farm animal feeding of roots and leaves.
4. To disseminate new technologies at the local, provincial and national level using farmer participatory extension methodologies.

3. METHODOLOGY

3.1. Institutions and Persons Involved in the Project

In accordance to the objectives of the research project, the persons involved in this project came from many different fields and institutions, i.e. Prof. Wani Hadi Utomo, cassava agronomist at Brawijaya University; Dr. Koeshartojo, cassava breeder of ILETRI in Malang; Mr. Wargiono, cassava agronomist in CRIFC in Bogor; Dr. Djoko Santoso and Mrs. Enggis Tuherkish from the Soil Research Institute in Bogor; Dr. Marjuki, animal nutritionist at Brawijaya University; Dr. Suhardjo and Mrs. Endah Retnaningtyas, cassava processing specialist from BPTP for East Java in Malang, and Mr. Aldon Sinaga, agribusiness specialists from the University Tribhuwana in Malang. The project was later joined by Mr. Adi Widjaja, leader of an NGO, Budi Mixed Farming (BMF), which was helping cassava farmers in Pati district of Central Java.

3.2. Location

Initially, the work was done in Malang (East Java), Gunung Kidul (Yogyakarta), and Tamanbogo (Lampung). In the second year, additional work was also carried out in Sukabumi (West Java), and with the involvement of Mr. Adi Wijaya from BMF, it was extended to Pati (Central Java).

3.3. Methodology

In order to improve the collaboration among institutions and among scientists, a small workshop was held prior to initiating the research activities. The workshop discussed the existing problems, alternative solutions and the design of project activities. The outputs of the workshop were:

1. Identification of the main problems encountered for cassava development, i.e. (a) low interest of farmers to plant cassava because planting cassava is not profitable due to the limited utilization and unpredictable price, (b) low yield due to lack of high-yielding varieties and soil degradation, and (c) low adoption of improved technologies.

   The activities to solve these problems were:

2. To conduct experiments on: (a) varietal evaluation, (b) soil fertility management to obtain sustainable production, (c) technologies for leaf production, and (d) the use of cassava, especially leaves, for animal feeding.

   The experiments were conducted on research stations or research sites, and to some extent these include on-farm experiments. The research was basically designed and managed by researchers; farmers are sometimes paid to maintain the experiment weed-free and may be paid for their labor during planting and harvest. The experimental sites and the types of experiments, which include trials on cassava agronomy, soil fertility managements and animal feeding with cassava leaves, are presented in **Table 1.**

3. To develop, together with farmers, new high-yielding varieties of superior nutritional quality, improved crop management practices to increase yields and to maintain the soil resource and better utilization through on-farm processing or its use in animal feeding.

The research was conducted in the form of FPR trials, which in turn were followed by the dissemination of the farmer-selected technologies using farmer participatory extension (FPE) methodologies.

Table 1. Type of on-station and on-farm cassava experiments conducted by partner institutions in Indonesia.

Location	Year(s)	Type of experiment
Jatikerto, Malang	2004-07	1. Use of chem. fertilizers and manures; C+Maize
Jatikerto	2004/05	2. Variety x spacing x pruning for leaf production
	2005/06	3. Spacing x N application rates for leaf production
	2006/07	4. Variety x cropping system x spacing for leaf production
Karangploso, Malang	2004/05	1. Methods of cassava leaf silage production
Karangploso	2005/06	2. Levels of cassava leaf silage for feeding sheep
Tamanbogo, E.Lampung	2004/05	1. Long-term NPK experiment conducted since 1991
	2005/06	to determine the long-term nutritional requirement of cassava
	2006/07	intercropped with maize and upland rice
Tamanbogo	2004/05	2. Variety evaluation experiment; C + Rice
Playen, Yogyakarta	2004/05	3. Variety evaluation experiment
Ngadirejo, Malang	2004-07	1. On-farm evaluation of new breeding lines
Sempol, Malang	2004-07	2. On-farm evaluation of new breeding lines
Karang Gayam, Blitar	2006/07	3. On-farm evaluation of new breeding lines
Selorejo, Blitar	2006/07	4. On-farm evaluation of new breeding lines
Tamansari, Pati	2005-07	1. On-farm evaluation of promising varieties

The conceptual model for this methodology is shown in **Figure 1** (Howeler, 2001). The unique feature of this approach is that farmers are involved in all steps of the process, from diagnosing their main problems, to selecting and testing various solutions, to selecting and then adopting those varieties or practices most suitable for their particular conditions; farmers can also help to disseminate those selected technologies to other farmers and communities through farmer-to-farmer extension. The sites of FPR activities were usually close to areas where on-station or on-farm experiments were also being conducted, so that these experiments could serve as "demonstration plots".

As indicated in **Figure 1**, the first step in conducting FPR trials is to select an appropriate site, in an area where cassava is presently an important crop or where it may become so in the future. Often times, local extension workers request to be involved in the project as farmers have shown interest in improving their cassava production. After an initial meeting to explain the objectives of the project and to gauge the interest of farmers and local leaders and extensionists to participate, the project staff visits the community and conducts a Rapid Rural Appraisal (RRA), to learn more about cassava production and utilization practices, and to diagnose, together with farmers, the problems that need attention. After prioritizing the problems and possible solutions, farmers can decide what type of trials they want to conduct on their own fields. Farmers who volunteer to conduct

these FPR trials may be taken to a demonstration plot or other villages where experiments are already being conducted. Farmers evaluate and discuss the various treatments being demonstrated and then select those they consider most suitable for their own conditions.

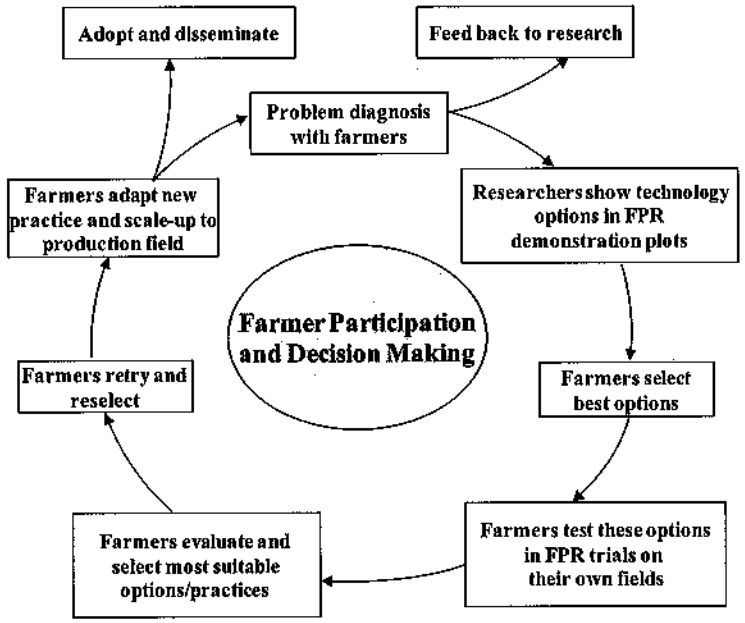

Figure 1. Farmer participatory model used for the development of sustainable cassava-based cropping systems in Asia.

Thus, farmers discuss and decide, while researchers and extension workers help farmers in selecting reasonable treatments, but without imposing their own opinions. At time of planting, the project staff helps the farmers set out the experiments and provides the planting material, seed or fertilizers, if required. Farmers themselves are the owners and managers of the trials, but project staff should visit regularly to discuss and solve the problems that might occur.

At some occasions, especially at harvest time, both collaborating and non-collaborating farmers from the village or district are invited to harvest the trials and to judge and select the best or preferred treatments. Some of these farmers may then be interested to join the project and in the following year may do the experiments in their own fields.

Most of these trials have 4-5 treatments with one treatment being the traditional farmer's practice for comparison. To facilitate accurate yield measurements it is suggested that the trials are conducted in small plots, often 5x5 or 6x6 m, and that stakes are planted at a regular plant spacing, often 1x1 m or 0.9x0.9 m. At time of harvest, the collaborating farmers in the village, together with project staff, help each other harvest all the trials and determine the yields in all treatments. Later in the day, or the following day, a farmer field day is organized in which other farmers in the village or from neighboring communities can

visit the trials, see the piles of harvested roots and evaluate the usefulness of each treatment. Finally, the yield data are tabulated, averaged and presented to the group for discussion and selection of best treatments by raising hands. The farmer-selected varieties or practices may then be tested again the following planting season, or be directly adopted in their larger production fields.

Oftentimes FPR trials are conducted in a particular village for 2-3 years until farmers have tested and selected the best options for adoption, at which point other new villages are selected and the process is repeated. Once farmers see in their own trials that a certain variety or practice produces higher yields or at a lower cost, they will want to adopt those varieties or practices. The project staff can help farmers to obtain the necessary planting material, seed of intercrops, or other inputs that are sometimes hard to find. Farmers from other new villages may want to visit those villages that have already adopted some new technologies in order to see and discuss their benefits. These farmers may either want to conduct their own FPR trials or start adopting those practices that others have already tested and selected. These cross-visits between villages is one way to stimulate farmer-to-farmer extension, which is often more effective than the traditional extension practices.

4. ACHIEVEMENTS AGAINST SPECIFIC PROJECT OBJECTIVES

4.1. To Support National Institutions in Conducting Strategic and Applied Research

Of the eight activities listed, the main focus has been on soil fertility maintenance, plant spacing and nitrogen fertilization for leaf production, varietal evaluation and improvement, and on-farm animal feeding. The first two activities were done in experimental stations, and were conducted by the project team. These experiments also function as demonstrations. The last two activities were done on farmers' fields and were conducted by farmers, while project staff acted as facilitators and provided guidance to conduct the experiments (these activities are also to achieve Objective 2)

4.1.1. Soil fertility management for sustainable production

Two experiments were conducted to determine the most economic way to achieve long-term sustainable cassava production; one was done on an acid soil in Lampung, and one on a low soil organic matter soil in Malang. The results, presented in **Figure 2,** shows that in a sandy loam acid soil in Tamanbogo, Lampung, the application of N, P and K are absolutely required by both cassava and the intercropped rice. The application of N-fertilizer had a negative effect on the growth and yield of rice, but not on cassava. In 2004/05 the rice in these plots fertilized with high rates of N grew very poorly and hardly produced any grain. It was thought that the negative effect of high rates of N application was due to the acidification effect of the applied urea fertilizer. Therefore, in 2005/06 and 2006/07 dolomitic lime was applied to all plots, and as a result the rice grew better and produced grain. The same phenomenon actually had occurred for the intercropped maize, which had already disappeared in the eighth year (**Figure 3**). These results indicate that cassava is much more tolerant than maize or upland rice to acid soil conditions, characterized by a low pH and high levels of exchangeable aluminum (Al).

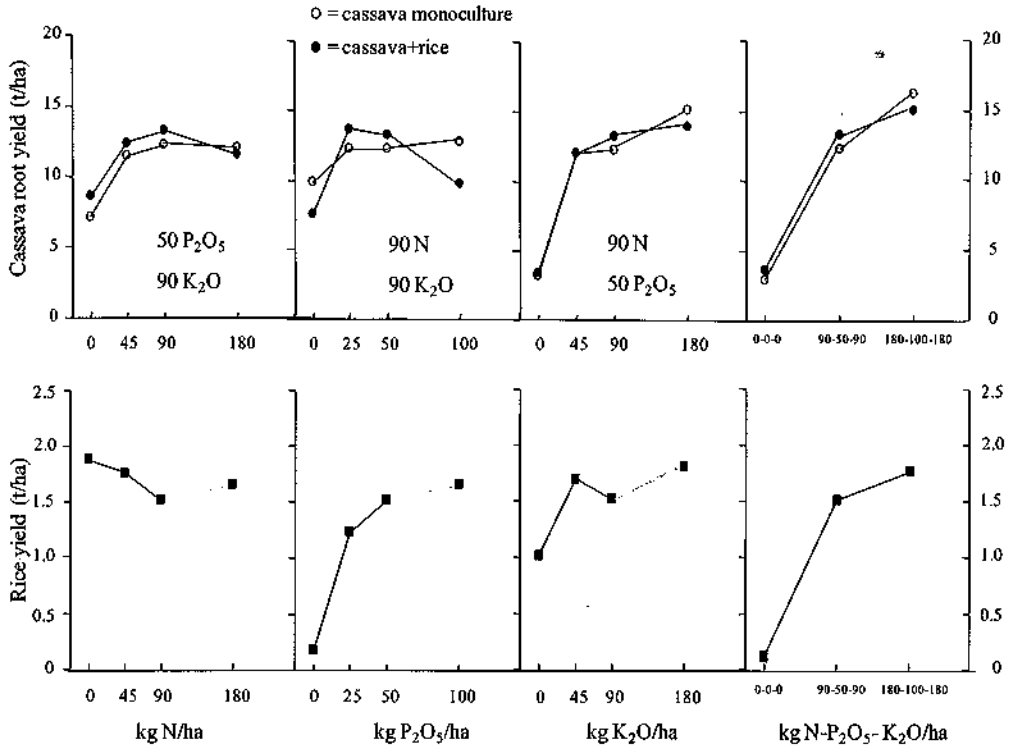

Figure 2. Effect of applications of various levels of N, P and K on the yields of cassava and intercropped rice, during the 16th consecutive cropping cycle in Tamanbogo, Lampung, Indonesia in 2006/07.

Figure 3 shows that the yield of intercropped maize decreased with an increase in the exchangeable Al saturation (as a result of acidification by N fertilizer), and the crop stopped to grow completely as soon as the exchangeable Al saturation was around 60%, while rice yields decreased when the Al-saturation reached about 80%. **Figures 2** and **3** also show that with correct fertilizers, after 16 years of continuous cropping, the acid low-fertility Ultisols could still produce reasonable yields of cassava. It is suggested that the application of organic matter, either in the form of organic compost or animal manure may further increase the yields.

As a result of the Participatory Rapid Appraisal, (PRA) (see section 3.2.1below), an experiment to use organic manures was conducted to determine the most sustainable cassava production practices. The experiment was carried out at Jatikerto Experiment Station, about 20 km south-west of Malang city. The results, presented in **Table 2,** show that without N fertilizer cassava yields rapidly decreased. The yield in the first year was 26 t/ha, but decreased to less than 10 t/ha in the third year. Application of N-fertilizer and/or FYM could minimize the yield decrease. The result in **Table 2** shows that in the third year

the yield of cassava fertilized with 135 kg N/ha (as urea) was 29.90 t/ha; this is still 90% of the yield in the first year (32.50 t/ha). The cassava yield decrease when 10 t/ha of FYM had been applied was 32% (the yield decrease from 35.50 t/ha to 24.10 t/ha). The yield decrease could be further minimized by the application of nitrogen fertilizer combined with 5 t/ha of FYM or compost. Application of K fertilizer on this K-rich soil did not have any positive effect on cassava yield, at least until the third year of cropping.

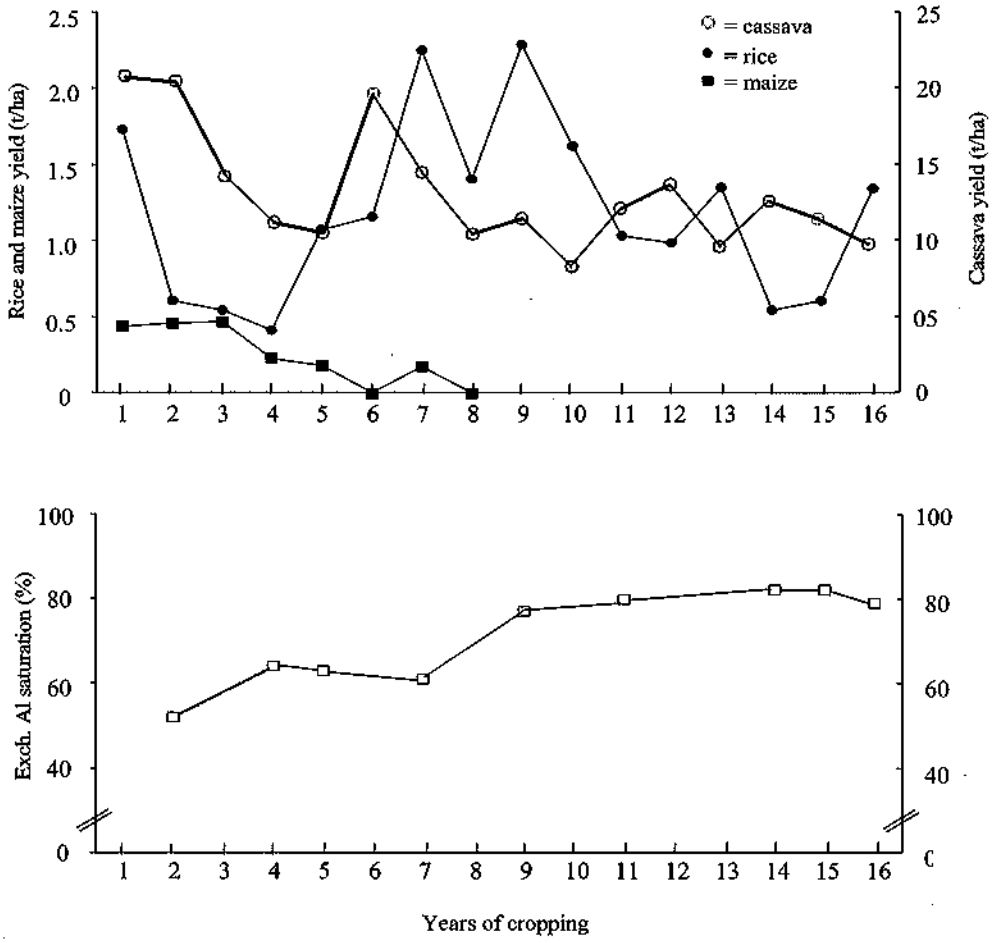

Figure 3. Change in the yields of intercropped maize and rice during 16 consecutive years of growing cassava, Adira 4, with intercropped rice and maize. Data are average values of 12 NPK treatments in a long-term NPK trial conducted in Tamanbogo, East Lampung, Lampung, Indonesia from 1991 to 2007.
Below: The change in the average percent Al-saturation of the soil
Note: 2 t/ha of lime were applied in Rep III before the 15th crop cycle and another 2 t/ha in Reps I and III before the 16th crop cycle.

Table 2. Effect of various fertilization alternatives on the intercropped maize yields and cassava root yields when grown for three consecutive years in Jatikerto, Malang, East Java from 2004/05 to 2006/07.

Treatments		Maize grain yield (t/ha)			Cassava root yield (t/ha)		
N-P_2O-K_2O (kg/ha)	Organic (t/ha)	1st year	2nd year	3rd year	1st year	2nd year	3rd year
0-0-0	0	2.40	1.10	1.06	26.00	10.96	9.83
135-0-0	0	3.80	1.93	3.37	32.50	35.60	29.90
135-50-0	0	3.74	2.07	3.33	43.88	36.80	28.40
135-50-100	0	3.76	2.10	3.43	42.05	37.47	28.17
0-0-0	10 FYM	2.83	1.66	3.00	35.50	26.53	24.10
0-0-0	10 Compost	2.69	1.63	2.55	33.00	22.67	20.63
135-0-0	5 FYM	3.86	2.26	3.71	48.61	35.63	30.50
135-0-0	5 Compost	3.36	1.97	3.51	46.66	39.33	33.60
135-50-0	5 Compost	3.72	1.87	3.79	46.11	39.07	36.27
135-0-0	5 Sugar mud	3.78	1.67	3.21	36.67	33.73	29.57

The yield stability of maize could not be concluded, because of the high fluctuation from year to year. In the second year, the yields of maize decreased in all treatments. However, in the third year, except for the unfertilized (0-0-0) treatment, maize yields increased to about the same levels as those of the first year. This fluctuation was not considered as the effect of the treatments, but as the response of maize to climatic conditions. Maize is very sensitive to climatic conditions, especially rain at the time of planting. We can only conclude that: without fertilizer application (0-0-0 treatment), the yields of maize, like those of cassava decreased with time. The yield of unfertilized maize in the first year was 2.40 t/ha, but decreased to 1.06 t/ha in the third year.

4.1.2. Planting cassava for both root and leaf production

Two experiments were conducted to explore the production technology for growing cassava to optimize total biomass production, i.e. (1) The effect of pruning on leaf and root yields of three cassava varieties planted at two plant spacing in a cassava + maize intercropping system; and (2) The effect of nitrogen fertilizer application to cassava planted for leaf production in a cassava + maize intercropping system. The experiments were conducted at Jatikerto station in Malang, East Java.

In the first experiment there were three pruning treatments, i.e. (a) No pruning, but at time of root harvest the young shoots were also harvested, (b) top pruning, by cutting the young shoot at a height of 30 cm above the ground, and (c) leaf pruning, by harvesting the whole leaves. The first pruning was done at three months after planting followed by pruning at 2-month intervals. The results of this experiment indicate that pruning and cassava plant spacing did not significantly influence maize yields, as the average maize yield was 4.75 t/ha. This is reasonable, because at those two cassava spacing maize was planted at the same density, and since maize grows faster than cassava, the growth of maize was not seriously affected by the cassava. Cassava leaf and root yields, on the other hand,

were significantly influenced by both the pruning treatments and the cassava plant spacing **(Table 3).**

Table 3. Effect of pruning and cassava plant spacing on dry leaf and fresh root yields of three cassava varieties in a cassava + maize intercropping system at Jatikerto Experiment Station in Malang, E. Java in 2004/05.

Cassava Varieties	Plant spacing (m x m)	Pruning methods	Dry pruned leaf yield[1)]	Fresh root yield
			(t/ha)	
UB 477-2	1.0 x 1.8	None	2.39 a	52.32 j
		Top	5.10 de	10.77 ab
		Leaf	3.17 bc	23.07 ef
	1.0 x 0.4	None	3.28 bc	64.72 k
		Top	7.14 f	13.58 b
		Leaf	4.11 cde	32.22 g
UB ½	1.0 x 0.8	None	2.30 a	42.79 i
		Tope	5.01 de	7.71 a
		Leaf	3.54 bcd	21.49 de
	1.0 x 0.4	None	3.19 bc	53.88 j
		Top	6.92 ef	11.09 ab
		Leaf	4.21 cde	27.44 fg
Faroka	1.0 x 0.8	None	1.90 a	37.39 h
		Top	3.18 bc	6.77 a
		Leaf	2.80 a	15.10 bc
	1.0 x 0.4	None	2.70 a	52.44 j
		Top	4.15 cde	9.94 ab
		Leaf	3.84 cde	23.80 e

Means followed by the same letters in each column are not significantly different (P = 0.05)

The data in **Table 3** also show that there was an interaction between pruning methods, cassava plant spacing and cassava varieties. Pruning, both top and leaf pruning, significantly decreased the root yields. In general, UB 477-2 produced the highest leaf and root yields.

In the second experiment, cassava, UB 477-2, was planted and pruning was done by cutting off the whole tops at about 30 cm above the ground; the first pruning was done at about 75 days, after which pruning was done at 2 month intervals. The results, given in **Table 4,** show that cutting off the cassava tops four times during the growth cycle significantly decreased the root yields, at both cassava plant spacing. Application of N fertilizer to the pruned cassava, up to 600 kg urea/ha, increased both the leaf and root yields. However, the maize yields were not significantly influenced by the cassava pruning, or spacing treatments, nor by the rate of nitrogen application. This is not surprising, because in this cropping system the maize grows much faster, and tends to be taller than cassava, so that in terms of light competition, there was no effect of the cassava on maize. It seems that application of 300 kg urea/ha was sufficient to meet the maize' requirement in the pruned cassava system. The lower yield of maize when cassava was

planted at high density (1.0 x 0.4 m) can be attributed to nutrient competition rather than light competition. The data in **Table 4** also show that the cassava yield in this latter treatment was very high, and much higher than those in other treatments.

Furthermore, data in **Table 4** shows that under the current prices and experimental conditions, the net income from growing cassava for both leaf and root production, using a cassava + maize intercropping system, was less profitable than growing cassava without leaf pruning, and that high rates of N application are required to increase the net income when tops are cut off regularly for leaf production.

Table 4. Effect of pruning, plant spacing and rate of N application on the leaf and root yields of cassava and the yield of intercropped maize, as well as on the gross and net income in 2005/06.

Pruning/spacing/urea rate	Maize yield (t/ha)	Dry leaf yield (t/ha)	Fresh root yield (t/ha)	Gross income maize grain[2)]	Gross income cassava leaves[2)]	Gross income cassava roots[2)] ('000 Rp/ha)	Production costs[3)]	Net income
No pruning/1.0x0.8/300	3.27	1.34[1)]	46.76	5,232	2,010	18,704	4,702	21,244
No pruning/1.0x0.4/300	2.64	1.68[1)]	48.68	4,224	2,520	19,472	4,981	21,235
Leaf pruning/1.0x0.8/300	3.68	3.14	10.11	5,888	4,710	4,044	5,247	9,395
Leaf pruning/1.0x0.8/400	3.97	4.32	13.62	6,352	6,480	5,448	6,275	12,005
Leaf pruning/1.0x0.8/500	4.04	6.27	15.82	6,464	9,405	6,328	7,823	14,374
Leaf pruning/1.0x0.8/600	3.97	7.73	18.09	6,352	11,595	7,236	9,025	16,158
Leaf pruning/1.0x0.4/300	2.97	4.18	12.27	4,752	6,270	4,908	6,028	9,902
Leaf pruning/1.0x0.4/400	3.17	5.19	15.81	5,072	7,785	6,324	6,936	12,245
Leaf pruning/1.0x0.4/500	3.05	6.32	19.02	4,880	9,480	7,608	7,923	14,045
Leaf pruning/1.0x0.4/600	3.43	9.07	20.57	5,488	13,605	8,228	10,026	17,295

[1)] Cassava leaves at time of root harvest only

4.2. To Develop, with Farmers, New High-yielding Cassava Varieties and Improved Cultural Practices, and Better Utilization Through On-farm Processing and Animal Feeding

4.2.1. FPR trials

The first activity of FPR was to conduct a Participatory Rapid Appraisal (PRA). Due to the limitation of personnel, time and budget, the PRA was only conducted in Malang. The PRA was done to explore, together with the farmers, the problems that farmers face, their needs, and willingness to participate in finding solutions. The results have been reported by Yunawati *et al.,* (2009). From this PRA, farmers identified some problems in cassava production and considered several possible solutions which they used as experimental treatments in FPR trials conducted on their own land. In other locations, no PRAs were conducted, but at the beginning farmers were still involved in the discussion

and selection of the experimental treatments. The number of participating farmers and the type of experiments conducted by the farmers are presented in **Table 5.**

In Malang, several experiments were conducted at the Brawijaya University experiment station in Jatikerto (see section 3.1). These experiments were used as demonstration plots during farmer field days. Field days were held by inviting the farmers, both the participating and non-participating ones, to visit, to take measurements, to evaluate and to select the experimental treatments. It was expected that some of these farmers would test the selected treatments in their FPR trials on their own fields. The field days for maize were held at the time of harvest of the intercropped maize in order to evaluate the maize stand and yield. The evaluation of cassava was done during the cassava harvest.

Table 5. Number and type of FPR trials conducted in Indonesia from 2004/05 to 2006/07.

	Variety			Fertilizers			Animal feeding	
District, Province	04/05	05/06	06/07	04/05	05/06	06/07	05/06	06/07
E. Lampung								
Lampung	-	3	3	2	9	3	-	-
Sukabumi,								
W. Java	-	3	6		3	-	-	-
Gunung Kidul,								
Yogyakarta	3	5	2	2	3	1	-	-
Malang,								
East Java	8	7	3	3	10	-	1	1
Total	**11**	**18**	**14**	**7**	**25**	**4**	**1**	**1**

The results of the farmers' evaluation and selection are shown in **Table 6** for maize and in **Table 7** for cassava. None of the farmers were interested in growing cassava for leaf production. The farmers argued that growing cassava for leaf production is less profitable than producing only the roots (see 3.1.2).

It is interesting to note that, based on the farmers' preferences, none of the farmers put the nitrogen fertilizer + manure as their first selection. However, after conducting the trial and seeing this treatment on their own fields, farmers selected this treatment. Although they put the NPK treatment as their second choice, they did not want to try this treatment because of the high cost and the difficulty of obtaining P and K fertilizers. Later (after they came to evaluate the demonstration plots in the third year), they were happy with their selection because they saw that this treatment (N fertilizer + manure), which they had tried in their own fields, resulted in a more stable cassava root yield.

Table 6. Farmers' preference for experimental treatments of organic and inorganic fertilizer application based on maize performance.

(1) Preference based on maize stand (total farmers involved were 30).

Preference ranking	Treatment[1)]	Number of farmers	Treatment	Number of farmers	Treatment	Number of farmers
First	N	12	NPK	9	NM	5
Second	NM	15	NPK	7	N	6
Third	NPK	11	NM	8	N	5
Fourth	N	9	NP	7	NM	7

(2) Preference based on maize grain performance and grain yield.

Preference ranking	Treatment[1)]	Number of farmers	Treatment	Number of farmers	Treatment	Number of farmers
First	N	15	NP	8	N	5
Second	NPK	11	N	9	NM	6
Third	NM	12	NB	9	NPK	6
Fourth	NM	11	N	10	NP	5

[1)]M= cattle manure; B= Blotong (sugar cane industry by product)

Table 7. Farmers' preference for experimental treatments of organic and inorganic fertilizer application based on cassava performance.

(1) Cassava preference based on cassava stand (total farmers involved were 30)

Preference ranking	Treatment[1)]	Number of farmers	Treatment	Number of farmers	Treatment	Number of Farmers
First	N	16	NP	7	N	3
Second	NPK	12	N	9	NM	6
Third	N	13	NM	9	NP	6
Fourth	N	12	NM	8	NP	5

(2) Cassava preference based on root performance and root yield.

Preference ranking	Treatment[1)]	Number of farmers	Treatment	Number of farmers	Treatment	Number of Farmers
First	N	21	NP	9	NM	5
Second	NPK	14	NP	9	NPK	5
Third	NM	11	N	9	NPK	5
Fourth	NPK	11	NP	10	N	7

[1)]M = cattle manure

The results of various FPR trials conducted in many parts of Indonesia can be summarized as follow:

1. Variety trials:

Malang	: the selected varieties are: UB 477-2, Faroka and UB ½
Pati	: the selected varieties are: UB 477-2, Markonah and KU 50.
Gunung Kidul	: the selected varieties are CMM 96-36-255, KU 50, UB ½ and UB 477-2
Sukabumi	: CMM 96-36-255, Bandung, Mangu, KU 50, UB ½ and UB 477-2
Lampung	: CMM 96-36-255, KU 50, Malang 6 and CM 99-23-12

2. Production technology trials:

Malang	: application of 135 kg N/ha + 5 t manure/ha
Gunung Kidul	: application of 200 kg urea/ha + 2 t manure/ha
Lampung	: application of 100-100-100 kg N-P_2O_5-K_2O/ha + 2 t manure/ha

4.2.2. Animal feeding trials.

After obtaining good results with the use of cassava leaf silage for feeding sheep (see Howeler, 2006) at the experiment station, a similar trial was conducted with farmers in Batu district. In this case, farmers preferred to use the leaf silage for feeding dairy cattle as they had observed that sheep or goats require time to adjust to eating the silage, while cows prefer the silage over their main diet of elephant grass. The result, presented in **Table 8,** show the effect of feeding cassava leaf silage on milk production in six farms as well as on the protein and fat content of the milk. On average, milk yields increased 6.2% with the feeding of cassava leaf silage in addition to the normal diet of elephant grass supplemented with some feed concentrate; the protein and fat contents of the milk increased by 13.6 and 2.5%, respectively.

Table 8. Effect of feeding dairy cattle with cassava leaf silage on milk yield and quality in six FPR feeding trials conducted by farmers in Tlekung village of Junrego subdistrict in Batu district of E. Java, in 2006/07.

	Daily milk yield (liters/cow)		
	Before[1)]	During[1)]	Significance
Farm 1	11.25	11.71	0.042
Farm 2	15.33	16.28	0.116
Farm 3	11.41	11.03	0.038
Farm 4	10.86	11.65	0.003
Farm 5	12.86	15.21	0.000
Farm 6	9.23	10.28	0.000
Average	**12.40**	**13.17**	**0.000**
Protein content (%)	3.15	3.58	-
Fat content (%)	3.62	3.71	-

[1)] Before and during the feeding of cassava leaf silage at about 6 kg/head/day in addition to the normal ration of 30-40 kg elephant grass plus 5-8 kg concentrate feed

After conducting the trial, farmers were very enthusiastic about the use of cassava leaf silage as they can probably reduce the amount of expensive feed concentrate. Their main problem, however, is to find enough cassava leaves as cassava growth is slow at the high elevation of nearly 1000 m above sea level where dairy farming is commonly practiced, while cassava leaves are generally available only at time of root harvest, i.e. in Aug-Sept of each year.

4.2.3. Cassava small-scale processing

In order to broaden cassava utilization and marketing, the project succeeded to establish three farmers' agro-enterprise groups, two groups in Jatisari village called "Mekar Sari" and one in Sempol village called "Puji Makur"; the latter with 37 members. The groups, with both male and female members, learned how to make *kripik* and *krupuk* using cassava fresh roots and cassava starch, as well as some other ingredients like maize. They have already produced a recipe book in the Indonesian language for 32 cassava products.

4.3. To Disseminate New Technologies Using Farmer Participatory Extension (FPE) Methodologies.

Although the transfer of selected technologies was not practiced long enough to be clearly evaluated, it can be suggested that the FPR methodology used is appropriate for generating and transferring the production technologies for cassava-based cropping systems. In Malang during the first year there were only three collaborating farmers, but this increased to ten farmers in the second year, and to 16 farmers in the third year. In the third year, 13 of those 16 farmers had already adopted the selected technologies on all of their farm land.

The project ended in 2007, so we could not further evaluate the full results of our work. However, a small survey conducted in February 2009 in Jatikerto, Malang, showed that out of 86 respondents, 56 farmers (65%) planted the variety UB 477-2 and 65 farmers (76%) used cattle manure for their cassava crops. At the beginning of the project, none of the farmers planted UB 477-2, and only seven farmers used cattle manure (Yuniwati *et al.*, 2010).

4.4. To Strengthen Inter-institutional Collaboration and Capacity for FPR in National Institutions.

The ACIAR Cassava Project has provided an opportunity to cassava researchers to meet at least once a year, to learn what others were doing, and to collaborate with each other in the provision of planting material of new varieties, and to share knowledge about improved production techniques, processing or animal feeding

To improve the research capacities of cassava researchers and to broaden the vision of cassava farmers, extension workers, and processors, a training course was held in Batu in East Java. The course was taught by resource persons from Indonesia, Vietnam, and East Timor and from CIAT, and consisted of 5½ days of lectures, demonstrations and field trips; it covered a wide range of topics, such as cassava production techniques, small-scale processing into a variety of products, use of cassava for animal feeding and farmer participatory methodologies for research and extension.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Technology transfer is a long process; therefore, it was difficult to draw a clear conclusion from the three years of activities. However, from our experiences there were some results that can be further explored to produce more reliable conclusions:

1. Several new cassava varieties, such as UJ-3, UJ-5, Malang 6, UB 477-2 and UB ½ were tested in various locations in Indonesia and they seem to be rather widely adapted, while the local varieties Faroka, Markonah, Manggu and Bandung, and the breeding lines CMM 96-36-255 and CMM 99-23-12 seem to be more suitable in particular areas such as in Malang (E. Java), Pati (C. Java), Sukabumi (W. Java), Gunung Kidul (Yogyakarta) and Sukadana (Lampung), respectively.
2. Due to the great variability in soils, climates and end-uses, especially in Java, it is difficult to identify one cassava variety that is well adapted throughout the country. Thus, it may be necessary to develop specific varieties for specific areas and end-uses.
3. In Lampung province where cassava is mainly grown for starch extraction, farmers select varieties mainly based on yield and starch content; in Malang and Pati districts of East and Central Java, respectively, farmers also select mainly on yield, while in Gunung Kidul district of Yogyakarta and Sukabumi district of W. Java farmers consider both yield and eating quality as important selection criteria.
4. In the acid infertile soils of East Lampung the main limiting nutrient for cassava is K followed by P, while in the volcanic ash-derived soils of Malang district the main limiting factor is N, especially if cassava leaves are harvested for animal feeding several times during the growth cycle.
5. With very simple equipment farmers can make several types of cassava-based products at home for sale in order to have some additional income.
6. Cassava leaves are a good source of protein that will increase the live weight gain of sheep and increase the milk yield of dairy cattle if fed in the form of leaf silage.
7. In Indonesia, especially in Java, farm size is very small and farmers tend to be very interested in trying out new varieties or technologies in FPR trials to increase their yields and income.

5.2 Recommendations

1. In Indonesia cassava is starting to play an increasingly more important role as an industrial crop for production of animal feed, starch, starch-based products, such as sorbitol and bio-degradable plastics, as well as bio-ethanol. In addition, cassava can become an important source of foreign exchange by the export of dry chips, starch or ethanol, especially to China, Korea and Japan. Considering the increasing demand for cassava roots for these diverse and rapidly growing markets, the current number of researchers working on cassava, and the funds available for research, are clearly inadequate. For Indonesia to remain competitive on world markets, cassava yields will need to increase further, mainly by breeding new and higher yielding varieties through modern breeding techniques combined with biotechnology. Besides higher yields, the various industries will demand different products, such as high-protein roots for animal feeding, low- or zero-cyanide for processing into food, either low- or high-amylose cassava for different end-uses such as biodegradable plastics, and sugary cassava for

production of ethanol. These specific-quality cassava varieties are being created or discovered at CIAT in Colombia, but they need to be improved for local adaptation by well-trained cassava breeders in Indonesia. Moreover, due to the huge variability in soils and climates there is a lot more to be done in the area of soil fertility management and soil erosion control. While there are currently few important diseases and pests in cassava in SE Asia, these can accidentally be introduced from India, Africa or Latin America. Thus, it is important to have local expertise in the area of cassava disease and pest management and to start incorporating cassava mosaic disease (CMD) resistance into existing high-yielding varieties. Thus, a whole new generation of cassava scientists need to be employed and trained, in order to face the challenge of increasing the productivity of the crop to meet the rapidly increasing demand.

2. While considerable progress has been made in the area of cassava production, little attention has been paid to improving processing efficiency, either by production of more suitable varieties for a particular industry, or by the development of new processes, enzymes etc that will reduce the cost of conversion to value-added products. The area of bio-engineering of cassava-based products needs urgent attention in Indonesia.
3. The long and fruitful collaboration between CIAT and Indonesian cassava researchers has produced some excellent varieties, but neither the personnel nor the funds have been available for more widespread testing, multiplication and distribution of planting material of these varieties. The bottle-neck for the successful establishment of large cassava plantations for production of bio-ethanol – by necessity mainly in the outer islands of Kalimantan, Sulawesi, East Nusa Tenggara and in some underutilized areas of Sumatra – will be the availability of planting material of high-yielding and high-starch varieties. These still need to be tested for local adaptation, and the most suitable varieties, once identified, will need to be multiplied in order to rapidly expand the planted area.

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THE ACIAR CASSAVA PROJECT IN EAST TIMOR

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ABSTRACT

Cassava in East Timor is mainly a food security crop, eaten at times that the family staple food supply of maize or rice has been exhausted, usually in the early part of the wet season before the new maize harvest. While cassava roots are currently used only for human consumption after boiling, there is a large potential to use both cassava roots and leaves for animal feeding, especially for pigs, while in the not-so-distant future there may be a huge potential to produce dry chips and starch, as well as fuel-ethanol, mainly for export to Indonesia and China. Cassava could thus become an excellent vehicle for initiating rural development in East Timor.

An ACIAR-funded project entitled "Enhancing the Adoption of Improved Cassava Production and Utilisation Systems in Indonesia and East Timor" was conducted from Sept 2004 to August 2007; it was coordinated by the CIAT Cassava Office for Asia in Thailand and implemented by colleagues in various institutions in Indonesia and East Timor. In East Timor this included the Ministry of Agriculture, Forestry and Fisheries (MAFF), the Seeds-of-Life Program and the National University of East Timor (UNTL).

The overall goal of the project was to improve food security, protect the soil from degradation and contribute to the alleviation of poverty in Indonesia and East Timor. The general objective was to increase the productivity of cassava-based cropping systems through the widespread adoption of higher yielding cassava varieties and improved cultural practices. This was achieved by conducting collaborative varietal evaluations in experiment stations in four ecologically distinct parts of the country, and through FPR trials conducted with farmers. Farmer field days were also organized at times of harvest to let farmers evaluate and select the best varieties; these field days were sometimes coupled with half-day farmer training courses on cassava production practices and animal feeding. Also, a one-week training course for 50 researchers and extension staff was conducted in January 2006.

The main achievement of this project was the identification of several high-yielding, high-starch and/or good eating varieties, that are suitable for industrial processing, animal feeding or for human consumption. In East Timor the highest yielding varieties were KU 50, Rayong 72, Rayong 5, and Sulawesi, while farmers selected Mentega, Ca 15, Ca 34, Ca 36, Ca 40 and Ca 42 for having good taste.

As part of the project, the Universidad Nacional de Timor Leste (UNTL) collected 73 accessions of local cassava varieties in many districts in East Timor. These were multiplied and characterized in a single row trial, and will be further evaluated for yield, starch content and eating quality. Of these 73 accessions, there are at least 18-20 with distinctly different morphological characteristics. Photo books have been prepared showing the morphological characteristics of the different local as well as introduced varieties.

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OPPORTUNITIES FOR IMPROVING LIVELIHOODS AND INTENSIFYING PRODUCTION BY LINKING SMALLHOLDERS TO CASSAVA AGRO-INDUSTRIES

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ABSTRACT

Cassava has long been an important secondary staple food crop that has improved the food security of resource-poor smallholder farmers in remote upland areas in Southeast Asia. In many largely subsistence-based production systems, farmers rely on cassava as a major component in locally produced feeds for household-based livestock production. Recently, because of strong and competing demands for cassava as feedstock for various domestic and regional agro-industries, and with improved transport and market linkages, cassava has become a cash crop for resource-poor smallholders in many countries in Southeast Asia. Policy makers and development assistance donors now appreciate the role of cassava-based production systems in supporting poverty alleviation for the poor in marginal areas.

This paper characterizes the role of cassava in a range of different production and livelihood systems practiced by smallholders in remote upland areas supported by rural development projects in Guangxi province in southern China, Oudomxay province in northern Laos, and Tuyen Quang and Ha Giang provinces in northern Vietnam. Benefits to smallholders from cassava production varied greatly among sites, largely depending on access to markets. While sales of cassava indirectly through feeding livestock or directly as a cash crop benefited farmers with adequate land holdings and labor resources, resource-poor farmers generally benefited more when proximity to, and effective linkages with, agro-industries allowed them to utilize production and processing by-products to intensify household- or village-based livestock production for further income generation. Integrated crop-livestock systems have potential for improving both profitability and sustainability of cassava production systems, benefiting both producers and processors.

Two new technical assistance projects, implemented by CIAT, CIP, and ICRISAT, together with research partners in Cambodia, China, Laos, and Vietnam, aim to improve linkages between cassava producers and processors, increase sustainable productivity of cassava-based systems, and improve livelihoods of rural smallholders. The objectives, components, and key activities of these two projects are described briefly below.

INTRODUCTION

Cassava is generally recognized as a pro-poor crop. Because it is tolerant of both drought and low fertility soils, it can be grown on marginal lands which are often farmed by the poorest households. Although inputs are required to maintain high levels of productivity, compared to many other crops, investments required to grow cassava are relatively low. Because of its indefinite maturity period, cassava is a flexible crop that can be harvested according to household needs and marketing opportunities (Nguyen Do Anh Tuan and Cuna, 2005).

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Cassava is important to poor smallholders in Asia because of its many important on-farm uses as food and livestock feed, and because it is a feedstock for a wide range of agro-industries. While cassava has long been a major cash crop for upland farmers located close to cassava-based agro-industries, improved trade and transport linkages and the emerging strong and competing demands for cassava as a feedstock for a wider range of domestic and regional agro-industries means that, in addition to its importance for on-farm uses, cassava is now becoming a more important cash crop for poor smallholders even in remote upland areas. The poverty alleviation potential from linking rural smallholders to cassava-based agro-industries is increasingly recognized by government policy makers and international development assistance donors.

The International Fund for Agricultural Development (IFAD) has funded three technical assistance grant projects (**Table 1**) in which CIAT[6] and national and international partners work to bring the fruits of cassava research to improve livelihoods of poor smallholder farmers. One of these projects was recently completed, one is on-going, and one will soon commence. Cassava plays a key role as a catalyst for rural development in each of these projects.

Table 1. IFAD-funded research-for-development projects implemented by CIAT and partners.

Projects	Period	Countries	Major Objectives
Participatory Research for Development in the Uplands (PRDU)	2003-2008	China, Laos, Vietnam	Improve livelihoods of remote upland poor through demand-driven research for development using participatory approaches
Programme for Linking the Poor to Global Markets: Pro-Poor Development of Biofuel Supply Chains (Biofuels)	2007-2010	(cassava component) China, Colombia, Vietnam	Integrate improved cultivars of bio-energy crops into smallholder farming systems while meeting needs for food security and animal feed
Food, Feed, Fuel, and Fibre for a Greener Future (4FGF)	2009-2013	Cambodia, Laos, Vietnam	Improve livelihoods of poor smallholders through integrated crop/livestock systems and develop facilitative linkages to agro-industrial processors

Livelihood Benefits to Smallholders from Cassava – The PRDU Project

The Participatory Research for Development in the Uplands Project (PRDU) was implemented by CIAT and CIP[7] with national research partners and worked with upland

[6] CIAT = Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)

[7] CIP = Centro Internacional de la Papa (International Potato Center)

farmers and local extensionists in focus villages of rural development projects in remote areas of China, Laos, and Vietnam (**Table 2**) to test and adapt technical innovations aimed at improving livelihood systems.

Table 2. PRDU project focus sites.

	IFAD Rural Development Project	Provinces	Focus villages
China	West Guangxi Poverty Alleviation Project	Guangxi (Long An county)	6 in 2 townships: (Nan Xue, Ping Shan)
Lao PDR	Xieng Khouang Agriculture Development Project	Xieng Khouang	5 in 2 districts: (Phaxay, Phou Kout)
	Oudomxay Community Initiatives Support Project	Oudomxay	7 in 3 districts: (Pak Baeng, Houn, La)
Vietnam	Rural Income Diversification Project	Tuyen Quang	5 communes in 3 districts: (Yen Son, Ham Yen, Chiem Hoa)
	Decentralized Project for Rural Poverty Reduction	Ha Giang	2 communes in 2 districts: Quang Binh, Yen Minh

The PRDU project began with no specific focus on cassava and worked with many different crops and production systems. Through various participatory approaches – including problem and opportunity diagnosis, household visioning of livelihood strategies, and household surveys – it became apparent that smallholders at all sites considered intensification of livestock production to be a high priority for increasing incomes and improving their livelihoods. Farmers were especially interested in improving livestock feeding systems by using on-farm feed resources. Root crops, particularly cassava, were an important component in the development of more nutritious and affordable locally-produced feeds in each of the focus villages.

Although each of the focus villages was located in mountainous, marginal upland areas, where access to commercial feeds was difficult or unaffordable, and utilization of locally-produced feed resources was thus important, there were considerable differences in market access and linkages with cassava-based agro-industries among the focus villages. The role of cassava in livelihood systems of focus villages of the rural development projects is described below.

Root Crops for Food Security and Intensified Village Pig Production – steep mountainous region of northern Laos (Oudomxay province)

Growing industrial (high-yielding, high-starch content) cassava varieties and starch processing is new to Laos. Recently, two medium-scale cassava starch processing factories began operation, one near Vientiane and another in Saravanh province. Two more factories are under construction in the relatively flat areas of central and southern Laos. In the more

mountainous northern region of Laos, cassava is grown only in limited areas near the Vietnamese and Chinese borders where traders buy dried chips for export. Prices paid to farmers are low and the market is uncertain. Farmers are reluctant to grow cassava as a cash crop even in villages with good road access.

In steep areas of Oudomxay province in northern Laos, transport is too difficult for market access. The Khamu ethnic minority people living in remote areas are only marginally connected to the cash economy, mostly through collection and sale of non-timber forest products. They have long grown local varieties of cassava and sweetpotatoes in upland rice swidden fields. Both of these secondary staple food crops are important for food security during times of rice deficiency, but they are not traditionally used to feed livestock.

With support from the Nippon Foundation-funded "Integrated Cassava-based Cropping and Livestock Systems Project", the PRDU project introduced seven cassava varieties from Thailand, two eating varieties and five industrial varieties, to farmers in focus villages. Introduced varieties and the local eating variety were multiplied by farmer groups in first-year demonstration variety trials. Provincial and district extension officers were trained in cassava production and livestock feed processing technologies in a course organized with the National Agriculture and Forestry Research Institute (NAFRI) prior to organizing farmer field days in villages during the first harvest. Villagers compared yields, measured starch contents, and evaluated eating quality (**Table 3**) of the local and introduced varieties. They also learned about processing roots and leaves for livestock feeding and silage preparation.

Table 3. Results of first-year cassava variety demonstration trials in Oudomxay, Lao PDR.

Variety	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)	Starch yield relative to local	Eating quality
Rayong 2	18.4	17	3.1	1.3	+++
Rayong 5	17.5	24	4.2	1.8	+
Rayong 60	17.4	19	3.4	1.4	+
Rayong 72	23.4	23	5.5	2.3	++
Rayong 90	16.7	24	3.9	1.6	+
KU 50	20.4	25	5.0	2.1	+
Hanatee	13.0	18	2.4	1.0	+++
Local (Oudomxay red)	13.0	18	2.4	--	+++

Farmers considered Rayong 2 and Hanatee to be better for eating and comparable to the local variety. (The local variety and Hanatee looked and yielded similarly and may, in fact, be identical). Most farmers chose to plant varieties with the highest starch yields (KU 50 and Rayong 72) in second-year household-level variety trials, as they planned to

use those varieties to feed pigs. Rayong 72 was especially popular, as it was both high-yielding and reasonably edible.

Farmers in focus villages used cassava as the primary component in locally-grown rations in demonstration pig feeding trials over a two-year period. In both years, silage and dry feed "concentrates" were fed to pigs in equal amounts (by weight, as fed). In the first year, different dry feed formulations were compared: a "lower nutrition" treatment and a "higher nutrition" treatment. The lower nutrition treatment used easily collected feeds, including the higher-yielding introduced cassava varieties. The higher nutrition treatment contained ingredients that could be, but were not commonly grown, stored, or processed in villages. During the second year, based on results from the previous year and analysis of feed samples by the National Institute for Animal Husbandry in Vietnam (NIAH, 2001; N.T. Tinh, unpublished data) the Life-Sim model (CIP, 2006) was used to try to improve the nutritive value of feed rations by increasing protein and decreasing fiber content. The silage formulation was simplified, using paper mulberry leaves, which are easily gathered from bush fallows or village gardens year-round (**Table 4**). Estimated nutritive composition from the locally produced feeds in the second year approached, but did not fully meet, the Vietnamese standard for cross-bred pigs: Crude protein (CP) = 15% for younger and 12% for older pigs; Crude Fibre (CF) = 6-7%; and metabolizable energy (ME) = 2.9 Kcal/kg of feed (NIAH, 2001).

Table 5 shows pig growth from feed treatments in both years. In the first year, adding maize and soybean flour and stylo leaf meal increased average daily weight gain (ADG) 23% compared to the base ration (lower nutrition treatment). In the second year, the ADG from the stylo protein treatment was comparable to that of the higher nutrition treatment in the first-year trial. The soybean protein treatment (flour made from roasted, ground beans) resulted in a 37% higher ADG compared to the stylo leaf meal treatment.

Even the lower nutrition treatments resulted in a major improvement in pig growth rates compared to the traditional pig feeding practices in Khamu villages. Traditionally, pigs are either completely free-ranging or sometimes semi-confined, and fed rice bran, kitchen wastes, and some collected greens that are cooked. Under these feeding systems, pigs do not reach marketable weight for 2-3 years. Monitored piglets of similar initial size to the trial pigs, raised according to traditional practices, gained only 2.5 kg (free-ranging scavengers) or between 3.8 to 8.5 kg (penned and fed) during the 120 day first-year trial period, which is only between 8 and 28% of growth achieved with the poorer ration.

There is a good market for village pigs and traders visit even the remote villages regularly to buy pigs. Growing improved cassava varieties and other food/feed crops, processing the locally grown feeds, and fattening piglets can transform livestock keepers into livestock producers – a potential livelihood alternative for subsistence farmers. Selling approximately one pig per year for each family member provides enough cash income for purchasing the household's rice requirements. Land area required for growing cassava, sweetpotatoes, maize, stylo, and soybeans to fatten pigs is considerably less than areas required for growing upland rice, thus supporting Lao government policy for reducing land area under shifting cultivation (Fahrney *et al.*, 2007). Diversified cropping systems that

include food/feed crops (cassava, sweetpotatoes, maize, and soybeans) may improve nutrition and food security for people, while helping to maintain soil resources, as well as feeding livestock.

Table 4. Formulations of dry feed and silage during 1st and 2nd year pig feeding trials in Oudomxay, Lao PDR.

	1st year trials		2nd year trials	
Dry feed formulation (% by weight -- as fed)	Lower nutrition	Higher nutrition	Stylo[3)] protein	Soy[4)] protein
rice bran	27.5	25	20	20
cassava root meal	37.5	20	20	20
cassava leaf meal	35	25	25	25
maize flour	--	20	20	20
soybean flour	--	5	--	15
stylo leaf meal [1)]	--	5	15	--
Silage formulation (% fresh weight)	Early season	Late season	Whole period	
cassava root slices	35	35	70	
paper mulberry leaves [2)]	60	--	30	
sweetpotato vines (wilted)	--	60	--	
cassava root meal	5	5	--	
salt (% of total weight)	0.5	0.5	0.5	

[1)] *Stylosanthes guianensis* - young leaves dried and crushed
[2)] *Broussonetia papyrifera* - young leaves wilted and chopped
[3)] Estimated nutritive composition (%): Dry matter (DM) = 88.0, Crude protein (CP) = 10.3, Crude fiber (CF) = 8.8, Metabolizable Energy (ME) = 2.6 Kcal/kg
[4)] Estimated nutritive composition (%): Dry matter (DM) = 88.3, Crude protein (CP) = 14.7, Crude fiber (CF) = 8.0, Metabolizable Energy (ME) = 2.9 Kcal/kg

Growing cassava on sloping lands could cause serious soil erosion and land degradation problems unless adequate controls are practiced. Farmers planted cassava on minimally disturbed land that was cleared of weeds by hand, greatly reducing soil loss. The project encouraged farmers to plant cassava on flatter land areas, where available, and worked with farmers and extensionists to implement various intercropping trials, strip-cropping, and contour hedgerow demonstration trials. Some farmers delayed the harvest of parts of their cassava fields and during harvest field days we discovered that root yields in two-year fields were more than twice the yield from a single-season crop. If two-year cropping was commonly practiced, this would potentially cut soil losses considerably and reduce labor requirements for weeding and land preparation. At harvest, fields of two-year cassava rotations were virtually free of annual weeds, which had been shaded out from over

18 months of dense canopy closure. Two-year cassava with some fertilizer inputs may be a promising and productive rotation for upland rice, a crop that is especially susceptible to weed competition and which otherwise requires bush fallow rotations for 3-4 years for weed control and regeneration of soil fertility.

Table 5. Pig performance from treatments in 1st and 2nd year pig feeding trials in Oudomxay, Lao PDR.

	1st Year trials		2nd Year trials	
Growth indicators[1)]	Lower nutrition	Higher nutrition	Stylo protein	Soy protein
initial weight (kg)	34	38	28	27
final weight (kg)	64	74	63	74
weight gain (kg)	30	36	34	47
days	120	120	117	117
Av. dayly gain (ADG) (g)	246	301	291	398
survival rate (%)	100	100	100	100

[1)] Means of 8 pigs per treatment (4 pigs/treatment from 2 sites, combined)

Cassava for Feeding Livestock and Cash Cropping – Northern mountainous region of Vietnam (Tuyen Quang and Ha Giang provinces)

From participatory diagnosis at the onset of the PRDU Project it was apparent that cassava was an important component in livelihoods systems of most households in focus communes in Tuyen Quang and Ha Giang provinces. The project worked with research partners in the Faculty of Agronomy at Thai Nguyen University of Agriculture and Forestry, extensionists in both provinces, and farmers to implement on-farm demonstration trials (cassava varieties, fertilization, erosion control practices, and intercropping) in Tuyen Quang in 2005-2006 and in Ha Giang in 2006-2007. Training for farmers and extensionists preceded most of the trials. Trial results and planting materials of improved varieties were disseminated during farmer field days at harvest.

The importance and function of cassava in livelihoods was quantified during randomized surveys of households in focus communes during 2007 (**Tables 6-8**). Subsequent focus group discussions with villagers in Hung Duc and Dao Vien communes in Tuyen Quang province and Yen Thanh commune in Ha Giang province, and interviews with processors in the area during 2008 helped to better understand market linkages and prospects for improving livelihoods of cassava growers through market linkages.

Cassava fields were generally small in communes in Tuyen Quang (**Table 6**) where the provincial government worried about soil degradation and so restricted cultivation of

cassava on sloping lands[8]. In Dao Vien commune, authorities allowed the interplanting of cassava during the establishment phase of plantation forests managed by households, temporarily increasing land holdings for cropping.

In Ha Giang province, no restrictions on cassava cultivation were imposed and the population density there is less, so fields in Yen Thanh commune, which borders Ham Yen district in Tuyen Quang, were comparatively larger. In Lao Va Chai commune, located in a steep higher-elevation zone, the cultivated land area is very limited and most non-rice land is planted in maize, the staple food crop.

Table 6. Surveyed households growing cassava and average holdings – PRDU focus communes in Tuyen Quang and Ha Giang provinces.

Province	District	Communes[1)]	Households surveyed	HH growing cassava (%)	Average cassava area (m^2)	% HH > 1 ha[2)]
Tuyen Quang (106 HH)	Yen Son	Dao Vien	28	89	4240	12
		Trung Son	26	81	2800	0
	Ham Yen	Hung Duc	26	62	2170	0
	Chiem Hoa	Tan An	26	77	1450	0
Ha Giang (54 HH)	Quang Binh	Yen Thanh	26	35	5950	44
	Yen Minh	Lao Va Chai	28	46	1480	0

[1)] Percent ethnicity of randomly selected survey respondents in Tuyen Quang communes: Kinh (43), Tay (27), Dao (18), Nung (6), Hmong, Cao Lan, and Hoa (2% each). In Ha Giang, Yen Thanh commune: Tay (54), Pa Then (27), and Hmong (19%); Lao Va Chai commune: Hmong (89) and Nung (11%).

[2)] Percentage of households with cassava land holding greater than one hectare.

Despite the small land holdings, cassava was crucial to livestock production in focus communes and livestock were the greatest source of cash income from farm production, especially for the poorer households. **Table 7** shows household uses of cassava and types of cassava varieties planted in the focus communes. Most households utilized cassava on-farm as livestock feed, especially to feed pigs and poultry, but also for feeding cattle and buffalos, goats, and fish.

Pigs are usually only fed cassava roots. Very few households reported feeding leaves to pigs, though some fed fresh, dried, cooked, and/or ensiled leaves to their pigs. Roots are either sliced and boiled or else chipped and dried, ground, mixed with water, and then cooked. A few households fed dried, ground cassava to pigs without cooking. Ensiling cassava roots and leaves to feed pigs was rare in the focus communes. A separate

[8] In response to concerns about land degradation from cassava cultivation, agronomists from Thai Nguyen University and media specialists from the Tuyen Quang Provincial Extension Center produced an extension video of the erosion control and associated cassava demonstration trials, supported by the PRDU project, which was disseminated to extensionists on VCDs.

CIP project trained advanced farmers to become trainers of improved feeding systems to other farmers, including some in the PRDU project areas in both Tuyen Quang and Ha Giang provinces. Trainings and demonstrations on silage making from cassava roots and leaves, pig feeding, and fish feeding were organized by the PRDU project in Tuyen Quang and Ha Giang.

Table 7. Cassava uses by surveyed households and varieties planted – PRDU focus communes in Tuyen Quang and Ha Giang provinces.

Location		Cassava uses (% of household production)			Cassava varieties (% of area planted)	
Province	Commune	Food (on-farm)	Animal feed (on-farm)	Cash sales (market)	Traditional varieties[1)]	Industrial varieties[2)]
Tuyen Quang	Dao Vien	0	58	43	6	94
	Trung Son	0	60	40	1	99
	Hung Duc	3	65	32	33	67
	Tan An	0	91	8	12	88
Ha Giang	Yen Thanh	9	78	13	28	72
	Lao Va Chai	19	76	5	73	27

[1)] Traditional varieties (good eating qualities): Local (unspecified), Nep, Xanh Vinh Phu, Chuoi.
[2)] Industrial varieties: La Tre, Bac Quang, KM94, KM140, KM98-7, KM21-12

Poultry are fed only roots, mostly dried, although a few households reported feeding fresh roots. Cattle and buffalos are mostly fed dried roots, sometimes cooked. A few households reported feeding fresh roots and fresh leaves, but not dried leaves, to large ruminants. None of the households reported feeding leaves to goats. Most households fed dried and milled roots or ensiled roots without cooking. Fish are mostly fed fresh leaves, though some households reported that they also fed dried roots to their fish.

Cassava was only eaten by households in focus communes in Ha Giang, especially in Lao Va Chai commune, where traditional eating varieties prevail and about half of the households reported consuming cassava as food. Traditional eating varieties are still grown on a fairly high proportion of cassava lands in several of the communes, even though livestock feeding and cash cropping are much more important uses for the crop.

Adoption of industrial varieties was higher in Tuyen Quang communes than in Ha Giang, probably because of the greater exposure to cassava industries and traders in Tuyen Quang over the past decade. Two of the earlier industrial varieties commonly grown in Tuyen Quang, Bac Quang and La Tre (which was reportedly planted on 85, 95, 26, and 36% of the cassava land in Dao Vien, Trung Son, Hung Duc, and Tan An communes), are higher yielding than traditional eating varieties, but have lower starch contents than newer industrial varieties. Higher yielding varieties with high starch contents (KM94, KM98-7, KM140, and KM21-12) were new to the focus communes, introduced to Hung Duc commune in Tuyen Quang in 2005-2006 and to Yen Thanh commune in Ha Giang by

PRDU in 2006-2007, and then by a starch factory in 2007. Adoption of newer industrial varieties with higher starch contents improves livestock productivity per unit of land area and, as a cash crop, could provide higher income to farmers, especially if processors and traders are willing to pay a premium price based on varieties or starch contents. Since several households reported feeding fresh roots and leaves to livestock, the introduction of more productive varieties with high cyanide contents needs to include adequate training on simple feed processing technologies to minimize the danger of HCN toxicity.

Although most cassava grown in the focus communes was fed to livestock on-farm, significant amounts were also sold through various market channels in three of the four communes in Tuyen Quang and in one commune in Ha Giang. Other than the sale of alcohol produced from cassava by one household, cassava was not traded in Lao Va Chai commune.

Villagers sold cassava in various forms (**Table 8**) at local markets for use within the communes, or to external collectors and traders who bought cassava in villages or at the commune market and arranged transport to nearby or distant markets and agro-industries. Dried slices, both thick and thin, were the primary form traded. Households in all of the focus communes in Tuyen Quang reported selling dried cassava. Most households sold thick slices (3-5 cm chunks of peeled roots) that were dried on bamboo trays or iron plate stoves. Some farmers sold fresh roots to other farmers in the commune who specialized in operating drying stoves. Thinner slices (< 1 cm) are of better quality, required for certain uses, and receive a higher price, but they cannot be dried on stoves and are difficult to sun-dry during the normal harvest season, so they are less commonly produced. Thick slices are either sold locally for village livestock feeding or bought by collectors for sale to feed processors in the Red River Delta region, or for export to China for feed or biofuel production. Traders in northern Vietnam generally purchase dry slices made from unpeeled roots.

Table 8. Amounts and form of cassava sold by surveyed households – PRDU focus communes in Tuyen Quang and Ha Giang provinces.

Location		Fresh roots		Dried thin slices		Dried thick slices		Alcohol	
Province	Commune	kg	%	kg	%	kg	%	kg	%
Tuyen Quang	Dao Vien	36,900	40	10,400	11	44,600	49	0	0
	Trung Son	0	0	500	1	33,700	99	0	0
	Hung Duc	20,000	38	2,000	4	31,250	59	0	0
	Tan An	1,500	50	0	0	1,500	50	0	0
Ha Giang	Yen Thanh	700	41	1,000	59	0	0	0	0
	Lao Va Chai	0	0	0	0	0	0	100	100

Fresh roots were sold mostly in Dao Vien and Hung Duc communes in Tuyen Quang, but there was also a developing market in Yen Thanh (Ha Giang). In Dao Vien, traders purchased fresh roots for transport to wet starch producing communes in Hoai Duc district of Hanoi.

In Hung Duc commune, a household-scale wet starch processing enterprise bought fresh roots for local processing, but also collected surplus fresh roots in the commune for transport to a large-scale dry starch factory located in neighboring Yen Bai province. The two brothers that operated the small enterprise (processing 10 tonnes of fresh roots/day) use most of the fiber residues left over from starch extraction and all of the "black starch" (by-product from purification) to feed 60-80 pigs annually. Small amounts of surplus fiber residues were also sold to neighbors for use as feed. They stored wet starch under water in tanks on-farm to sell when the seasonal price for wet starch was high, but when prices were lower and their starch production was not as profitable, they still received a good income from selling pigs based on their reliable supply of low-cost feed.

In Yen Thanh commune, farmers sell fresh roots to a broker in the commune who supplies a large-scale dry starch factory (capacity of 125 tonnes of roots/day at peak) in Lao Cai province. Two commune-scale wet starch processing cooperatives (approximately 20 tonnes of roots/day each) located in nearby Vi Thuong and Tan Trinh communes could also buy fresh roots from Yen Thanh, but the Lao Cai factory extended planting materials to farmers, guaranteed a floor price, and arranged for transport at harvest time, so the farmers sold their fresh roots to the larger factory. Because of difficulties in obtaining adequate supplies of cassava roots, the cooperative in Tan Trinh commune is changing to processing wet starch from canna rhizomes (*Canna edulis*).

All of the processing enterprises reported difficulties in obtaining fresh roots as feedstock for processing and attributed this to the strong demand – and thus high prices paid – for dried cassava. It was not possible to determine what proportion of the dried cassava purchased from focus villages was exported to China, but processors and farmers believed that the export market was the driving force behind the strong market demand. The director of the dry starch factory in Lao Cai province estimated that 40% of the cassava in his factory's intended supply area was sold as dried chips, so they were forced to source feedstock from a wider radius (including Yen Thanh commune).

In addition to problems accessing sufficient quantities of roots (which caused operation below capacity), all of the starch processing enterprises mentioned difficulties accessing good quality fresh roots. Local varieties have lower starch concentrations, which raises processing costs, and starch from local varieties or mixtures is not as white as starch processed exclusively from improved industrial varieties, decreasing the prices paid for their products. All of the processors indicated that they paid a premium of 15-25% for the preferred variety (KM94), but some intermediaries reportedly did not. Unless traders pass the premium on to farmers or the farmers deal directly with the processors, they will only have the higher yield incentive, but not a higher quality incentive for growing preferred varieties.

Even though the dry starch factory in Lao Cai had distributed large quantities of planting materials of an improved variety (KM94) they still needed to buy about 25-35% of their total feedstock as local varieties. Although there is no varietal premium paid for dry cassava, since both the yield and dry matter content of improved varieties is higher than traditional varieties (**Table 9**), farmers growing improved varieties for drying will also benefit. KM94 is attractive to both sellers of fresh and dried cassava. Farmers will have increased incentive to sell fresh roots of preferred varieties and factories could have greater access to those roots only if farmers are sure that intermediaries will pass the varietal premium on to them.

Table 9. Fresh and dry root yields and starch yields of improved varieties compared to the local eating variety – Yen Thanh commune, 2007 trial.

Varieties	Fresh root yield (t/ha)	Dry matter content (%)	Starch content (%)	Dry root yield (t/ha)	Starch yield (t/ha)
Chuoi (local)	16 b	36	24.5	5.7	3.9
KM94	29 a	42	31.9	12.3	9.3
KM98-7	27 a	40	31.0	11.0	8.4
KM140	20 b	40	31.3	7.9	6.3

[1)] Means of 3 replicates followed by different letters are significantly different at $P < 0.05$ (unpublished data: PRDU Project)

In contrast to the household-scale wet starch producer in Hung Duc commune, which utilizes most of the processing wastes directly as a feed resource for income generation, directors of both the large dry starch factory in Lao Cai and the commune-scale wet starch cooperative reported that waste management was a problem.

The factory in Lao Cai sells about 10 tonnes/day of fiber residues to local livestock producers, but there is still a large surplus which causes an odor problem and complaints. Surplus residue is sometimes bagged and sent by train to feed factories, but because the residues are wet and bulky, this is not very profitable. The company experimented with drying residues to decrease bulk before shipment, but energy costs were too high. The factory is currently exploring various "green alternatives" for waste management. The wet starch processing cooperative in Vi Thuong commune gives away fiber residues to neighboring livestock producers. The cooperative wanted to sell residues to livestock producers in nearby lowland areas, but they determined that transport costs were too high.

Fattening Cattle with Forages and Residues from Cassava Starch Factories – Western Guangxi province, southern China

Although Guangxi is the major cassava growing province in China, producing 5,875,000 tonnes of fresh roots on 290,000 hectares (Tian Yinong, 2009, pers. comm.), most cassava is grown in the eastern plains. In the mountainous karst region of western Guangxi, cassava is a minor crop. The Zhuang people in Luan Zheng village (Nanxue township, Long An county) grow one or two crops of rainfed maize as their staple food crop on rocky slopes. Soils are porous and the second maize crop is especially drought-

prone, frequently failing. All villagers in Luan Zheng reported planting cassava. Each household grows an area of approximately 1.25 mu (833 m^2), but cassava is almost always intercropped – with either maize or peanut. Cassava is planted at the same time as the primary crop.

Although some eating varieties are grown as a minor snack food, villagers in Luan Zheng village grow cassava primarily for feeding livestock. Livestock is the main on-farm source of cash income in the village. Until recently, none of the cassava was sold, as holdings were small, yields of traditional varieties were low, and all of the cassava was consumed by livestock. At harvest, roots were chipped, dried, and stored. Dried chips were milled and mixed with other ingredients to feed pigs, goats, and cattle.

During participatory diagnosis, villagers identified low maize yields, lack of forages for feeding cattle and goats, and low-yielding varieties of cassava and soybeans as constraints to productivity. They also wanted to learn about new technologies for feeding livestock, especially pigs.

PRDU Project partners in the Guangxi Subtropical Crops Research Institute and the Long An County Agriculture Bureau worked with township extensionists and farmers to establish on-farm variety trials of maize hybrids, and soybean and cassava varieties in focus villages. Legumes and forage grasses, from the Chinese Academy of Tropical Agricultural Sciences (CATAS) in Hainan and from local sources, were planted in small observation trials. One forage grass, a Napier hybrid called "Guimu 1" (from the Guangxi Forage Research Center), proved to be particularly productive and drought tolerant and farmers adopted it enthusiastically.

Seven high-yielding cassava varieties, most with high starch contents, were planted in comparison with the local variety in a demonstration trial, harvested in 2005. A fertilizer demonstration trial was also planted. During the harvest field day, farmers selected planting materials of varieties for on-farm trials in 2006 (harvested in early 2007). **Table 10** shows fresh root yields and characteristics of cassava varieties harvested in late 2005 and early 2007.

In 2006, villagers and extensionists from Luan Zheng and other focus villages visited the Hong He District Animal Husbandry Station in Yunnan province to learn about various improved feeding technologies using locally grown resources. In early 2007, a livestock feeding specialist from the Hong He station came to Guangxi to give a short training course on improved feeding technologies to farmers in focus villages. The course included silage making and using cassava processing residues.

After the training course, extensionists helped link farmers to nearby cassava starch factories. Although about 60% of the cassava harvested in the village was still sun-dried and stored for use as feed, farmers began selling fresh roots to the factories and buying back fiber residues for feeding livestock in the village. They also began using cassava leaves in their pig feed formulations.

Villagers who owned hand tractors to pull small trailers bought cassava roots from other villagers and sold them at the factories. They then bought fiber residue from the factories and transported it back to the village for their own use and/or for sale to other villagers. As the trade volume increased, drivers of small trucks from outside the village also began the two-way transport of roots and fiber residue. Although fresh roots were only

sold between November and February, residues were available year-round and the quality and price did not vary much seasonally. The average load of residue transported by villagers was about 3 m^3 and it was usually shared by three households.

Table 10. Fresh root yields and characteristics of varieties harvested in 2005 and 2007 – Multiplication trials and on-farm trials (Luan Zheng village).

Varieties	Fresh root yield (t/ha)		Characteristics
	2005	2007	
SC 201	26.5	--	local control, adapted to poor soils
SC 205	37.0	36.5	high yield, high starch content
OMR 36-31-1	35.7	--	high yield, high starch content
Nanzhi 199	32.2	38.4	high yield, high starch content
OMR 36-34-1	30.6	--	high yield
SC 5	29.4	23.5	high yield, high starch content
GR 911	28.1	--	high yield
GR 891	24.0	--	high starch content, good eating quality
SC 8	--	49.3	high yield, high starch content

Villagers reported that one cubic meter of cassava starch residue was enough to feed ten pigs (averaging 50 kg) for one month or one cow for fattening for about two months. Residues were stored in concrete tanks, covered with plastic sheets, where it fermented naturally. Some villagers added yeast to the residue to ensure a good fermentation, but leaves were not added.

For feeding pigs, maize meal, rice bran and greens were added to starch residues at the time of feeding. For feeding cattle, fresh chopped grass (Guimu 1) was added to the starch residue. Cattle were reportedly more selective about the quality of the residues than pigs. Fermented residues were palatable to cattle, but they rejected residues that were beginning to spoil and smelled bad.

The starch residue/forage grass feeding system for fattening cattle was especially popular in Luan Zheng village because crop land holdings for each household were very limited and they were able to use less productive, drought-prone lands on hillsides for growing the forage grass. They bought cattle from other villages and fattened them, usually for 2-3 months, making a profit of about 1000 yuan (USD $150) per head. Some villagers bought very young calves (2 months old) and raised them on the forage/residue ration for about one year before selling.

Villagers who fattened cattle reported that the consequent increased quantities of manure that they applied to their maize fields, combined with the use of improved hybrid maize varieties, increased yields of their spring crop enough to satisfy their annual food requirement for the main staple food. As they no longer needed to plant the more drought-prone autumn maize crop, they planted instead new soybean varieties, for both household

consumption and for sale. Several households also used pig and cattle manure for biogas production before applying the effluent to fields as fertilizer.

Long An county extensionists working with the IFAD project saw the benefits of the forage grass/cassava residue feeding system and mobilized the project's infrastructure development funds to support construction of concrete tanks for storing cassava residues. They also invited extensionists and farmers from three other counties in western Guangxi province to participate in a workshop and field visit to Luan Zheng village so that farmers from other villages could learn about the feeding systems and associated livelihood benefits.

While the residue feeding systems provided livelihood benefits to farmers, it benefited factories through increased sales of a by-product and improved "waste" management. It also provided off-farm employment for service providers, such as truck drivers. We interviewed one driver/trader who claimed to be the only professional starch residue trader in Long An county. He raised pigs commercially for several years by feeding starch wastes and gradually saved enough money to buy a small truck, with a capacity of about 5.5 tonnes of residues per load. He buys only highest quality residues from up to 14 starch factories in the county and delivers it to farmers who place orders by mobile phone from within a 40 km radius. He sells residues for twice the purchase price (currently about 200 yuan or US$ 30/load). He said that this margin is enough to cover transport costs and still make a reasonable profit. He said his customers consider his price to be reasonable and that he has a loyal customer base because of the consistent high quality of the product he delivers, and because he provides helpful information to farmers on feed formulation and livestock management. (He still raises pigs at home and experiments with various feeds, fermentation techniques and silage formulations). He said he was able to ensure consistent high quality by maintaining good relations with middlemen who contract with factories to manage the waste and by selecting only the whiter-colored residues from deep within containment ponds. Even though the factories operate for only a 3-4 month period each year, residues from the deeper areas of containment ponds were preserved through fermentation, so if properly selected, good quality residues were available year-round.

Summary of Cassava Benefits to Poor Smallholder Livelihoods (PRDU Project)

Farmers in each of the focus villages of the PRDU Project gained significant livelihood benefits from growing cassava. The function of cassava in livelihoods and the products consumed or sold were largely dependent on the degree of linkages with markets.

Cassava is an important secondary crop for food security in very remote areas where production of staple food crops is insufficient. Because of its indefinite maturity, cassava is especially flexible as a "food bank".

Livestock are important to poor smallholders, both for subsistence and for sale. They are often the major source of cash income for households, especially in more remote areas. Even where there were no agro-industrial markets, households were still able to derive cash income from growing cassava by processing it into livestock feed and then selling pigs. Cassava was a major component of livestock feed in all of the focus villages. Improved varieties can increase livestock production per unit of land area. Both roots and leaves can be used to improve growth, though the benefits of using cassava leaves is

generally under-appreciated, and balancing locally-produced feed rations is poorly understood.

Increasing demand for cassava by agro-industries is creating opportunities for cash-cropping which is extending into fairly remote rural areas. Villagers who have greater access to cassava agro-industries, either directly by close proximity to factories and processing enterprises or indirectly through traders, are able to sell cassava fresh roots or dried chips for cash income.

Farmers receive more economic and productivity enhancement benefits from cassava when two-way linkages allow them to sell roots to agro-industries and then utilize the processing wastes as livestock feed. Increased animal production increases income and improves stability of livelihood systems through diversification of the household production portfolio. Intensified village livestock production also increases on-farm supplies of manure, a low-cost resource for improving productivity and sustainability, and even for producing energy through biogas.

Recognizing the importance of linkages to emerging agro-industrial markets for improving livelihoods of poor smallholders, IFAD provided funding for CIAT, CIP, and ICRISAT to work with national research partners and agro-industries to implement two new projects which work with smallholders who utilize cassava as feedstock.

Improving Linkages of Smallholder Cassava Farmers to Agro-Industries – The Food, Feed, Fuel, and Fibre for a Greener Future (4FGF) Project

The 4FGF project will be implemented by CIAT and CIP and is expected to commence in early 2009. The purpose of the project is to improve livelihoods of smallholder farmers through integrated crop/livestock systems and sustainable production and utilization of food, feed, fiber, and energy crops, with facilitative linkages to agro-industrial processors. It will build on the experiences and outcomes of the PRDU project.

The 4FGF project will work with national research partners and with extensionists, agro-industries and farmers in or around IFAD-funded development projects in Cambodia, Laos, and Vietnam to integrate multiple components:

sustainable production of cash crops, primarily cassava, and other food/feed crops
agro-industrial processing, by-product utilization, and waste management
livestock production
market development

There are many uses and current or potential markets for cassava (**Table 11**) in countries of the Greater Mekong Subregion (GMS). Cassava has important on-farm uses as both food and feed, especially in remote areas. There is also significant small-scale wet starch production and associated market opportunities for localized production of products derived from wet starch in Cambodia and Vietnam. Large agro-industrial processing markets are currently found in all GMS countries and market opportunities are increasingly reaching smallholders in remote areas. In some cases, linkages with distant large-scale processors provide local processing opportunities like chipping and drying. Cassava-based ethanol distilleries for biofuel production are now operating in Thailand and southern China and the local press regularly reports on emerging operations in Cambodia and Vietnam. As the price of petroleum rises and concerns about the environmental impacts of petroleum-

based industries increase, it is expected that "bio-refineries" will present producers of starch-based crops with new market opportunities (Worldwatch Institute, 2007).

Table 11. Multiple uses, current and potential markets for cassava.

On-farm use	Household consumption of cassava roots for food security
	On-farm feeding of fresh roots for household and village livestock production
	On-farm processing, feed formulation for intensified village livestock production
Local processing	Sales of fresh roots to nearby starch and feed processing factories
	Chipping and drying roots for sale to distant factories or off-season local processing
	Household- and village-scale wet starch extraction enterprises
	Household processing of starch-based foods (noodles, sweets) for local sales
Large agro-industrial markets	Medium and large-scale starch extraction enterprises
	Commercial starch-based food processing factories
	Commercial feed mills
	Bio-ethanol distilleries
	Chemical modification of starches (MSG, sweeteners, sorbitol, bioplastics, etc.)
	"Bio-refineries" for synthesis of multiple, complex products (petroleum replacement)

While the range of higher value products derived from cassava is increasing in the region, it is important to note that increasing value to processors does not necessarily result in increased benefits to smallholder producers that are linked to higher value markets. Benefits to producers can be improved through technical and management innovations that result in mutual producer-processor benefits (such as introduction of higher-yielding varieties, better fertility management, better timing of crop harvests to coincide with periods of factory demand and thus peak prices, introduction of labor saving innovations, etc.) and by utilization of production and processing by-products to improve crop/livestock interactions, increasing smallholder income and diversifying farming systems. Issues of governance and agreements between actors are also key drivers for smallholder benefits. Improving communications between producers and processors can help to achieve win-win outcomes (Wandschneider, 2009).

While larger processors provide an attractive market for both fresh and dried roots, small-scale processing of wet starch is especially attractive for adding value and income for cassava-growing households, because once the fresh roots are sold to local processing enterprises or processed by households, residues are locally available for livestock feeding. Increased availability of manure can provide renewable energy to households, if utilized as biogas, and improve productivity and sustainability of cassava and other crops when utilized as fertilizer – offering farmers a "greener future". By contrast, farmers who grow cassava and sell dried chips for processing by distant agro-industries often receive a price that is too low to afford investment in fertilizers to sustain productivity, and they miss out

on the opportunity to utilize processing wastes which are concentrated at factories and become a pollution problem – perhaps a "blacker future" for farmers, industries, and the environment. **Figure 1** shows how localized wet starch processing can improve crop/livestock interactions and contribute to more eco-efficient production systems.

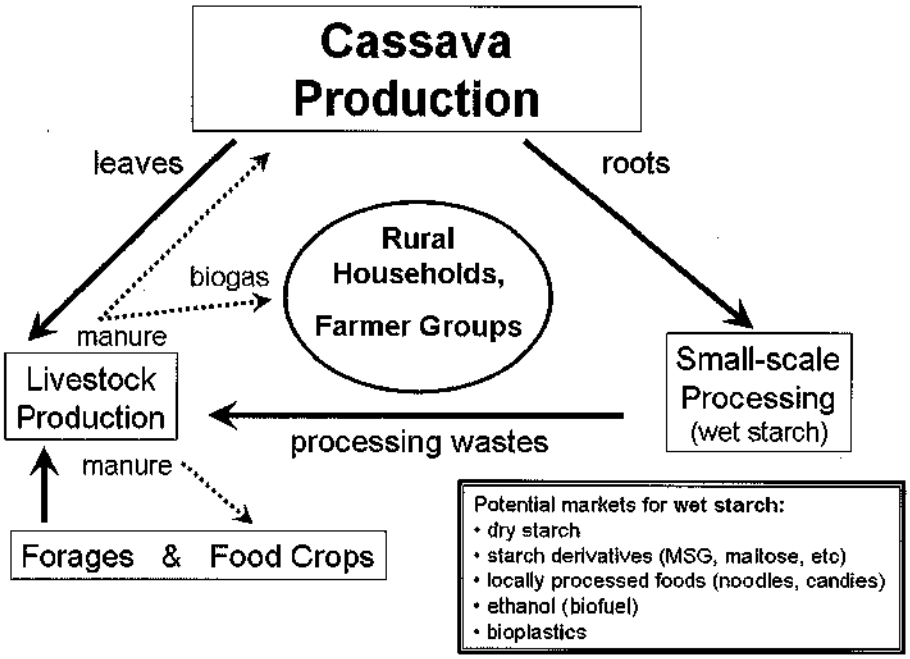

Figure 1. Integrated crop/livestock production systems linked to cassava-based agro-industry (wet starch production model).

Wet starch micro-extraction enterprises can be established with low investment (Nguyen Do Anh Tuan and Cuna, 2005). Simple processing systems are reasonably efficient, with low capital and energy costs, and may be attractive at household-scale. Higher capacity systems operate more efficiently with less labor, but have higher energy requirements (Da *et al.*, 2008). Because they require higher capital investment, higher capacity systems are probably more suited to cooperative processing enterprises.

Locating processing enterprises close to cassava production reduces transport costs of wet starch compared to those of the bulkier and perishable fresh roots. This could lead to lower production costs of feedstock for value-added enterprises. Concerns over waste management and pollution caused by wet starch extractors and downstream enterprises located in peri-urban areas, and the reduced transport costs, could result in increased opportunities for relocating processing enterprises to rural areas.

Value can be added to wet starch by a variety of follow-on processing micro-enterprises, including: wet starch refiners, dry starch producers, maltose producers, noodle, cake, and candy makers, etc. Wet starch is also in demand in Vietnam as a feedstock for larger-scale processors of starch derivatives, such as MSG, glucose, maltodextrin, etc.

Clusters of rural wet starch extraction enterprises could also feed centralized intermediaries (large dry starch producers) or specialized processors (modified starch, bioplastics, ethanol, etc.) located in rural or semi-rural locations.

The 4FGF project will work with extensionists and smallholder cassava farmers in three to five IFAD-funded rural development projects in Cambodia, Laos, and Vietnam to improve productivity and sustainability of cassava cropping systems through various technical innovations. Existing, planned, or potential cassava processing facilities nearby will be identified and their benefits to smallholders assessed. Where local processing enterprises already exist, the project will explore opportunities for improving linkages between producers, intermediaries and processors by facilitating communications that promote mutual benefit. Where market opportunities for cassava products are identified and no local agro-industries currently exist, the project may support farmer groups to establish small-scale processing enterprises and provide training on livestock feeding using production and processing by-products.

Biofuels from Cassava to Improve Livelihoods of Rural Smallholders – CIAT Research on Cassava for Biofuels

CIAT, together with research partners in the Latin American and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA), the Guangxi Subtropical Crops Research Institute (GSCRI), and the Vietnam Cassava Program (VNCP), is implementing the cassava component of an IFAD-funded project, led by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), which will integrate improved cultivars of biofuel crops into smallholder farming systems. The biofuel crops (cassava in Colombia, China, and Vietnam; sweet sorghum in India, the Philippines, and Mali; and jatropha in India and Mali) are expected to provide alternative sources of income, while meeting the needs of rural communities for food security and animal feed.

The cassava component of the Biofuels Project includes the following types of activities: breeding and varietal evaluation; agronomy and crop management; analysis of livelihood systems; assessment of market linkages; models for decentralized bioethanol production; waste management; and, knowledge sharing.

Varietal improvement and evaluation includes both short-term and longer-term objectives and activities. In the short-term, the project will undertake an inventory and evaluation of varieties currently used for ethanol production in pilot sites, evaluate new varieties already developed by CIAT and partners with potential for superior ethanol production, and pre-breed and evaluate materials with novel traits (starch granules with higher surface area for improved enzyme access, "waxy starch" with low or zero amylose, "sugary cassava" with lots of free sugars instead of starch, low cyanogenic varieties, and varieties with delayed post-harvest deterioration) which may increase ethanol yields or improve the economics of processing, or both. After evaluation of new traits, the longer term breeding objective is to incorporate promising new traits into high-yielding, locally adapted varieties, which can be rapidly multiplied and disseminated to smallholder farmers who produce feedstock for ethanol production.

CLAYUCA is developing automated laboratory equipment and procedures for measuring ethanol yield from varieties currently in use, promising breeding lines, and potential pre-breeding lines. These bioreactors will assess fermentation (CO_2 evolution) under controlled conditions, using both the conventional two-step saccharification and fermentation process, which requires heating, and the improved simultaneous hydrolysis and fermentation (SHF) process, which uses enzymes combined with yeast at ambient temperature. After the equipment has been developed and the methodology has been validated at CIAT in Cali, assessment of varieties will begin in Colombia, and then later in China and Vietnam.

While production of feedstock for large-scale cassava-based ethanol factories is expected to provide livelihood benefits to poor smallholders, decentralized processing of ethanol could improve access of rural communities to supplies of renewable energy and provide income and employment to cassava growers and rural ethanol processors. CLAYUCA is developing a prototype pilot bioethanol plant at CIAT (Cali, Colombia) and will test the technical and economic feasibility of decentralized ethanol production and management of wastes and by-products. The pilot plant will utilize flour from dried cassava or dried sweetpotato roots, and juice from sweet sorghum stalks to produce 96% (hydrous) ethanol, which can be used in electrical power generators, vehicles, and cooking stoves. Organic solids in the liquid waste (vinasses) will be precipitated using bio-polymers to clarify water for reuse in processing. Organic solids will be combined with other processing by-products (filtercake, bagasse) and other ingredients to produce concentrated animal feeds or fertilizers.

CONCLUSIONS

Through the range of technologies assessed in these three projects, and through sometimes novel approaches for reaching end-users, be they producers, traders, or processors, we fully expect the existing and emerging opportunities from cassava in the region to have positive impacts on household livelihoods, especially of the rural poor, on rural-based agro-industries, and on national economies through increased production, rural employment opportunities, and reduced environmental problems.

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THE ROLE OF CONTRACT FARMING IN THE DEVELOPMENT OF A COMPETITIVE CASSAVA SUB-SECTOR: INSIGHTS FROM THE CENTRAL HIGHLANDS OF VIETNAM

Tiago S. Wandschneider[1]

ABSTRACT

Cassava is not an obvious choice for contract farming. From the perspective of farmers, the crop is easy to grow, does not require significant input credit and can be sold easily at the time of harvest, either in fresh or dried form. From the perspective of a starch processing firm, fresh roots can be easily purchased at harvest time provided a competitive, market-based price is paid at the factory-gate. However, this analysis does not apply to the off-season months, when starch factories experience acute problems in accessing feedstock and farmers face higher marketing risks. Furthermore, contracts provide a useful framework for promotion of a sustainable supply of fresh roots over the long-term. Given this context, CIAT has been working with a cassava starch factory in the Krong Bong district, Dak Lak province, Central Highlands of Vietnam, to pilot and scale-up long season cultivation models that have the potential to deliver increased profits at the farm level while also generating a more even supply of feedstock within the year and reducing soil losses. If proven successful, such models will make a significant contribution to the development of a competitive cassava sub-sector in Vietnam.

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THE GREAT LAKES CASSAVA INITIATIVE (GLCI): PART OF A LOCAL ANSWER TO CONTINENTAL DISEASE THREATS

Jonathan Schofield[1] and James Legg[2]

ABSTRACT

Cassava is an important staple in sub-Saharan Africa, grown predominantly by women. Up to 300 million people in the region consume the crop's starchy roots and nutritious leaves for at least six months of the year. Cassava Mosaic Disease (CMD) and, more recently, Cassava Brown Streak Disease (CBSD), which are both spread by whitefly and by the movement of diseased planting materials, have devastated cassava production in the Great Lakes Region and thus jeopardized livelihood security of resource-poor households dependent on the crop. In 2005, CMD reduced yields by an average of 47% in pandemic affected areas. Research is on-going to understand these diseases, as are measures to reduce the further spread and mitigate their impacts.

In sub-Saharan Africa the pandemics have been addressed through two projects facilitated by Catholic Relief Services (CRS), in collaboration with the International Institute of Tropical Agriculture (IITA), the National Agricultural Research Systems (NARS) and a broad network of local NGO partners, in which clean material of new highly tolerant varieties have been distributed through a dispersed network of farmer group multipliers.

Considerations for cassava stakeholders from SE Asia include: how to avoid the inadvertent importation of cassava pests and diseases from Latin America, Africa or India, and what can be done now to minimize the impacts should particularly CMD or CBSD arrive. Actions to consider include conducting a risk analysis, raising awareness about the dangers of the importation of diseased material, ensuring the restriction/control of such importation, increasing capacity to recognize, quarantine and eradicate these diseases, developing CMD resistant varieties, and eventually CBSD resistant varieties.

INTRODUCTION

In this paper, we provide the background information on the importance of cassava in sub-Saharan Africa, describe the principle constraints to production, particularly Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD); identify solutions and lessons learned; provide an overview of the Great Lakes Cassava Initiative (GLCI) and its results to date in mitigating the principle constraints to cassava production (including key activities such as identification, multiplication and dissemination of improved disease-tolerant cassava cuttings); and conclude with the next steps for GLCI and considerations for cassava stakeholders in Southeast Asia, including conducting a pest risk analysis of the potential of importing CMD or CBSD into the region, raising public awareness, and taking other actions to prevent and prepare for the arrival of these devastating cassava viruses.

BACKGROUND

Importance of Cassava in Sub-Saharan Africa

Cassava in sub-Saharan (SS) Africa is a livelihood security crop for more than 300 million people in the region, and is the second most important food crop after maize (Nweke *et al.*, 2002). Ninety percent of production is for human consumption and the roots

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and leaves are grown and consumed mainly by the poor. These farm families have very small holdings and generally grow cassava on 0.2 ha or less, which represents 32-80% of total household land-holding.

The production of cassava has increased in importance, tripling in the last four decades (Hillocks *et al.*, 2002). This can be explained as cassava produces even on poor/exhausted soils, in areas of declining and erratic rainfall, and with little management. The latter has proven particularly important in conflict zones. Cassava is a hunger crop that can be harvested plant by plant over an extended period to provide food for the family. To increase and diversify crop production, cassava is commonly intercropped with beans, peanuts, sweetpotato, pigeon pea, or maize. **Figure 1** indicates cassava production in each country, with Nigeria leading followed by the Democratic Republic of Congo (DRC) and Mozambique.

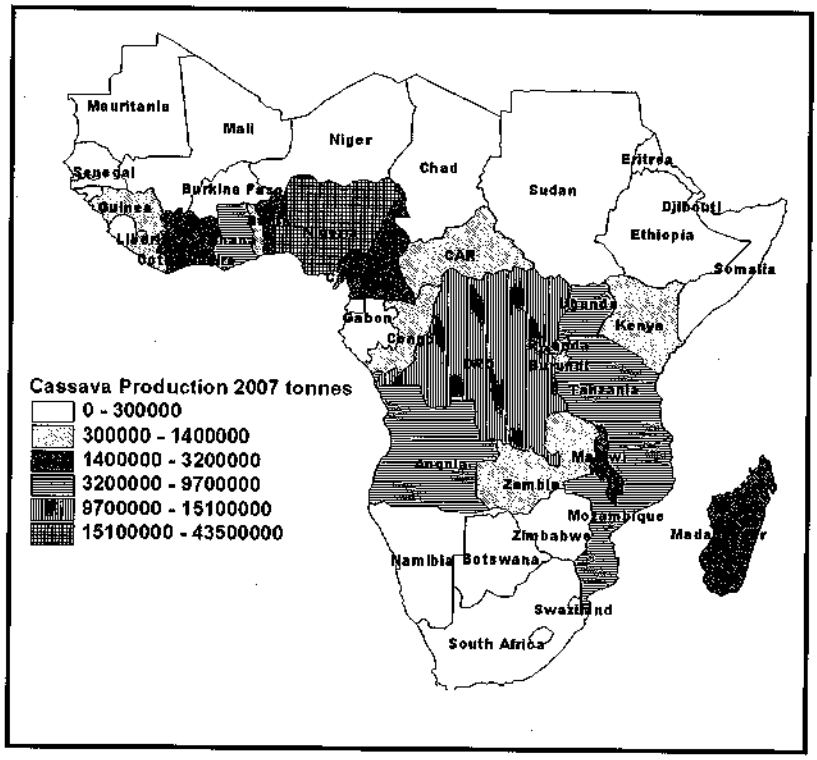

Figure 1. Cassava production (tonnes) in sub-Saharan Africa.
Source: *Unknown, 2007.*

Cassava leaves are often prepared as a sauce in DRC, Burundi and Rwanda, and provide a cheap source of protein and vitamins. Some roots are boiled if sweet and low in HCN, but generally roots are hand-peeled and sun-dried after harvesting; they are then fermented using local processes (in water or under cover) and then milled into flour, which can then be made into a wet dough or dry 'cake' which is eaten with leaf sauces. The final column of **Table 1** underscores the importance of cassava to food security: note the high percentage of calorie intake derived from cassava. Per capita intake is highest in DRC at 73%.

Table 1. Cassava production (fresh roots) and consumption per country in East and Central Africa in 2007.

Country	Area planted (ha)	Production (tonnes)	Yield (t/ha)	Per capita production (kg/year)	Daily intake (g/capita)	% calorie intake derived from cassava
Burundi	82,000	710,000	8.65	134	228	29
DRC[1)]	1,845,510	14,974,470	8.11	435	750	73
Rwanda	116,000	781,640	6.74	113	245	32
Tanzania	660,000	7,000,000	10.61	273	378	22
Kenya	N/A	630,000	-	18.2	N/A	Up to 45*
Uganda	405,000	5,031,000	12.42	300	309	28

[1)] DRC = Democratic Republic of Congo
Source: *FAOSTAT, June 2007*

There has been limited development of value adding beyond cottage-level processing due to limited production and infrastructure (processing equipment, roads, industry). Nigeria is ahead with significant starch and ethanol production.

Constraints to Cassava Production

There are a number of challenges currently limiting cassava productivity to 6-10 t/ha in sub-Saharan Africa. These include diseases, poor quality planting material (often diseased and of low-yielding varieties) low soil fertility and intensive land use, poor crop management, and limited infrastructure for processing and marketing. The result is reduced food and livelihood security across East and Central Africa. Chief amongst these constraints is severe CMD followed by the emerging threat of CBSD.

Cassava Mosaic Disease

The single biggest factor limiting cassava production in East and Central Africa is cassava mosaic disease (CMD). A mild form of this disease has been endemic (first reported in 1894) for more than a hundred years, but with relatively low virulence and yield losses. However, a severe CMD epidemic was first reported in 1989 in Uganda through the emergence of a virulent recombinant strain of Cassava Mosaic Virus (CMV) called the Uganda Variant (CMV-UgV). This strain limits photosynthesis and can result in complete root loss. In 2005, CMD-UgV was affecting more than 3 million square kilometers, leading to average losses of 47% in nine affected countries (Legg *et al.*, 2006). **Table 2** shows CMD associated yield losses in 2005 in six East and Central African countries.

Table 2. CMD-associated yield losses in GLCI target countries in 2005[3].

Country	CMD incidence (%)	Actual production ('000 tonnes)	Estimated loss ('000 tonnes)	Estimated loss (%)
Burundi	61	710	556	44
-DRC pandemic affected areas	*67*	*9,982*	*9,303*	*48*
-DRC pandemic unaffected areas	*34*	*4,991*	*674*	*12*
DRC total	-	*14,973*	*9,977*	*40*
Kenya (Western only)	63	420	349	45
Rwanda	50	782	440	36
-Tanzania pandemic affected areas	*53*	*2,333*	*1,440*	*38*
-Tanzania pandemic unaffected areas	*26*	*4,667*	*467*	*9*
Tanzania total	-	*7,000*	*1,907*	*21*
Uganda (after pandemic recovery)	60	5,500	1,048	16
Total		**29,385**	**14,277**	**33**

Source: *adapted from Legg et al., 2006.*

The viruses causing CMD are carried by the whitefly *Bemisia tabaci* and are transmitted through its feeding activity. CMD-causing viruses are also propagated through the movement of infected cuttings. CMD symptoms are variable according to season and variety, but always include a chlorotic mosaic on infected leaves making them twisted and distorted. The color of chlorosis varies from pale green to whitish yellow. In the severe pandemic type of CMD, heavily infested plants are distorted and stunted. There are no symptoms on the stem or roots. CMD causes a reduction of the foliar area and, as a consequence, a reduction in root tuberization. In resistant varieties, plants may 'recover', a phenomenon in which newly emerging leaves of an infected plant sprout without symptoms.

Yield losses depend on the cultivar, viral strain and environmental factors. If severe CMD emerges in SE Asia, such high level of loss would be devastating to farmers and industry.

CMD is already an important problem in some parts of Asia. It occurs widely in cassava-producing areas of southern India and Sri Lanka where it is caused by the two Asian members of the cassava mosaic geminivirus family, *Indian Cassava Mosaic Virus* (ICMV) and *Sri Lankan Cassava Mosaic Virus* (SLCMV).

Figure 2 indicates CMD severity in East and Central Africa. The data is from a single set of surveys implemented under the Crop Crisis Control Project (C3P) implemented in 2006-2007 by CRS and IITA.

First seen in Uganda, CMD-UgV has been spreading at a rate of up to 100 km per year. The map indicates the extent of spread of the severe CMD pandemic to the south and west. It is likely that the spread will continue southward along Lake Tanganyika. It also appears, however, in other more distant places (e.g. western DRC), which may be due to human transport of diseased cuttings, although there is as yet no direct proof of this.

[3]Losses were estimated at an average of 47% for pandemic affected countries, for further details please see paper by Legg *et al.*, 2006.

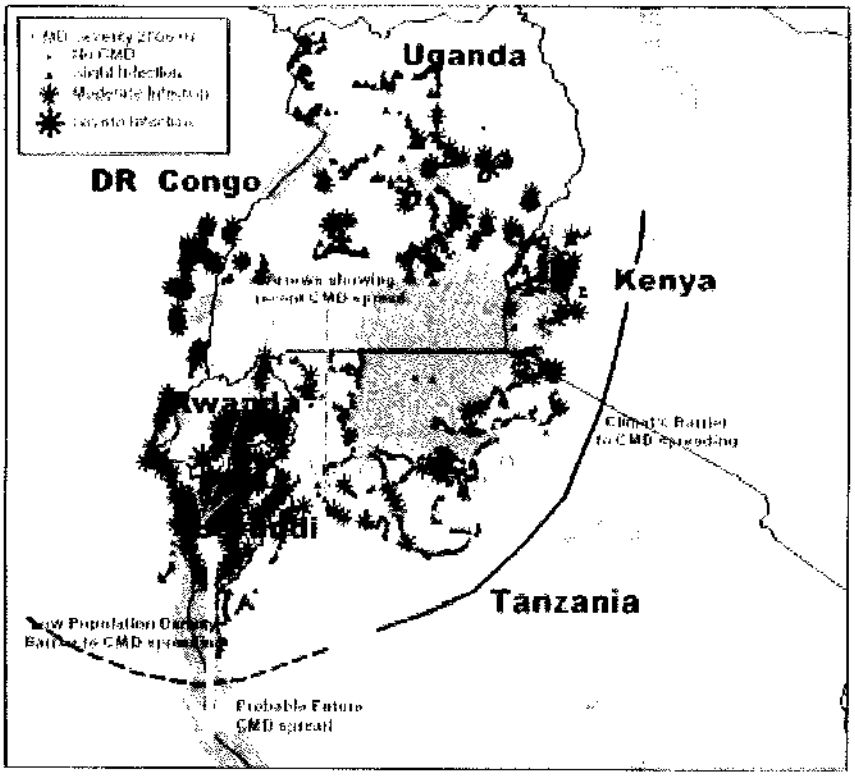

Figure 2. CMD severity in the Great Lakes Region of East and Central Africa in 2006-2007.

To date, the CMD-UgV epidemic has been addressed through the identification of resistance, breeding of resistant varieties and the wide-scale multiplication and dissemination of these resistant varieties. There are two main sources of resistance to CMD. One comes from early breeding work done at the Amani Station, Usambara Mountains, Tanzania, back in the 1940s/50s. Most importantly, they made interspecific crosses with the wild Manihot species *Manihot glaziovii*, and then back-crossed with cultivated cassava (*Manihot esculenta*). That material was taken to Nigeria where it was used by IITA and formed the basis of all the early CMD resistance breeding work. Two important varieties obtained through this were TMS 30572 (officially released as Nase 3 in Uganda) (TMS stands for Tropical Manihot Species).

The second source is derived from local landraces, mainly from West Africa. Many of these were collected by IITA and given the designation TME (Tropical Manihot Esculenta). These varieties tend to have slightly better eating characteristics than TMS varieties, are often more upright, but the resistance is narrower and so more open to being overcome through changes in pathogens.

Lessons Learned to Date from the CMD-UgV Pandemic

The identification, breeding, multiplication and dissemination of resistant variety approach has shown success in Uganda where some 60% of farmers are now growing improved CMD-resistant varieties. Further, planting material schemes have proven successful in making the improved varieties widely available through a combination of primary multiplication under close control of researchers, followed by secondary multiplication in many decentralized sites under moderate quality control of local NGOs, government extension services or private multipliers; and finally, in many small decentralized tertiary sites under individual or farmer group management. Tertiary multiplication is of great importance as it brings the CMD-resistant planting material ("seed") nearer to the farmers (increasing local availability and efficiency resulting in reduced cost of production and losses, and increased awareness). Generally, however, interventions have been retro-active, not pro-active as there have been limited efforts to control the spread. Lastly, interventions have generally not benefited from good coordination of the many actors, and have been hindered by poor quality control (i.e. inadvertent dissemination of diseased cuttings).

Cassava Brown Streak Disease

A more recent threat to cassava productivity is the emergence of Cassava Brown Streak Virus (CBSV). The virus has been endemic in coastal lowlands (<1,000 masl), but in 2004 was reported in south-central Uganda and has since appeared in western Kenya and in the lake zone of northwest Tanzania. Issues of particular concern include the fact that the spread and severity of CBSD is increasing, the spread is erratic, some of the CMD-resistant varieties are highly susceptible, varieties initially thought tolerant of CBSD have subsequently proven to be sensitive, and there is a general lack of basic knowledge and a lack of farmer awareness.

CBSD reduces the quantity and particularly the quality of roots rendering them inedible. Infection is often difficult to recognize as foliar symptoms can be inconspicuous or even absent (latent infection). The most obvious symptom of CBSD is chlorosis (yellowing), expressed along and between the secondary veins, mainly on the lower older leaves (**Figure 3**). This gives a "feathery" appearance which is different from CMD symptoms. Unlike CMD symptoms, most CBSD symptomatic leaves have no or only mild leaf distortions regardless of the amount of chlorosis. There may be dark brown/purplish lesions (streaks) present on the green parts of the stem of severely infected plants. Corky yellow-brown necrosis of tuberous roots can be seen in some plants. In very severely infected plants, roots develop constrictions which can reduce yields. This can be worsened when secondary rots come in, which are commonly soft, and the plant begins to die back, which is indicated by defoliation and stem dieback. Root necrosis accounts for the qualitative reduction in total yield. On susceptible varieties, root necrosis is usually evident by six months. Symptoms vary depending on variety, crop age, and season. CBSV is propagated through infected cuttings, but may also be transmitted by the whitefly *Bemisia tabaci*. Recent research has indicated that there is more than one strain of CBSV.

Figure 3. CBSD on leaves and CBSD on roots, (Photos J. Legg and E. Kanju).

A major problem is that many of the CMD-resistant varieties are susceptible to CBSD. This is likely because one of the two sources of CMD resistance is from West Africa where there is no endemic CBSD (thus no natural tolerance). To date there is no known resistance, only tolerance. Many of the CMD-resistant varieties currently being promoted under GLCI are derived from TMS by TME crosses, so have advantages from both sources of resistance. It has been hypothesized that TMS may offer better resistance to CBSV, since the original parent material came from coastal East Africa, and had been selected for a measure of resistance to CBSV. The converse is true for TME material. Recent work in Uganda, however, has shown that there is lots of variation within TMS/TME crossed materials, and many of these seem to have promising levels of resistance to CBSV (P. Ntawuruhunga, personal communication). Some of these promising clones are currently being virus indexed and multiplied in tissue culture in the hope that they can be shared with CBSD-affected countries in the near future. The identification of robust sources of CBSV resistance is an important priority for future CBSD management initiatives.

The map in **Figure 4** indicates the incidence of CBSD in parts of the Great Lakes region of East and Central Africa. Note that these data is the result of numerous surveys implemented with different objectives and methods. CBSD is also present in Coastal Kenya, Mozambique, Malawi, and western DRC. CBSD data for Uganda are from the Crop Crisis Control Project (C3P), and for Tanzania from the OFDA Project. Data for coastal Tanzania are derived from a 1998 Tropical Whitefly Integrated Pest Management IPM (IPM) Project survey published in Ndunguru *et al.* (2005). All these data are from above-ground symptoms only. This may have resulted in a significant underestimation of the problem.

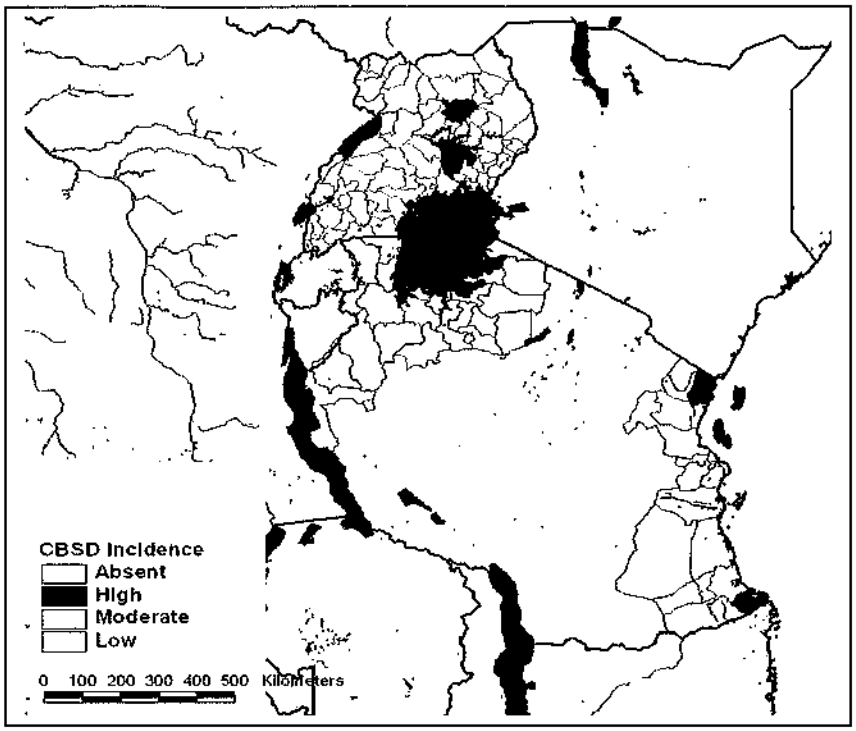

Figure 4. CBSD incidence in GLCI project areas,
Sources: *CRS/ C3P, IITA/OFDA and IITA /Tropical Whitefly IPM surveys*

Actions being taken

A policy was enacted in 2005 to control the movement of cassava germplasm in an effort to limit the spread of diseases through propagation, i.e. it was recommended that germplasm should only move between countries via virus-tested tissue culture plantlets. Efforts have been made to develop diagnostics and to increase surveillance. Investments have been made in research and breeding, sequencing, identifying tolerance and developing tolerant varieties. Training and sensitization of farmers, multiplication and dissemination of improved cuttings, disease recognition and management, field sanitation, use of clean planting materials and quality control in "seed" systems. Efforts have been made to get government buy-in and to enhance coordination between GLCI, FAO, ASARECA, governments and other stakeholders. These areas of work, together with the application of experience from the CMD-pandemic mitigation, are the main areas of focus for the GLCI Project

OVERVIEW OF THE GREAT LAKES CASSAVA INITIATIVE (GLCI)

The Great Lakes Cassava Initiative is a four-year project (Phase 1) which started in December 2007 and built on previous efforts (C3P Project, the OFDA Project, and others) to address constraints to cassava production in six countries in East and Central Africa, namely Burundi, DRC, Kenya, Rwanda, Tanzania and Uganda. The project is led by Catholic Relief Services (CRS) in collaboration with the International Institute for Tropical Agriculture (IITA), the Food and Environment Research Agency (FERA), in the UK, six National Agricultural Research programs, and 53 local Non-Governmental Organizations (NGO).

The principal objectives of the project are (1) to enable >1,150,000 ***farmer families*** to improve their livelihood security by controlling cassava diseases through increased access to improved cuttings and through improved production and marketing; and (2) to strengthen the ***cassava seed system*** so that future shocks can be averted.

The project is organized into five objectives summarized as follows:

- *Partnership and Planning - CRS and partners plan and partner effectively*
  This covers cross cutting issues such as gender and diversity, M&E, and sustainability. It includes coordinating with external partners/other projects such as FAO and ASARECA (Association for Strengthening Agric. Research in East and Central Africa) to increase synergies and avoid duplications.
- *Disease - improved knowledge and disease diagnostics for sustainable management of cassava viruses and vectors*
  Key activities include conducting a pest risk analysis (PRA), testing of all multiplication plots for CBSV, increasing knowledge of cassava viruses and vectors, CBSV whole genome sequencing, investigating vector transmission, developing new diagnostic techniques, ELISA for CBSV, routine and widespread use of RT-PCR, strengthening country capacity to diagnose and control through providing facilities, regional training, country training, using diagnostics to monitor and forecast disease, developing a surveillance system – conducting annual disease surveys and developing a digital early warning network (DEWN), improving disease control through better varieties and quality management, germplasm selection and exchange through tissue culture, developing a quality management protocol (QMP).
- *Training - partner capacity building*
  Key activities include partner capacity building through staffing, infrastructure, transportation, training and performance management.
- *Seed - farmers' access to improved and preferred varieties for production*
  Key activities include the application of QMP to ensure seed quality, raising farmer awareness and demand for new and improved varieties, farmer participatory research - Participatory Variety Selection (PVS) - for farmer selection, demonstration and dissemination of improved disease-tolerant varieties.
- *Farmer Groups - cassava production scaled up through farmer groups*
  Farmer groups facilitate all components of GLCI (seed multiplication/dissemination, disease monitoring, training, production). Groups serve as the community entry point for trainings, seed multiplication and dissemination. Prepare farmers for marketing of cassava products (cuttings, roots, processed products). Farmer participatory research on integrated crop management practices (ICM). Issues for ICM trials: fertilization -

types, rates and timing of application; weed management - how many times to weed and when; planting dates; intercropping - combinations, spacing and timing; erosion control (Burundi and Rwanda), etc.

This objective also facilitates development of internal savings and lending communities (SILC) – small groups who self-select, who mobilize their financial resources internally and lend it out to one another with interest. This builds financial management skills and assets, builds confidence and leads to entrepreneurship, sustainability and gearing up for further activities.

RESULTS TO DATE OF GLCI

Comments on cumulative results to date (see Table 3)

Disease

Two seasons of CBSV testing in multiplication sites have been completed, and the much lower levels of infection in year-2 compared to year-1 indicate that much progress has been made in improving the health status of project multiplication sites. Testing and Quality Management Protocol (QMP) standards have been developed for each of the stages of cassava variety multiplication, from primary to tertiary, and these are to be fully implemented during the second half of the project. Comprehensive surveys conducted by NARS in all target countries are providing information that is helping to guide the implementation of QMP and testing work, as well as site identification for new multiplication fields. NARS' capacity to diagnose cassava viruses has been strengthened both through training courses as well as through the procurement of essential laboratory equipment. Community-based disease monitoring systems are being developed under the DEWN initiative at a pilot level in Tanzania. Feedback has been poor from some of the participating districts, but the project will address this by developing a link with the Bill and Melinda Gates Foundation-funded (BMGF) Voice of the Farmer Project, which will allow much more interaction with rural communities through voice and SMS communication.

Seed dissemination

This is progressing well in all countries except in Tanzania which has been hampered by severe disease infections, particularly in the Lake Zone, and by limited CRS and partner capacity in the Coastal Zone. While Uganda has met targets to date, there are likely to be difficulties moving forward due to high disease pressure, limited availability of clean planting material and dependence on a single variety. There may thus be a need to shift some targets from Tanzania and Uganda to other countries. Efforts have been made to emphasize and ensure, across the board, adequate documentation of seed dissemination at partner level. Emphasis has also been placed on ensuring that the QMP is used to supply only disease-free seed.

Seed multiplication

Overall the project is ahead in seed multiplication and is thus well positioned to achieve the project dissemination targets. As noted above, however, CBSV is limiting the availability of clean planting material in the lake and coastal zones of Tanzania. Similarly,

while Uganda has established a large acreage of seed multiplication, large losses may be experienced.

Participatory Variety Selection (PVS)

There have been relatively high loss rates of PVS sites (theft, abandonment, drought, goats). This is partly due to a quick start up to get trials underway and the limited- or non-involvement of our local NGO partners. Despite these difficulties, year one trials have enabled the identification of varieties to enter multiplication in each participating country. Local NGO partners are now being trained and involved by the NARS to improve farmer participation and ownership of the trials. There is a need to 'fast track' varieties showing tolerance to CBSV and resistance to CMD into PVS trials and seed multiplication.

Table 3. GLCI cumulative results against cumulative targets (years one and two of the project).

	Seed dissemination		Seed multiplication (2009 only)		Farmer groups multiplying seed		SILC groups		PVS trials		ICM trials	
Country	Achieved (farmers served)	Targeted	Achieved (ha)	Targeted (ha)	Achieved	Targeted	Achieved	Targeted	Achieved	Targeted	Achieved	Targeted
Burundi	44,142	28,773	123	105	210	266	4	133	10	30	0	30
Kenya	12,954	8,547	114	36	142	84	67	42	24	30	4	30
DRC	141,765	70,412	227	212	377	312	135	156	43	90	31	90
TZ coast	2,901	63,743	97	182	100	237	5	119	22	30	1	30
TZ lake	33,526	63,744	184	182	264	237	68	118	43	30	4	30
Rwanda	56,356	21,974	78	86	214	219	133	110	52	30	0	30
Uganda	18,782	17,902	139	61	208	168	112	84	0	30	0	30
Totals	310,426	275,095	962	864	1,515	1,523	524	762	194	270	40	270

Integrated Crop Management (ICM)

Initially a limited number of on-station agronomic trials were planted. Only DRC and Kenya established farmer participatory trials in 2009. During the year, however, a strategic partnership with CIALCA (operating in French-speaking countries) was established, which is enabling GLCI to begin taking their results to scale, where appropriate, through a revised multiplication protocol at tertiary level. All countries are establishing farmer participatory ICM trials in 2010.

Farmer groups

Participation of farmer groups in the project is progressing well generally, but is a bit behind in Burundi and in coastal Tanzania. Burundi initially focused purely on seed multiplication but is now progressing with farmer group participation and strengthening as

well. Progress has been slow in coastal Tanzania as this is a new operational area for CRS-TZ, and because there has been a gap in staffing. Farmer group training should pick up considerably in years 3 and 4 as partner staffs are now in place, and appropriate training materials have been developed and are being disseminated.

Internal Savings and Lending Communities (SILC)

Progressed well initially in Rwanda, Uganda and DRC and made significant progress in 2009. Despite having existing CRS country program experience, SILC is slow to develop in Burundi, Kenya and Tanzania. There is thus a need to kick-start SILC in these countries and/or shift some targets to other countries.

CONCLUSIONS AND IMPLICATIONS FOR SOUTH-EAST ASIA

Two years into the project and with two years remaining, future efforts will include: (1) to continue to learn more about CBSD, particularly its epidemiology, and to develop reliable, inexpensive diagnostics; (2) to monitor the movement of the diseases; (3) to ensure the identification of dual CMD- and CBSD-resistant varieties; (4) to speed up multiplication and dissemination of CMD-resistant and CBSD-tolerant varieties; (5) to consolidate farmer group strengthening activities; and (6) to rigorously assess progress and prepare for phase II.

Given the importance of cassava as a cash crop and a raw material for various industries in SE Asia (animal feed, starch and bio-fuel) and the devastating impacts of these viruses on cassava production in Africa, it is important for stakeholders to be pro-active in preventing and preparing for the inadvertent import of these diseases into SE Asia.

To these ends, actions to consider include conducting a pest risk analysis (PRA), a public education/awareness campaign, controlling the movement of planting materials, and breeding for resistance to CMD and eventually CBSD.

Conducting a PRA and sharing the results with local authorities would show them the potential ramifications of not doing anything by addressing the following questions: are CMD and/or CBSD of quarantine concern? What is the probability of pest entry (e.g. a travelling businessman carries a diseased cassava stake – or a 'carrier', e.g. Jatropha), establishment, and spread, and what are their potential economic consequences? What are the management options for reducing the risks identified, such as evaluating for efficacy, feasibility and impact in order to select those that are most appropriate? (Smith *et al.*, 2008)

Key issues to address in a public awareness raising campaign might include the following:

- Don't import planting material of cassava or of known host plants of cassava diseases
- Increase capacity to identify these diseases

Other preparatory activities might include increasing capacity for rapid response to quarantine and eradicate; and to import or develop tolerant/resistant varieties.

To mitigate the threats of these diseases, it is important to act now to prevent CMD, to start introducing sources of CMD resistance, or make crosses at CIAT between promising local varieties and the source of CMD resistance, to use marker assisted breeding

techniques, and introduce those to SE Asia. The same should be done for CBSD once a good source of resistance has been identified.

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THREE MAJOR CASSAVA PESTS IN LATIN AMERICA, AFRICA AND ASIA

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ABSTRACT

The origin of cassava (Euphorbiaceae: *Manihot esculenta* Crantz) is in the Neotropical Americas, where it is estimated that domestication occurred some 7,000 to 9,000 years ago. The greatest diversity of arthropod pests attacking the crop is from this region. An estimated 200 species have been reported, many of which are specific to cassava. The pest complex varies greatly between the main cassava growing regions, indicating that careful quarantine measures could prevent pest introductions into uninfested areas. The accidental introduction of the cassava green mite (CGM: (*Mononychellus tanajoa*) and the cassava mealybug (*Phenacoccus manihoti)* from the Americas into Africa has caused devastating damage on that continent. In Asia, until recently, none of the major Neotropical cassava pests have become established, although severe infestations of red spider mites (*Tetranychus sp.*), white flies, mealybugs and white grubs are observed occasionally or tend to be localized. Agronomic characteristics such as vegetative propagation, a long growth cycle, drought tolerance, staggered planting dates and intercropping contribute to the considerable diversity of pests that feed on the crop.

The cassava pest complex can be divided into two groups: (1) those that have probably co-evolved with cassava, which is their primary or only host; and (2) generalist feeders that may attack the cassava crop sporadically or opportunistically and are often limited in geographic distribution. The first group includes the *Mononychellus* mite complex, mealybugs (*P. herreni* and *P. manihoti*) the hornworm *Erinnyis ello*, lacebugs, whiteflies, stemborers, fruitflies, shootflies, scales, thrips and gallmidges. The generalist feeders include several *Tetranychus* mite species, certain whitefly species (*Bemisia tabaci* and others) a complex of white grub species, termites, cutworms, grasshoppers, leaf-cutting ants, burrowing bugs, crickets, stemborers and others.

The most serious pests of cassava – those causing economic damage or yield loss – are generally those that have co-evolved with the crop, including mites, hornworms, whiteflies, mealybugs, lace bugs and stemborers. Generalist feeders reported causing yield losses, often on a localized basis, include *Tetranychus* (red-spider) mites, burrower bugs, white grubs, leaf-cutting ants, grasshoppers and whiteflies. Most cassava arthropod pests cause indirect plant damage given that they are foliage feeders or stemborers, reducing leaf area, leaf life or photosynthetic rate. Few cassava pests damage the roots directly. Three exceptions are white grubs, burrower bugs (*Cyrtomenus bergi*) and root mealybugs (e.g. *Pseudococcus mandio*). White grubs have been found feeding directly on cassava roots causing yield loss and severe root rot.

In general, arthropod pests are more damaging during the dry season, being less severe in areas of considerable and constant rainfall; however, there are exceptions to this rule. Hornworm and whitefly attacks often coincide with the rainy season when there is considerable new growth with young succulent leaves. Studies have also shown that burrower bugs and white grubs prefer soil with higher soil moisture content. Climate change predictions indicate that certain agricultural lands may receive less rainfall in the future. The cassava crop may have a comparative advantage in these extended seasonally drier regions; however, this could result in severer pest outbreaks that will reduce yield, or increase pesticide use. Yield losses due to mites ranged from 21-80% depending on length of attack, varietal susceptibility and region. A 1-, 6- and 11-month whitefly attack resulted in a 5, 42 and 79% yield loss in Colombia, respectively. Mealybug attacks in Brazil and Africa resulted in yield losses as high as 80%. Stemborer attacks in Colombia led to a 45-62% yield loss when stem breakage exceeded 35%.

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A successful cassava pest management strategy minimizes or prevents chemical pesticide use and concentrates on the implementation of host plant resistance, biological control and appropriate cultural control practices. With the increased emphasis on large-scale plantations, where the cassava crop has a high commercial value, there is a tendency to apply pesticides when noticeable crop damage occurs. This should be avoided and only used as a measure of last resort. Pests that induce pesticide applications include whiteflies, mites, white grubs, hornworms, mealybugs, burrower bugs and thrips.

CIAT maintains a large germplasm bank that offers entomologists and breeders a potential pool for pest resistance genes. Moderate levels of resistance have been identified for cassava mites, but only low levels to the mealybug. High levels of resistance have been found in *M. esculenta* genotypes for whiteflies and thrips and this resistance has been incorporated in commercially released cultivars. In addition, high levels of resistance to whiteflies, mites and mealybugs have been identified in accessions (genotypes) of wild *Manihot* species (Carabalí et. al 2009). Interspecific crosses with *M. esculenta* have been made with the objective to introduce this resistance into commercial cultivars.

Biological control agents have been identified for many of the cassava arthropod pests but their efficacy in controlling pests in field plantations is not well documented. Classical biological control has been successful in Africa against two introduced pests from the Americas; the cassava mealybug (*P. manihoti*) and green mite (*M. tanajoa*). The mealybug *P. herreni* was successfully controlled in northeast Brazil with the introduction of parasitoids from Colombia. The use of fungal, viral and bacterial entomopathogens has shown a potential for control of several cassava pests, including whiteflies, hornworms, white grubs and burrower bugs.

Traditional farmers in many cassava-growing regions have relied on an array of cultural practices that can reduce pest populations. Intercropping has been shown to reduce populations and damage of whiteflies, hornworm, burrower bugs and stemborers. Additional cultural practices that can reduce pest populations include the selection of pest-free planting materials (scales, mites, mealybugs and stemborers), the use of varietal mixtures, destruction (burning) of plant debris (stemborers, scales), crop rotation and changed planting dates.

Quarantine measures to prevent the movement of pests, especially into Africa and Asia, are an important issue and strict regulations need to be enforced to prevent the introduction of important cassava pests into noninfested areas. Cassava pests, through the movement of vegetative planting materials, have shown the ability to disseminate great distances as evidenced by the introduction of the mite and mealybug into Africa from the Americas. There are several additional pests that could cause severe crop losses if introduced into Asia or Africa. These include several mite species, lacebugs, mealybugs, several whitefly species, stemborers, hornworm, burrower bugs and thrips. Moreover, what may be considered a secondary pest in the Neotropics could become a major pest outside its center of origin, as evidenced by the mealybug, *P. manihoti*. Vegetative materials should be introduced into a country only through tissue culture and initially grown under quarantined conditions to assure that they are free of arthropod pests and pathogens.

INTRODUCTION

Given that cassava originated in the Neotropics (the Americas), the greatest diversity of arthropods reported attacking the crop is from these regions. More than 200 species have been reported (**Table 1**), many of which are specific to cassava and have adapted in varying degrees to the array of natural biochemical defenses in the host, which include laticifers and cyanogenic compounds.

The pest complex varies greatly among the major cassava-growing areas in the Americas, Africa and Asia. The crop, whose origin is in South America (Allem, 2002), was introduced into Africa in the 1500s and into Asia in the seventeenth century. In Asia,

until recently, none of the major Neotropical pests has become established. Native arthropods that have adapted to cassava have not been reported as causing serious economic damage. However, recent surveys in Thailand indicate that pest species, originally from the neotropics may be causing crop losses. The whitefly species, *Aleurodicus dispersus*, and the mealybug, *Phenacoccus manihoti*, were observed in moderate to high populations in cassava fields (Bellotti, personal observations). In Africa, the whitefly (*Bemisia tabaci*) is presently considered to be the major pest of cassava because it is the vector of cassava mosaic disease (CMD) (Calvert and Thresh, 2002). Moreover, recent reports indicate that *B. tabaci* is also causing root yield reductions due to direct feeding on the crop. There is also the possibility of the accidental introduction of pests via planting material, which can wreck havoc. The cassava green mite (CGM: *Mononychellus tanajoa* and the cassava mealybug (*Phenacoccus manihoti*), which were introduced from South America, have caused considerable crop losses and have been the target of massive biological control efforts in Africa (Bellotti *et al.*, 1999; Neunschwander, 2004).

Overview of the Cassava Arthropod Pest Complex and Crop Damage

Studies indicate that several arthropod species can cause considerable yield loss and that the pest complex is not geographically uniform. Two cassava mealybug species offer an example of the geographic influence on crop damage. *Phenacoccus herreni*, which has caused considerable damage in northeast Brazil, was probably introduced from northern South America (Venezuela or Colombia), where mealybug populations are controlled by natural enemies not found in Brazil. *P. manihoti*, which has caused severe crop damage in Africa, had, until recently, been reported only from Paraguay, the Mato Grosso area of Brazil and the Santa Cruz area of Bolivia. In 2005, this species was collected from the states of Bahia and Pernambuco in Northeast Brazil. The spread of *P. manihoti* into the drier, hotter regions of Brazil is probably associated with the movement of cassava planting material (i.e., stem cuttings) from southern Brazil into the Northeast.

The cassava pest complex can be divided into two groups: (i) those that have probably co-evolved with cassava, which is their primary or only host; and (ii) generalist feeders that may attack the cassava crop sporadically or opportunistically and are often limited in geographic distribution **(Table 1)**. The first group includes the *Mononychellus* mite complex, mealybugs, the hornworm *Erinnyis ello*, lacebugs, whiteflies, stemborers, fruitflies, shootflies, scales, thrips and gall midges. The generalist feeders consist mainly of a complex of white grub species, termites, cutworms, grasshoppers, leaf-cutting ants, burrower bugs, crickets, *Tetranychus* mite species and other stemborers and mealybug species (Bellotti, 2008).

The most serious pests of cassava—those causing economic damage or yield losses—are generally those that have co-evolved with the crop, including mites, hornworms, whiteflies, mealybugs, lacebugs and stemborers. Generalist feeders reported causing yield losses, often on a localized basis, include burrower bugs, white grubs, leaf-cutting ants and grasshoppers.

Table 1. Global distribution of cassava arthropod pests.

Arthropod pest	Major species	Americas	Africa	Asia
Whiteflies	*Aleurotrachelus socialis*	x		
	Aleurothrixus aepim	x		
	Aleurodicus dispersus	x	x	x
	Aleurodicus flavus	x		
	Aleuronudus sp.	x		
	Bemisia afer		x	x
	Bemisia tuberculata	x		
	Bemisia tabaci	x	x	x
	Paraleyrodes sp.	x		
	Tetraleurodes sp.	x		
	Trialeurodes vaporariorum	x		
	Trialeurodes variabilis	x		
Mealybugs	*Dysmicoccus sp.*	x		
	Ferrisia virgata(2)	x	x	x
	Maconellicoccus hirsutus(1)			x
	Phenacoccus madeirensis	x		x
	Phenacoccus manihoti	x	x	
	Phenacoccus herreni	x		
	Pseudococcus jackbeardsleyi	x		x
	Pseudococcus adonidum		x	
	Phenacoccus longispinus(1)			x
	Pseudococcus elisae(1) (8) (9)			x
Root mealybugs	*Pseudococcus mandio*	x		
	Planococcus citri (3)		x	
	Protortonia navesi	x		
	Stictococcus vayssierei		x	
Mites	*Allonychus brasiliensis*	x		
	Allonychus littoralis	x		
	Allonychus reisi	x		
	Aponychus schultzi	x		
	Atrichoproctus uncinatus	x		
	Eotetranychus falcatus		x	
	Eutetranychus africanus		x	x
	Eutetranychus banksi Eutetranychus	x		
	cratis			x
	Eutetranychus enodes Eutetranychus		x	
	orientalis		x	x
	Mononychellus bondari	x		
	Mononychellus progresivus	x	x	
	Mononychellus caribbeanae	x		
	Mononychellus chemosetosus	x		
	Mononychellus manihoti	x		
	Mononychellus mcgregori	x		x
	Mononychellus planki	x		
	Mononychellus tanajoa	x	x	
	Oligonychus peruvianus	x		

Table 1. Continued

Arthropod pest	Major species	Americas	Africa	Asia
	Oligonychus gossypii (7)	x	x	
	Oligonychus coffeae	x	x	
	Oligonychus grypus	x		
	Oligonychus biharensis		x	x
	Oligonychus mcgregori	x		
	Oligonychus thelytokus		x	x
	Oligonychus yothersi	x		
	Petrobia uncata	x		
	Tetranychus amicus Tetranychus		x	
	bellottii			x
	Tetranychus desertorum Tetranychus	x		
	escolasticae Tetranychus gloveri	x		
	Tetranychus urticae	x		
		x	x	x
	Tetranychus bastosi	x		
	Tetranychus incestificus			x
	Tetranychus kanzawai	x		x
	Tetranychus lambi			x
	Tetranychus lombardini		x	
	Tetranychus ludeni	x		
	Tetranychus marianae			x
	Tetranychus mexicanus	x		
	Tetranychus neocaledonicus	x	x	x
	Tetranychus paschoali	x		
	Tetranychus piercei			x
	Tetranychus sayedi		x	x
	Tetranychus tumidus	x		
	Tetranychus truncatus			x
	Tetranychus yusti	x		x
Scale insects	*Aonidomytilus albus*(4)	x	x	x
	Ceroplastes sp.	x		
	Coccus viridis		x	
	Eurhizococcus sp.	x		
	Hemiberlesia sp.	x		
	Mytilaspis dispar		x	
	Monophebus sp.	x		
	Parasaissetia nigra (2)	x	x	x
	Pinnaspis minor	x		
	Saissetia coffeae		x	
	Saissetia miranda	x	x	x
	Saissetia hemisphaerica		x	
White grubs	*Anomala obsoleta*	x		
	Euchlora viridis		x	
	Euchlora pulchripes		x	
	Heteronychus plebejus		x	
	Lepidiota stigma			x
	Phyllophaga menetriesi	x		

Table 1. Continued

Arthropod pest	Major species	Americas	Africa	Asia
	Phyllophaga obsoleta	x		
	Phyllophaga sneblei	x		
	Leucopholis rorida			x
	Phyllophaga bicolor	x		
	Lepidiota stigma (9)			x
	Aserica sp.			x
	Holotrichia sp.			x
Termites	*Heterotermes tenuis*	x		
	Coptotermes paradoxis		x	
	Coptotermes spp.	x	x	x
Thrips	*Ayyaria chetophora* (1)			x
	Caliothrips masculinus	x		
	Corynothrips stenopterus	x		
	Elaphrothrips denticollis(1)			x
	Frankliniella williamsi	x	x	x
	Nesothrips lativentris(1)			x
	Retithrips syriacus			x
	Scirtothrips manihoti	x		
	Scoloptrips sp.	x		
Leafhoppers	*Empoasca bispinata*	x		
	Scaphytopius fuliginosus	x		
	Scaphytopius marginelineatus	x		
Grasshoppers	*Zonocerus elegans*		x	
	Gryllotalpa africana		x	
	Gryllotalpa sp.	x		
	Gryllus assimilis	x	x	
	Zonocerus variegatus		x	
Leaf-cutter ants	*Atta sexdens*	x		
	Atta cephalotes	x		
	Acromyrmex landolti	x		
Shootflies	*Neosilva perezi*	x		
	Lonchae chalibea	x		
	Silva pendula	x		
Fruitflies	*Anastrepha pickeli*	x		
	Anastrepha manihoti	x		
Stemborers	*Chilomima clarkei*	x		
	Chilozela bifilalis	x		
	Coelosternus alternans			
	Coleosternus granicollis	x		
	Coelosternus manihoti	x	x	
	Coelosternus notatices	x		
	Coelosternus tarpides	x		
	Coelosternus rugicollis	x		
	Eubolus sp.	x		
	Eulecriops manihoti	x		
	Lagocheirus araneiformis	x		
	Lagocheirus obsoletus	x		x

Table 1. Continued

Arthropod pest	Major species	Americas	Africa	Asia
	Lagocheirus rogersi	x		
	Lagocheirus sp.		x	x
	Dorysthenes buqueti (9)			x
	Sinoxylon brassai		x	
	Heterobosthrychus brunneus		x	
Lacebugs	*Vatiga illudens*	x		
	Vatiga. manihotae	x		
	Vatiga lunulata	x		
	Amblystira machalana	x		
Burrower bugs	*Cyrtomenus bergi*	x		
	Pangaeus piceatus	x		
	Tominotus communis	x		
Hornworm	*Erinnyis ello*	x		
	Erinnyis alope	x		
Tiger moth	*Phoenicoprocta sanguinea*	x		
	Agrotis ipsilon	x		
Army worm	*Spodoptera frugiperda*	x		
	Spodoptera eridania (6)	x		
	Spodoptera sunia	x		
Gall midge	*Iatrophobia brasiliensis*	x		
Pests of dried cassava	*Aeracerus fasciculatus*	x	x	x
	Lasioderma serricorne	x	x	x
	Rhyzopertha dominica	x	x	x
	Tribolium castaneum	x	x	x
	Sitophilus oryza	x		
	Sitophilus zeamais		x	x
	Prostephanus truncatus		x	x

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Most cassava arthropod pests cause indirect plant damage given that they are foliage or stem feeders, reducing leaf area, leaf life, and thus photosynthetic rate, or are causing stem breakage. Those pests that can attack the crop over a prolonged period, especially during seasonally dry periods (3-6 months) can cause severe yield losses as a result of decreased photosynthesis, premature leaf drop and death of the apical meristem. Potential yield reduction by these pests can be greater than that by cyclical pests such as hornworms, leaf-cutter ants and grasshoppers, which cause sporadic defoliation; however, these highly visible pests often induce cassava producers to apply pesticides.

Few cassava pests damage cassava roots directly. Four exceptions are burrower bugs (*Cyrtomenus bergi*), white grubs (Scarabaeidae), root mealybugs (e.g., *Pseudococcus mandio*) and termites. *C. bergi* causes root punctures during feeding that can introduce fungal pathogens that reduce root yield and quality. White grubs have been found feeding directly on cassava roots causing yield loss and severe root rot. Yield losses of 17% have been reported for *P. mandio* feeding on cassava roots in southern Brazil. Termites and millipedes are reported occasionally feeding on tuberous roots; however, these may be secondary feeders, attacking already damaged and decaying roots.

In general, arthropod pests are most damaging during the dry season, being less severe in areas of considerable and consistent rainfall; however, there are exceptions to this rule. Hornworm attacks will frequently occur at the onset of the rainy season when there is considerable new growth and young leaves. Severe whitefly attacks often coincide with the rainy season when young, succulent leaves are preferred for oviposition. Studies have also shown that burrower bugs and white grubs prefer soils with higher soil moisture content.

The cassava plant is well adapted to long periods of limited water and responds to water shortage by reducing its evaporative (leaf) surface rapidly and efficiently and by partially closing the stomata, thereby increasing water-use efficiency. The crop has the potential to recover and compensate for yield losses from seasonally dry periods and pest attack due to the higher photosynthetic rate in newly formed leaves (El-Sharkawy, 1993). Younger leaves play a key role in plant carbon nutrition. Most pests prefer the younger canopy leaves; thus, dry-season feeding tends to cause the greatest yield losses in cassava.

Climate change predictions indicate that certain agricultural lands will receive less rainfall in the future. The cassava crop may have a comparative advantage in these extended seasonally drier regions; however, increased cassava production in drier regions of the Neotropics and Africa could result in severer pest outbreaks, reducing yields and/or increasing pesticide use.

Cassava yields on an average per-hectare basis, are highest in Asia (19.8 t/ha) and the Americas (13.2 t/ha) and lowest in Africa (9.8 t/ha). The higher yields in Asia may be due to the fact that, until recently, none of the major Neotropical cassava pests has become established.

MANAGEMENT OF THREE MAJOR CASSAVA ARTHROPOD PESTS: WHITEFLIES, MITES AND MEALYBUGS

1. Whiteflies

a. Taxonomy

Considered one of the world's most damaging agricultural pest groups, as both direct feeders and virus vectors, whiteflies attack cassava-based agroecosystems in the Americas, Africa and in Asia. Currently, they may be causing more crop damage and yield loss on cassava than any other pest attacking the crop.

There is a large species complex associated with the crop, the importance of which can vary between regions or continents. The largest complex on cassava is in the Neotropics, where 11 species are reported, including *Aleurotrachelus socialis, Trialeurodes variabilis, Aleurothrixus aepim, Bemisia tuberculata* and *Bemisia tabaci* (=*B. argentifolii*). *A. socialis* and *T. variabilis* cause considerable direct damage and yield losses in northern South America (Colombia, Venezuela and Ecuador) and in certain regions of Central America. *T. variabilis* is observed primarily in the higher altitudes (> 1000 m), while *A. socialis* is confined to lower altitudes (up to 1200 m). *A. aepim* is found in high populations causing yield losses in Northeast Brazil. *B. tuberculata* has recently been identified as causing yield losses in Southern Brazil.

Bemisia tabaci, the vector of CMD, caused by several geminiviruses, has a pantropical distribution, feeding on cassava throughout most of Africa, several countries in Asia (India and Malaysia) and more recently in the Neotropics. It has been speculated that the absence of CMD in the Americas may be related to the inability of its vector to colonize cassava effectively. Prior to the early 1990s, the *B. tabaci* biotypes found in the Americas did not feed on cassava. The B biotype of *B. tabaci*, regarded by some as a separate species (*B. argentifolii*), has been collected from cassava in several regions of the Neotropics. Although seldom observed in high populations, it is now considered that CMD poses a more serious threat to cassava production given that most traditional cultivars grown in the Neotropics are highly susceptible to the disease.

The potential of *B. tabaci* to adapt to cassava is considered a threat to cassava production in the Americas. A study was initiated to verify whether *B. tabaci* could become gradually adapted to *M. esculenta*. Trials were conducted in rearing chambers (growth rooms) measuring life cycle and population development on *B. tabaci* individuals that passed through a series of intermediate hosts, that had previously been selected and based on phylogenetic proximity to *Manihot*. The ability of *B. tabaci*, biotype B to gradually adapt to cassava (*M. esculenta*), started with individuals from a colony on a legume (*Phaseolus vulgaris*), and continued on two Euphorbiaceae, *Euphorbia pulcherrima* (poinsettia) and *Jatropha gossypiifolia*, and finally on a commercial cassava variety. The highest oviposition rate (2.66 eggs/female/2 days), the shortest development time (44.4 days) and the highest value of r_m (0.48/day) were for populations coming from *J. gossypiifolia*. 27.5% of *B. tabaci* coming from *J. gossypiifolia* survived on cassava, whereas only 3.0% survived on *E. pulcherrima* and 2.0% from *P. vulgaris* (Carabalí *et.al.*, 2005). The importance and potential impact of phylogenetically close plants as hosts

facilitating the adaptation of *B tabaci* to cassava is evident, especially in the Neotropics where cassava is not an efficient host to *B. tabaci*. *Jatropha* is being considered as a potential source for biofuels and plans call for the planting of large plantations to this crop. This could lead to "host shifting" and cassava could become a suitable host for *B. tabaci*. This enhances the possibility of *B. tabaci* vectoring virus diseases to cassava. Studies in India (Raj *et al.*, 2008) have identified a begomovirus from *Jatropha curcas* that possessed high identities and a close relationship with Indian and Sri Lankan cassava mosaic virus isolates. Precautions should be taken to insure that large *Jatropha* plantations should not be established proximate to major cassava growing regions, such as in southern Brazil.

The whitefly species *A. dispersus* is found in several cassava growing countries of Asia (India, Thailand, Laos) and may be causing yield losses. The origin of this species is in South America, possibly north of the Amazon region. Although *A. dispersus* is reported from several countries in the Americas, it is seldom observed in high populations and no yield losses have been reported on cassava. Numerous parasitoid natural enemies have been observed in the neotropics and this may account for the low populations and lack of economic damage due to this pest. Studies need to be done in Asia, especially in Thailand, to determine the effects of *A. dispersus* on cassava yields.

b. Damage

Whiteflies can cause direct damage to cassava by feeding on the phloem of leaves, inducing leaf curling, chlorosis and defoliation. High populations, combined with prolonged feeding, result in considerable reduction in root yield. Yield losses resulting from *A. socialis* and *A. aepim* activity are common in Colombia and Brazil, respectively. With *A. socialis* feeding, there is a correlation between duration of attack and yield loss. Infestations of 1, 6 and 11 months resulted in a 5, 42 and 79% yield reduction, respectively. More recently, yield losses of 58% due to *T. variabilis* feeding have been recorded in the Andean region of northern South America (Bellotti, 2008). In several East African countries yield losses due to direct feeding by *B. tabaci* have been recorded in recent years as a result of the higher populations observed (Calvert and Thresh, 2002). In Uganda, over 50% reductions in root yield have been recorded. Observations on large cassava plantations in southern Brazil (states of Parana, Sao Paolo and Mato Grosso Sur) indicate that high *B. tuberculata* populations are reducing yields, but these losses have not been quantified.

c. Biology and behavior

Research with *A. socialis* and *A. aepim* indicates that populations of both species can occur throughout the growing cycle (one year or more) but are usually highest during the rainy season when there is considerable new growth. *A. socialis* females prefer ovipositing on the undersides of the young apical leaves, reaching a high of 244 eggs (avg 181, min. 155) per female. The individually oviposited banana-shaped eggs hatch in about ten days and pass through three feeding nymphal instars and a pupal stage (4th instar) before reaching the winged adult stage. During the third instar, the body color changes from beige to black, surrounded by a waxy white cerosine, making this species easy to distinguish from other whitefly species feeding on cassava. *A. socialis* egg-to-adult development was 32 days under growth chamber conditions (28±1°C, 70% RH).

A. socialis may be specific to cassava, as populations have not been observed on other plant species (Holguin and Bellotti, 2004).

Aleurodicus disperses, the spiraling whitefly originates from the tropical Americas. It has been reported from many countries in Central and South America, the Caribbean, Africa (Nigeria, Benin, Congo, Togo, etc.) (Neuenschwander, 1994) and Asia (Thailand, Laos, Indonesia, India, Philippines and several others). *A. disperses*, a highly polyphagous species, has a wide host range that include many vegetables, ornamentals and fruit crops (banana, citrus, avocado, guava, soybean) as well as cassava. The immature and adult stages cause direct feeding damage that can cause premature leaf-fall. Feeding damage is accompanied by a heavy production of honeydew and a white, waxy material produced by the insect. Sooty mould develops on the honeydew and decreases photosynthetic activity. High *A. disperses* populations have been observed on cassava in Thailand; these may be causing root yield losses but this has not been documented. High *A. dispersus* populations are also reported from Benin, Africa (D'Almedia *et al.*, 1998). The multiple host range of this species has probably contributed to its widespread dissemination.

The biology of this species has not been extensively studied on cassava. Adults are white, large and very visible on host plants. Adults are easily found on the under-surface of leaves where eggs are oviposited and covered in wax, in loose circular whorls. Eggs are oviposited singularly on a stalk and hatch in 4 to 10 days depending on the temperature and the host plant. The nymphal period has four instars and lasts for 12 to 14 days or longer. The 2 to 3 day pupal stage is covered with a large amount of white wax, which may act as a protective shield against natural enemies. The total life cycle ranges from 34 to 38 days (Palaniswami *et al.*, 1995). Females can live up to 39 days and deposit 80 or more eggs.

A. dispersus damage symptoms include yellowish speckling of the leaves and, with severe infestations, a curling, crinkling and death of cassava leaves. Leaf damage and infestation is from bottom leaves to the top. Populations can range up to hundreds of inmature white flies per leaf. Higher whitefly populations will also result in increased sooty mold cover. In general, whiteflies require high humidity levels, especially during their developmental stages. However, high *A. dispersus* populations have been recorded during dry periods (D'Almeida *et al.*, 1998).

d. Control

Integrated management of cassava whiteflies depends on having effective, low-cost, environmentally-sound technologies available for farmers. A successful whitefly control program requires continual research input to acquire the basic knowledge needed to develop the technologies and strategies for appropriate implementation. A recent survey in an important cassava-growing region of Colombia showed that 34% of the farmers surveyed applied chemical pesticides for whitefly control *versus* only 4.6% for biological products. Farmer field trials in the region revealed a 58% reduction in yield due to whitefly attack; however, 52% of the farmers surveyed employed no control measures. Pesticide applications have not provided adequate control, probably for lack of knowledge of whitefly biology, especially the immature stages (the presence of eggs and early-instar

nymphs). This has resulted in inappropriate timing of applications and the misuse of chemical pesticides (Holguín and Bellotti, 2004).

Recent research and field observations on cassava whiteflies in the Neotropics indicate that control measures, especially pesticide applications, are compromised because of the whitefly's capacity for rapid population increases and its ability to develop high levels of pesticide resistance. When *A. socialis* feeds on a susceptible cassava variety, it doubles its population every 4.2 days (Holguín *et al.*, 2006). Other whitefly species may follow a similar pattern. When there are overlapping crop cycles (e.g., multiple plantings) and favorable rainfall patterns, the conditions are ideal for a rapid buildup in whitefly populations as a constant food supply of young cassava leaves are available for adult feeding, high oviposition and nymphal development. Field observations indicate that once whitefly populations begin this rapid increase, they are very difficult to control, requiring repeated pesticide applications that disrupt natural biological control and that are also uneconomical for small farmers. This capacity for rapid population buildup makes it urgent to introduce efficient management practices early in the plant growth cycle, possibly during the first month of plant growth and before the economic threshold is reached. Therefore, field surveys to monitor and determine the onset of the whitefly population build-up are an important component in an IPM strategy.

Four methods of whitefly control in cassava are discussed: host plant resistance, biological, cultural and chemical.

Host plant resistance (HPR)

This form of resistance to whiteflies is rare in cultivated crops. HPR studies initiated at CIAT more than 25 years ago have systematically evaluated the accessions in the CIAT cassava germplasm bank for resistance to whiteflies, especially *A. socialis*. Of approximately 5,500 genotypes evaluated in the field in Colombia, about 75% are susceptible, with damage ratings above 3.5 (1=no damage, 6=severe damage). Emphasis is placed on those genotypes with damage ratings under 2.0 (about 8%). As there may be susceptible escapes due to insufficient selection pressure, they were reevaluated in subsequent trials. Several sources of resistance to *A. socialis* have now been identified: Genotype MEcu 72 has consistently expressed a high level of resistance, while MEcu 64, MPer 334, MPer 415 and MPer 273 express moderate-to-high levels. When feeding on resistant genotypes, *A. socialis* has less oviposition, a longer development period, smaller size and higher mortality than those feeding on susceptible genotypes. *A. socialis* nymphal instars feeding on MEcu 72 and MPer 334 suffered 72.5 and 77.5% mortality, respectively, mostly in the early instars (Bellotti and Arias, 2001). This resistance, a combination of reduced oviposition and high nymphal mortality, depresses the early buildup of whitefly populations. This allows other methods of control, such as biological control to be more effective. The early establishment of natural enemies, especially parasitoids, can be more successful in maintaining whitefly populations below economic injury levels.

A cross between MEcu 72 (female parent, whitefly resistant) and MBra 12 (male parent, high yielding, good plant type) resulted in 128 progeny, four of which were selected for whitefly resistance, yield and cooking quality. These four hybrids, along with

susceptible genotypes and local farmer varieties, were evaluated at three sites in Tolima province in Colombia by CORPOICA-MADR (Colombian Corp. for Agricultural Research/Ministry of Agriculture and Rural Development) over a four-year period. The hybrid CG 489-31 was selected for high whitefly resistance, high yield and good cooking qualities. In 2003, it was officially released by MADR under the name of Nataima-31. It has attained yields of 33 t/ha, outyielding the regional farmers' variety in Tolima by 34% with no pesticide applications. Nataima-31 is now being grown commercially in several areas of Colombia and has been introduced into Ecuador and Brazil.

Given that *B. tabaci* is a pantropical species that is the vector of CMD, which causes severe cassava crop damage in Africa and India, several cassava genotypes were sent by CIAT to NRI (Natural Resources Institute-UK) to be evaluated for resistance to *B. tabaci*. Genotype MEcu 72 had the lowest rate of *B. tabaci* oviposition so it was introduced into Uganda during 2005 and will be included in a breeding program to develop whitefly-resistant varieties.

The resistance expressed in MEcu72, Natiama-31 and other genotypes should also be evaluated for resistance to *A. dispersus* in Asia where this species is being observed in high field populations.

Biological control

Numerous natural enemies are found associated with whiteflies on cassava in the Neotropics. In recent field explorations in Colombia, Ecuador, Venezuela and Brazil, a complex of parasitoids, predators and entomopathogens were collected from several whitefly species (Bellotti *et al.*, 2005). The most representative group is that of the microhymenopteran parasitoids. The richness of species in Colombia, Venezuela and Ecuador is primarily represented by the genera *Encarsia, Eretmocerus* and *Amitus*, frequently associated with *A. socialis* **(Table 2).** Gaps in knowledge about this natural enemy complex have limited the determination of their effectiveness in biological control programs. There is little knowledge regarding levels and rates of parasitism by species or specification of the host and its effect on the regulation of whitefly populations.

Eleven species of parasitoids (five genera) were collected from the cassava-growing regions of Colombia; an additional five species were collected from Ecuador and seven from Venezuela. On the Caribbean Coast of Colombia, *A. socialis* was parasitized by eight species, with the genus *Eretmocerus* comprising 70% of the parasitoids. In Magdalena province, 73% of *A. socialis* parasitism was by *Amitus macgowni*, followed by *Encarsia* sp. (26%). In the Andean region, *Eretmocerus* spp. parasitized all whitefly species, but *Encarsia pergandiella* was the predominant parasitoid of *T. variabilis*.

Greenhouse studies with *E. hispida* parasitizing *A. socialis* show that the third whitefly instar is preferred. Parasitism rates reached 75% in the third instar and 16, 45 and 43% in the first, second and fourth instars, respectively. The average parasitism rate was 45%, and peak parasitism occurred 72-96 hours after exposure (Bellotti, 2002).

Table 2. Natural enemies (parasitoids, predators and entomopathogens) of white flies feeding on cassava.

Principal Species	*Parasitoids*	*Predators*	*Entomopathogens*
Aleurotrachelus sociales	*Amitus macgowni*	*Delphastus sp*	*Beauveria bassiana*
	E. americana	*D. quinculus*	*lecanicillium lecani*
	E. bellotti	*D. pusillus,*	*Aschersonia*
	E. cubensis	*Chrysopa sp. nr. cincta,*	*aleyrodes*
	Encarsia hispida	*Condylostylus sp.*	
	E. luteola		
	E. sophia		
	Encarsia sp. nr. *variegata*		
	Encarsia sp.		
	E. tabacivora		
	Euderomphale sp.		
	Eretmocerus spp.		
	Metaphycus sp.		
	Signiphora aleyrodis		
Aleurothrixus aepim	*Encarsia porteri*		*Cladosporium sp.*
	E. aleurothrixi		
	E. hispida		
	Eretmocerus sp.		
Aleurodicus dispersus	*Aleurotonus vittatus*		
	E. haitiensis		
	Encarsia sp.		
	Eretmocerus sp.		
	Euderomphale sp.		
Aleuroglandulus similis	*Encarsia guadeloupae*	*Nephaspis namolica*	
	Encarsia desantisi		
Aonidomytilus albus	*Aspidoiphagus citrinus*	*Chilocorus distigma*	*Septobasidium sp.*
	Signiphora sp.		
Bemisia tuberculata	*E. hispida*	*Condylostylus sp.*	
	E. pergandiella		
	E. sophia		
	Encarsia sp.prob. variegata		
	E. tabacivora		
	Eretmocerus sp.		
	Euderomphale sp.		
	Metaphycus sp.		
Bemisia tabaci	*Encarsia sophia*	**1. Delphastus pusillus**	
	E. lutea	*Condylostylus sp.*	
	E. Formosa		
	E. mineoi		
	Encarsia sp.		
	Eretmocerus mundus		

Table 2. Continued

Principal Species	*Parasitoids*	*Predators*	*Entomopathogens*
Trialeurodes variabilis	*E. bellotti* *E. hispida* *E. luteola* *E. nigricephala* *E. pergandiella* *Encarsia sp.* *E. sophia* *E. strenua* *E. tabacivora* *Eretmocerus spp.*	*Chrysopa sp.* nr. *cincta* *Condylostylus sp.*	*Aschersonia aleyrodes* *Beauveria bassiana* *Lecanicillium lecani*
Trialeurodes vaporariorum	*Encarsia tabacivora*		

Parasitoid species associated with *B. tuberculata* include *Encarsia hispida, E. pergandiella, E. sophia, E. tabacivora, Eretmocerus* sp. and others. However, there are no studies that indicate the effectiveness of these parasitoids. Research on the presence of *B. tuberculata* parasitoids in Southern Brazil, and their potential in biological control needs to be carried out.

In Northeast Brazil, the predominant whitefly species is *Aleurothrixus aepim*. Several parasitoid species have been identified, including *Encarsia porteri, E. hispida, E. aleurothrixi* and *Eretmocerus* sp. However, there is little information available on the effectiveness of these natural enemies (Farias and Bellotti, 2006).

Several parasitoid species have been recorded parasitizing *A. disperses*; these include *Aleurotonus vittatus, Encarsia* sp., *E. haitiensis, E. guadeloupae, Eretmocerus* sp. and *Euderomphale* sp., *E. haitiensis* and *E. guadeloupae* (both species probably from the Caribbean region) have been shown to be effective in reducing *A. dispersus* populations in Benin, Africa (D'Almeida *et al.*, 1998). It is estimated that these two species were accidentally introduced, along with *A. dispersus*, into Benin during the early 1990s. *A. dispersus* populations in Asian countries need to be surveyed in order to determine if these two parasitoids, or other parasitoids, are present and their effectiveness evaluated. *E. haitiensis* and *E. guadeloupae* are both reported as parasites of *A. disperses* in the Philippines and Malaysia **(Table 2)**.

More than 20 species of entomopathogens have been reported infecting whiteflies on cassava, including *Aschersonia* sp., *Lecanicillium* (*Verticillium*) *lecani, Beauveria bassiana* and *Paecilomyces fumosoroseus*. However, there has to be a careful selection of the species, as well as the identification of native isolates of entomopathogenic fungi. Greenhouse experiments at CIAT with an isolate of *L. lecani* resulted in 58-72% *A. socialis* nymphal mortality and 82% egg mortality. The *L. lecani* isolate has been formulated into a commercial biopesticide BioCanii®. The commercial biopesticide Mycotrol®, (isolate of *B. bassiana*, a product of Laverlam S.A.), gave very effective control (> 90% mortality of the egg and first two nymphal instar stages) of *A. socialis* in greenhouse experiments at

CIAT. Mycotrol®, was also effective against *B. tabaci* and *T. variabilis*, but needs to be evaluated in field trials.

The employment of biopesticides (e.g. fungal entomopathogens) for whitefly control appears to be most effective if applied when whitefly populations are low and in the egg and nymphal stages. Field experiments indicate that biopesticides, if applied when whitefly populations are high, do not deter the continual increase of the population. The combination of a resistant variety with applications of a biopesticide (if needed) would probably be very effective in maintaining whitefly populations below economic injury levels.

The most frequently observed predators feeding on cassava whiteflies are crysopids (Neuroptera: Crysopidae). These generalists feed on the eggs and immature stages of numerous arthropods. *Chrysoperla carnea* is frequently collected feeding on *A. socialis* in cassava fields. In lab studies at CIAT, *A. socialis* egg and nymphal consumption by *C. carnea* were measured by recording the time required for 50% consumption of the prey state being offered. *C. carnea* adults required 80 hours to consume 50% of the nymphal instars and pupae and 77 hours to consume 50% of the eggs.

Cultural control

In traditional cropping systems cassava is often intercropped, a practice that has been shown to reduce populations of certain pests. Intercropping cassava with cowpeas reduced egg populations of *A. socialis* and *T. variabilis* by 70%, compared to those in monoculture. Yield losses in cassava/maize, cassava monoculture and mixed cultivar systems were ca. 60% versus only 12% in cassava/cowpea intercrops (Gold *et al.*, 1989).

When cassava is grown in overlapping cycles or multiple plantings, it is difficult to 'break' the whitefly development cycle so rapid population buildups occur. Upon emerging from the pupal stage, adults migrate to feed and oviposit on recently germinated young plants in adjacent fields. A successful tactic for countering this situation is to implement a 'closed season', defined as an interdiction or prohibition when cassava cannot be present in the field. Field observations at CIAT have shown that a 1- to 2-month period with no cassava in the field decreases whitefly populations dramatically over a four-year period. The success of this ban is enhanced by the fact that *A. socialis* does not appear to have efficient alternate hosts so their populations 'crash' when adults cannot find an alternate host species to sustain or increase populations. Nevertheless, the economic practicality of this strategy for producers is debatable. In many regions, a constant supply of cassava roots is economically desirable for meeting the demands of local fresh and processing markets. This same tactic may not be as effective for a species such as *A. dispersus* and *B. tabaci*, both of which have numerous alternate hosts on which their populations can be sustained and multiplied.

Chemical control

Several products with new or novel active ingredients have been evaluated for controlling *A. socialis* and *T. variabilis*. Foliar applications of Theamethoxam and Imidacloprid were most efficient in reducing whitefly populations. Best control was

obtained when applied as a drench at a high dose (0.8 and 0.6 l/ha) on young plants (Holgu n and Bellotti, 2004). The treatment of cassava planting material (stem cuttings) with a 7-min. emersion in a solution of Theamethoxam (Actara)(1 g/l H_2O) is also giving promising results. More than two pesticide applications during the crop cycle should be avoided. Pesticide applications should be made when whitefly populations are still low. Pesticides are used as a deterrent to the rapid build up of whitefly populations. Field experiments have shown that high whitefly populations are difficult to control with chemical pesticides, even when applied at high doses. Field experiments have also shown that pesticides need not be applied after six months of crop growth as yield loss due to whitefly attack will not occur. A cost-benefit analysis indicates that chemical pesticide applications for whitefly control in cassava are generally uneconomic, and only slightly economic when the cassava root price is high. Research is under way to evaluate the feasibility of substituting entomopathogens as biopesticides to replace chemical pesticide applications (Holguin and Bellotti, 2004)..

e. Recommendations for whitefly management in cassava

Resistant varieties: Nataima 31

Stake treatment:

Immersion of cassava cuttings in a solution of Thiamethoxam (Actara), 1,0 gr/l water, for 7-10 minutes

Foliar application:

1. Monitor the crop every five days after the first leaves appear; evaluate the whitefly population (egg, nymphs, adults)
2. When adult populations reach 50 per plant (and 200 nymphs) apply Imadacloprid-B-Cyflutrina (Probado Combi) and Buprofezin (Oportune) at 4,0 and 1.0 cc/l water, respectively. The application is applied to the undersurface of leaves
3. Continue to monitor for six months:
   - >200 adults and nymphs; apply Thiamethoxam
   - 10-20 adults and few and no nymphs, apply Etoferprox (Trebon), 5 cc/l water
   - Low population of adults, eggs and nymphs apply fungal entomopathogens, *Lecanicillium lecani* or *Beauveria bassiana.*

2. Cassava Mealybugs

a. Taxonomy

Approximately 15 species of mealybugs are reported attacking the cassava crop **(Table 1)**. Two species, *Phenacoccus herreri* and *P. manihoti*, are economically important in the Americas where they have caused yield reductions in cassava fields (Bellotti, 2008). *P. manihoti* was introduced inadvertently into Africa in the early 1970s, where it spread rapidly across the cassava-growing regions of that continent, causing considerable yield loss. Both species are of neotropical (the Americas) origin and both species have been the object of successful biological control programs (Neuenschwander, 2004; Bento *et al.*, 2000). In the Americas, *P. manihoti* was first found in Paraguay in 1980 and was later collected from certain areas of Bolivia and Mato Grosso do Sul state in Brazil, causing no

economic damage. More recently, *P. manihoti* has also been collected from the Brazilian states of Parana, Sao Paulo, Bahia and Pernambuco where it appears to be causing losses of cassava root yields. *P. manihoti* was probably introduced into the northeastern states of Bahia and Pernambuco through the introduction of cassava stems for planting material from Southern Brazil.

The origin of *P. herreni* is probably northern South America, where it was found in cassava-growing regions of Colombia and Venezuela. It was first reported during the mid-1970s in Northeast Brazil, where high populations caused considerable yield losses. Surveys in the region found few parasitoid natural enemies, suggesting that *P. herreni* is an exotic pest, probably coming from northern South America where parasitoids are frequently observed (Bento *et al.*, 2000).

During the past year (2008/09) the mealybug species *Dysmicoccus sp.* has been observed attacking the roots of young, recently germinated, cassava plants in Southern Brazil. Damage symptoms include the wilting of young leaves, often resulting in plant mortality (Fadel, peronal communication).

Recent mealybug collections from cassava fields in Asia, especially in Thailand, indicate that there may be several species involved. There is an urgent need to do continual collections from different regions and countries to clarify this situation. The striped mealybug, *Ferrisia virgata*, has been reported feeding on cassava in Asia for many years, but was never observed in very high populations. Recent observations indicate that populations have increased dramatically and are now causing yield losses (Bellotti, pers. obs.). A second mealybug species recently collected from cassava appears to be *Pseudococcus jackbeardsleyi* (identification pending). A third species could be *Pseudococcus elisae*; this species is closely related to *P. jackbeardsleyi* and was reported on cassava in Thailand (and other Asian countries) in 1998. A fourth species, *Phenacoccus solenopsis,* is reported as a recent introduction into Asia. A fifth species has recently been identified by taxonomists at the British Museum as *Phenacoccus manihoti*, and it has been observed in high populations causing yield losses estimated as high as 25% in Thailand. Recent reports indicate that *P. manihoti* is also present and causing damage to cassava in Cambodia. All five of these species are native of the Americas and are reported on several other hosts besides cassava. *Phenacoccus hirsutus* is reported to be feeding on cassava in the Philippines.

b. Damage

P. manihoti and *P. herreni* cause similar damage: adult and nymph feeding causes leaf yellowing, curling and cabbage-like malformation of the apical growing points. High populations lead to leaf necrosis, defoliation, stem distortion and shoot death (Bellotti *et al.*, 1999). Reductions in photosynthetic rate, transpiration and mesophyll efficiency—together with moderate increases in water-pressure deficit, internal CO_2 and leaf temperature—were found in infested plants (Polan a *et al.*, 1999). Yield losses in experimental fields at CIAT ranged from 68-88%, depending on cultivar susceptibility. Farmers in NE Brazil estimated their losses to be over 80%, and cassava production decreased in the region during the 1980s. In Africa yield losses due to *P. manihoti* feeding and damage were around 80%.

In general, mealybugs can cause two types of damage to cassava; a mechanical or direct damage caused by their sucking feeding habits, and an indirect damage produced by the build-up of sooty mold on the leaf surface due to mealybug excrement. This fungus build-up reduces leaf photosynthesis. *Ferrisia virgata*, the striped mealybug, can often be found in high populations feeding on the undersurface of leaves and in clusters along the stems and branches of the cassava plant. When high populations occur, considerable sooty mold can be observed. *F.virgata* causes leaf yellowing and eventually defoliation, usually beginning with the basal leaves. The mealybug infestation can spread rapidly eventually covering most leaves, stems and shoots. When high populations occur on young plants, growth is slowed, resulting in stunted and dwarfed plants. Stems will have shortened internodes, shoots and leaves are deformed and wilting occurs, eventually leading to leaf and shoot desiccation and defoliation.

High *F. virgata* populations have occurred in certain regions of Thailand in recent years, specially in areas where the rainy season was delayed, prolonging the dry season. It was estimated that yields were reduced by 20 to 80% in fields where high populations occurred.

c. Biology and behavior

In general, mealybugs are all very much alike in their life history and biology. Mealybugs may be placed into two groups: The short-tailed mealybugs and the long-tailed mealybugs. The short-tailed mealybugs reproduce by laying eggs, often in an ovisac. The filaments that surround the body are of about equal length and none more than one-fourth the length of the body. The long-tailed mealybugs generally do not form an egg sac, giving birth to live nymphs. It derives its name from the four filaments near the tip of the abdomen, which may be as long as the body. *P. herreni* and *P. maniloti* are short-tailed species, while *F. virgata* is a long-tailed species.

Mealybugs are oval, flattened, soft-bodied insects, distinctly segmented but without a clear definition between the head, thorax and abdomen. They are covered with a white, powdery, or mealy wax and feed by inserting their slender mouth parts into the plant tissues and sucking cell contents. Mealybugs pass through four stages, egg, nymph, pupae and adults. Nymphs and adults will move about to some extent over the plant, and although sluggish, do not remain fixed. The female nymphs change little in their appearance, except to increase in size, and they are not winged in the adult stage. The males will enter a cocoon-like pupal stage and emerge as tiny active, two-winged insects. Upon emerging from the cocoon, the males actively fly about and mate with the females. Adult males do not feed whereas adult females can continue to feed.

Both *Phenacoccus herreni* and *P. manihoti* are morphologically similar and originally thought to be only one species. *P manihoti* is parthenogenic, whereas males are required for reproduction of *P. herreni* (Bellotti, 2008). The females deposit ovisacs containing hundreds of eggs on the undersides of leaves and around apical and lateral buds. Eggs hatch in 6-8 days, and there are four nymphal instars; the first instars are highly mobile and will spread over the plant or between plants. The fourth instar is the adult stage for females, while males have four nymphal instars plus the adult stage. The third and

fourth instars occur in a cocoon, from which the winged male adults emerge, living only 2-4 days. The life cycle of the female is 49.5 days; that of the male, 29.5. The optimal temperature for female development is 25-30°C (Herrera *et al.*, 1989). Populations of both species peak during the dry season (Calatayud *et al.*, 2002). The onset of rains reduces pest populations and plant damage, permitting some crop recovery.

Ferrisia virgata females are described as flat bodied, 1.8 x 3.0 mm with a tail about 1.6 mm long. The winged male body is about 0.5 x 1.3 mm. The life cycle has been recorded as 35 to 92 days and females can oviposit on average 364 eggs. The adult female is covered with a powdery white wax and has a pair of purplish dorsal stripes along the back. Long, glossy white wax threads extend from the body and there are two long waxy tails. Although mobile, they generally do not move very far and large clusters of the mealybug can appear (Schreiner, 2000). *F. virgata* can attack a wide host range that includes sweetpotato, coffee, cacao, citrus, guava, tomatoes and eggplants, as well as cassava (Schreiner, 2000).

Pseudococcus jackbeardsleyi has not been reported as a serious pest and there is little information available on this species. It has both a wide distribution and host range. Commonly known as the Jack Beardsley mealybug, it is reported on a diverse range of fruits, vegetables and ornamentals, as well as cassava. Hosts include pineapple, cherimoya, celery, cabbage, pigeon pea, bell peppers, star apple, grapefruit, melon, banana, beans and numerous others (from 88 genera and 38 plant families). It has been reported from nearly all countries of the tropical Americas and several countries in Africa and Asia.

Mealybug dissemination between regions, countries or continents is probably through infested stem cuttings. The introduction of *P. manihoti* into NE Brazil from Southern Brazil can probably be traced to the movement of cassava varieties between these two regions.

Immature mealybugs can be found around the lateral buds on cassava stems, and subsequently on the stem cuttings used as planting material. If infested stem cutting are transported from one region to another, this can result in infesting an area where the mealybug was not previously established. The planting of infested stem cuttings also results in mealybug infestations from one crop cycle to the next.

d. Management

Mealybugs can be effectively controlled through the proper employment of biological control agents, especially parasitoids. The use of chemical pesticides for mealybug control can be both difficult and costly. The objective is to prevent mealybug populations from reaching economic damage (yield loss) levels. Therefore, any mealybug management action need to be employed when pest populations are still low. Unless there is constant monitoring of pest populations in the field, it is often difficult to detect the initial build up of mealybug populations. This is especially true on larger cassava plantations, where a monitoring scheme is often not implemented. The establishment and presence of key or effective natural enemies, especially parasitoids, can prevent or retard the initial build up of the mealybug populations. The employment of a chemical pesticide

can be disruptive to the natural biological control that exists, or is introduced into a cassava field. Most natural enemies, especially parasitoids, are very sensitive to pesticides, even when they are applied at low doses. In contrast to biological control methods, the use of chemical pesticides does not require as much knowledge of the ecological origins of the pest. Effective biological control requires considerable knowledge and information on the origin, biology, ecology, behavior and taxonomy of both the pest and their natural enemies (Van Driesche and Bellows, 1996). Cassava mealybug management is a well-documented example of classical biological control, in both Africa and the Americas. In Africa, *P. manihoti* is being controlled successfully after introducing the parasitoid *Anagyrus lopezi* from the Neotropics. After several years of exploration in the Neotropics by scientists from IIBC, IITA and CIAT, the target species *P. manihoti* was finally located by a CIAT scientist (A.C. Bellotti) in Paraguay in 1980. IIBC collected natural enemies of *P. manihoti* that were sent via quarantine in London to IITA in Benin for multiplication and release in Africa. The encyrtid parasitoid *A. lopezi* and the coccinellid predators *Hyperaspis notata*, *Hyperaspis raynevali,* and *Diomus* sp. became established in Africa. The parasitoid is credited with being the principal agent reducing the mealybug populations. *A. lopezi* became established in all ecological zones occupied by *P. manihoti* and is now found in 27 countries, covering an area of 2.7 million km^2. Cassava losses have been reduced by 90-95% with an estimated savings of US$ 7.971 to 20.226 billion (Neuenschwander, 2004).

Surveys in Colombia and Venezuela identified numerous parasitoids, predators and entomopathogens associated with *P. herreni* **(Table 3)**. Several parasitoids show a specificity or preference for *P. herreni*: *Acerophagus coccois, Anagyrus diversicornis, Anagyrus putonophilus, Anagyrus isolitus, Anagyrus elegeri* and *Aenasius vexans*. Based on numerous field and lab studies, three encyrtid parasitoids (*A. diversicornis, A. coccois* and *A. vexans*) were identified as effective in reducing *P. herreni* infestations (Van Driesche *et al.*, 1988). Comparative life-cycle studies show that they completed two cycles for each cycle of *P. herreni.* This is a favorable ratio for biological control. *A. diversicornis* prefers third instar nymphs, whereas the smaller *A. coccois* parasitizes male cocoons, adult females, and second instar nymphs. *A. vexans* prefers second and third instar nymphs. Field studies with natural populations of *A. diversicornis* and *A. coccois* estimated *P. herreni* mortality at 55% for their combined action.

Through the combined efforts of CIAT and CNPMF/EMBRAPA, these three parasitoids were exported from CIAT to EMBRAPA, Brazil, where they were mass reared and released into *P. herreni*-infested cassava fields, primarily in the northeastern states of Bahia and Pernambuco from 1994 to 1996. More than 35,000 parasitoids were released, and all three species became established. Studies prior to release had determined that none of these species existed in this region. In Bahia, *A. diversicornis* dispersed 120 km in six months after release and 304 km in 21 months. *A. coccois* was recovered in high numbers nine months later, 180 km from its release site. *A. vexans* was consistently recaptured at its release site in Pernambuco, having dispersed only 40 km in five months (Bento *et al.*, 2000).

Table 3. Natural enemies (parasitoids, predators and entomopathogens) of mealybugs feeding on cassava.

Principal Species	*Parasitoids*	*Predators*	*Entomopathogens*
Phenacoccus manihoti	*Apoanagyrus lopezi* *Acerophagus sp.*	*Cleothera onerata,* *Hyperaspis sp.* *Nephus sp.* *Chrysopa sp.* *Sympherobius sp.,* *Typhlodromalus aripo*	
Phenacoccus herreni	*Acerophagus coccois* *Apoanagyrus diversicornis* *Aenasius vexans,* *Anagyrus insolitus* *A. thyridopterygis* *A. pseudococci* *Anagyrus. sp. nr. greeni* *Aenasius sp.* nr. *putonophylus* *Prochiloneurus dactylopii* *Chartocerus sp.* *Hexacnemus sp.* *Eusemion sp.*	Ocyptamus *sp.* Sympherobius *sp.* *Hyperaspis sp.* *Nephus sp.* *Cleothera onerata* *C. notata* *Diomus sp.* *Coccidophylus sp* *Scymnus sp.* *Olla sp.* *Curinus colombianus,* *Cycloneda sanguinea,* *Hippodamia convergens* *Azya sp.* *Chrysopa sp.* *Kalodiplosis coccidarum,* *Zelus sp.*	*Cladosporium sp.* *Neozygites fumosa*
Phenacoccus madeirensis	*Anagyrus sp.* *Apoanagyrus sp.* *Aenasius masii* *Acerophagus coccois* *Hexacnemus sp.* *Eusemion sp.* *Haltichella sp.* *Prospaltella sp.* *Signiphora sp.*	*Azya sp.* *Curinus colombianus,* *Cleothera onerata* *Chrysopa sp.* *Coccidophylus sp.* *Emesaya sp.* *Hippodamia convergens* *Kalodiplosis coccidarum* *Nephus sp.* *Ocyptamus sp.* *Olla sp.* *Pentillia sp.* *Scymnus sp.* *Sympherobius sp.* *Zelus sp.*	*Cladosporium sp.*

Table 3. Continued

Principal Species	*Parasitoids*	*Predators*	*Entomopathogens*
Ferrisia virgata	*Aenasius advena* *Anagyrusbrevicornis* *Anagyrus qadrii* *Anaysis alcocki* *Anusioptera aureocincta* *Blepyrus insularis* *Coelinius* *Gyranusoidea citrina* *Myiopharus doryphorae* *Patiyana coccorum* *Pseudaphycus debachi*	*Alloagrapta javana* *Alloagrapta obliqua* *Azya luteipes* *Cheilomenes sexmaculata* *Chrysopa orestes* *Exochomus flaviventris* *Hyperaspis senegalensis hottentotta* *Mallada boninensis* *Nephus regularis* *Scymnus castaneus* *Scymnus coccivora*	*Empusa fresenii*

Personal observations in recent years indicate that *P. herreni* populations have decreased considerably as cassava farmers in the region have not reported severe outbreaks, and cassava cultivation has returned to areas where it had been previously abandoned due to *P. herreni* damage. However, the recent introduction of *P. manihoti* into the region has resulted in reports of severe mealybug damage in Bahia, causing alarm among cassava producers. An effort by local institutions and researchers is needed to determine if key *P. manihoti* parasitoids are present or need to be introduced into the region. *P. manihoti* was probably introduced into Northeast Brazil via infested cassava stems, transported from Southern Brazil and used as planting material.

Southern Brazil (the States of Panama, Sao Paulo and Mato Grosso) has recently experienced considerable damage to the cassava crop due to increased populations of the mealybug *P. manihoti.* This species has been in the region for many years and Southern Brazil, Paraguay, Northern Argentina appears to be the center of origin of this species. However, it was not previously observed in high populations, causing economic damage to the cassava crop. There are probably several factors that have contributed to the increase in *P. manihoti* populations in this region. Cassava monoculture production on large plantations has provided ample vegetative material for mealybugs to feed on and rapidly increase in population.

Changes in the climate, with a warmer "winter" period (June to August), has altered crop management practices enabling a staggered or more frequent plantings of cassava. This results in multiple planting systems with the cassava crop at several different growth stages in the same or surrounding plantations. Observations indicate that this multiple planting system is favorable for increased mealybug populations, leading to yield losses. In addition, the increased use of chemical pesticides to control whiteflies and lacebugs, two important pests in the region, has probably reduced the effectiveness of the natural biological control agents, especially the parasitoid *A. lopezi.*

As stated earlier, mealybug populations in Asia, especially in Thailand have also increased in recent years. Factors such as warmer temperatures, a longer dry season, or the

use of pesticides may have contributed to these increases in mealybug populations and damage. The two major species collected from Thailand have been identified as *F. virgata* and *P. jackbeardsleyi*, both of neotropical (the Americas) origin. Several parasitoid species of *F. virgata* have been reported **(Table 3)** but there is little data on field efficacy.

A third mealybug species, *Phenacoccus manihoti*, has now been identified in Thailand where it is causing severe crop damage. The genus *Phenacoccus* is of neotropical origin. *P. manihoti* is specific to cassava and does not appear to have additional major hosts. This species can cause considerable cassava yield losses, especially in areas of a long dry season (3 to 6 months). A classical biological control program that includes the introduction of key natural enemies from the Americas is recommended.

A concerted research effort and surveys need to be undertaken in the neotropics to identify, evaluate and research the most important natural enemies, especially parasitoids of *F. virgata, P. jackbeardsleyi and P. madeirensis.*

e. Recommendations for control of cassava mealybug.

Strategies for prevention

1. Knowledge of biology (life cycle) ecology and behavior of pest species.
2. Selection and treatment of planting material (Thaimethoxam) in areas of high pest pressure.
3. Minimize movements from infested to non-infested fields. Enforce quarantine regulations.
4. Avoid use of chemical pesticides (conserve mealybug natural enemies-parasitoids).

Control Strategies

1. Constant monitoring of plantations (every 2-4 weeks).
2. Detect focal point of infestation (hot spots).
3. Focal point: Remove infested growing areas of plant (apical buds) and destroy (burn).
4. Application of a systemic pesticide in area of infestation and surrounding area.
5. Release and establishment of natural enemies (depending on mealybug species).
6. Avoid movement of planting material (stem cuttings) from one region to another.

3. Cassava Mites

a. Taxonomy

More than 40 species of mites have been reported to feed on cassava in the Americas, Africa and Asia. The most important are *Mononychellus tanajoa* (syn=*M. progresivus*), *Mononychellus caribbeanae, Tetranychus cinnabarinus* and *Tetranychus urticae* (also reported as *T. bimaculatus* and *T. telarius*) **(Table 1)**. Cassava is the major host for the *Mononychellus* spp., while the *Tetranychus* spp. have a wide host range. Mite species reported from Asian cassava fields include *Tetranychus urticae, T. tumidus, T. kaqnzawai, T. bellotti, T. neocalidonicus, T. truncates, Olygonychus biharensis* and *Eutetranychus orientalis. M. mcgregori* has recently been identified from cassava fields in Vietnam (Bellotti, per. obs. 2009).

M. tanajoa, the Cassava Green Mite (CGM), is the most important species, causing crop losses in the Americas and Africa. It is native to the Neotropics, first being reported from northeast Brazil in 1938. It is presently found in most cassava-growing regions in the Americas, especially in seasonally dry regions of the lowland tropics in Brazil, Colombia and Venezuela (Bellotti *et al.*, 1999). *M. tanajoa* is reported in most cassava growing countries of Africa where it can cause severe crop damage (Herren and Neuenschwander, 1991). *M. tanajoa* has not been reported from any of the Asian cassava growing countries. However, climatic conditions in several Asian countries are favorable for *M. tanajoa* invasion and high population buildups. Every precaution should be taken to prevent the introduction of *M. tanajoa* into Asian countries and strict quarantine regulations should be observed.

b. Damage

In experimental fields in Colombia, *M. tanajoa* attacks of 3, 4 and 6 months resulted in yield losses of 21, 25 and 53%, respectively. Under high mite populations on the Colombian Atlantic Coast, yields were reduced by 15% in resistant cultivars compared with an average 67% loss in susceptible cultivars (Bellotti, 2008). In Africa *M. tanajoa* was first reported from Uganda in 1971; and within 15 years it had spread across most of the cassava-growing belt, occurring in 27 countries and causing estimated root losses of 13-80%. CGM has been the objective of a major biological control effort since the early 1980s (Yaninek *et al.*, 1993).

Yield losses due to the Red Spider Mites, *Tetranychus* sp., feeding on cassava have been reported from the Philippines, Indonesia and India. Yield losses ranging from 18 to 47% have been recorded in field trials. The mite species involved include *T. kanzawai* (Philippines), *E. orientalis*, *T. neocalidonicus* and *O. biharensis* (India) and *Tetranychus* sp. (Indonesia).

Mite attacks will reduce the quality and quantity of planting material (cuttings) as well as decrease the root yields.

4. Biology and behavior

Mites, especially the cassava green mite (CGM), are dry-season pests that can cause yield losses where there is a seasonally dry period of at least three months. At the onset of the rainy season, mite populations decrease and cassava plants produce new foliage. If the rains do not persist, CGM populations will again increase, causing defoliation and severer yield losses. This pattern has been observed in the semi-arid cassava-growing regions of Northeast Brazil. CGM populations prefer to feed on the undersides of young emerging leaves, by penetration of the stylet into leaf tissue, sucking cell content. Leaves develop a mottled whitish-to-yellow appearance and may become deformed or reduced in size. Heavy infestations will cause defoliations, beginning at the top of the plant, often killing apical and lateral buds and shoots.

The adult mite is green in color with an average body length of about 350 mμ. Females oviposit on the leaf undersurface; eggs hatch in 3-4 days (30 Cand 70±5% RH). At 15, 20, 25 and 30 C,the egg-to-adult stage is 41.4, 19.5, 10.3 and 7.8 days, respectively. These data indicate that CGM populations can increase rapidly in warm regions of the lowland tropics. At 30 C,each female oviposits 90-120 eggs; during the initial population

buildup, mostly females are produced, adding to the rapid population increase (Bellotti, 2008).

Mites of the genus *Tetranychus* tend to first attack mature leaves at the basal part of the plant, then move to the upper leaves. First symptoms generally occur at the base of the leaf and along the midrib. *Tetranychus* mite colonies feed on the lower leaf surface, but in the case of heavy infestations, they attack both leaf surfaces, often causing considerable webbing. Initial spotting becomes reddish or rust-colored as the infestation increases; defoliation occurs from bottom to top leaves and, if dry conditions persist, plants may die (Bernardo and Esquevia, 1981).

Tetranychidae mites pass through five development stages: egg, larvae, protonymph, deutonymph and adult. Mites have a rapid development rate and their reproductive capacity is influenced by relative humidity, temperature, plant variety, cellular nutrition and the presence of effective natural enemies.

Tetranychus urticae females oviposit on the leaf undersurface; eggs hatch in 3-4 days; and the egg to adult stage (25 to 28 C, RH 60-70%) is 7 to 11 days. Higher temperatures favor a higher net reproductive rate, a shorter generational time, a higher intrinsic rate of population growth and a shorter doubling time of the population.

d. Management

Pesticide applications for controlling mites on a long-cycle crop such as cassava are not a feasible or economic option for low-income farmers. Moreover, even low doses of pesticides have adverse effects on natural enemies. Cultural control methods have not been explored, and there is little mention of their use in the literature. Research into the control of *M. tanajoa* and *T. urticae* has followed two main thrusts: host plant resistance and biological control. It is expected that these two complementary strategies can reduce mite populations below economic injury levels.

Host plant resistance (HPR)

It is hypothesized that in the presence of efficacious natural enemies, only low-to-moderate levels of HPR are needed to reduce CGM populations below economic injury levels. A level of resistance that would hinder, delay or suppress the initial buildup of CGM populations could provide sufficient opportunity for establishing effective natural enemy populations that would prevent an eruption of the CGM population. Therefore, an important objective of an HPR strategy is to develop cultivars that are not highly susceptible to the CGM and that hopefully contain low-to-moderate levels of resistance. Immunity or even high levels of resistance do not appear to be available in *M. esculenta* germplasm.

A considerable effort has been made to identify CGM resistance in cultivated cassava. CIAT, IITA and several national research programs in the Americas and Africa have screened cassava germplasm for CGM resistance. Of the more than 5,000 landrace cultivars in the CIAT cassava germplasm bank, only 6% (300 cvs.) were identified as having low-to-moderate levels of resistance. A select number of cultivars with moderate levels of resistance have been released to farmers after a considerable effort by plant

breeders and entomologists. Two hybrids (ICA Costeña and Nataima 31), both with low levels of mite resistance, are being grown by cassava farmers in Colombia (Bellotti, 2008).

Most mite-resistance field evaluations by CIAT have been carried out at the Colombian Atlantic Coast in the lowland tropics with a prolonged dry season (4-6 months) and high mite populations. In Brazil, CGM evaluations were conducted by CNPMF/EMBRAPA, primarily in the semi-arid regions of the Northeast. Of the 300 cultivars identified by CIAT as promising for CGM resistance (over several years and 2-7 field cycles), 72 have consistently had damage ratings below 3.0. Low-to-moderate levels of resistance are indicated by 0-3.5 (0-6 damage scale).

Mite resistance-mechanism studies indicate strong antizenosis (preference vs nonpreference) for oviposition, as well as moderate antibiosis. In lab studies, *M. tanajoa* displayed a strong ovipositional preference for susceptible varieties. When paired with the moderately resistant cvs. MEcu 72, MPer 611 and MEcu 64 in free-choice tests, 95, 91 and 88%, respectively, of the eggs were oviposited on the susceptible cultivar CMC 40. Antibiosis is expressed by mites having lower fecundity, a longer development time, a shorter adult life span, and higher larval and nymphal mortality when feeding on resistant vs. susceptible cultivars.

Host plant resistance studies for *Tetranychus* mite species have been less intensive than those carried out for the CGM. Field evaluations of cassava germplasm by CIAT in Colombia have been hindered by low *Tetranychus* mite field populations. However, some laboratory studies have been conducted. *T. urticae* larval and nymphal mortality was 68% higher on the cultivar MBra 12 than on the susceptible cultivar MCol 22. Mortality on the cultivar MCol 1434 was 50% higher than that on MCol 22. Egg eclosion and larval survival was significantly lower (25%) on MCol 1351 than on MCol 22. Germplasm evaluations for resistance to *Tetranychus* mite need to be carried out in regions where high mite populations occur. The opportunity for this line of research is better suited for those regions of Asia where *Tetranychus* mite species are reported to cause economic damage.

Several wild *Manihot* species have been evaluated as a potential source of resistance to cassava mites by CIAT in Colombia. Moderate levels of resistance (2.0 on a 1.0 to 6.0 damage scale) to *M. tanajoa* have been found on some accessions of *M. esculenta* subspp. *flabellifolia*. In laboratory studies, *M. tanajoa* oviposition was reduced considerably on some accessions of *M. tristi*, *M. filamentosa* and *M. alutacea*, when compared to a susceptible *M. esculenta* (CMC 40) cultivar. These results indicate that a research effort to utilize wild *Manihot* species as a source of resistance to cassava mites is needed. This effort could also be extended to include Tetranychus mite species

Biological control

Biological control offers an alternative and a practical solution for management of cassava mites, provided that chemical pesticides are not being employed to control other arthropod pests, such as whiteflies and mealybugs.

Beginning in the early 1980s, extensive evaluations of the natural enemy complex associated with cassava mites were conducted at more than 2,400 sites in 14 countries of

the Neotropics (Bellotti *et al.*, 1987). The primary target in most of these field and lab studies was the CGM. Predator species feeding on *Tetranychus* mite species were also collected and evaluated. These ongoing extensive surveys indicate that the CGM is present throughout much of the lowland Neotropics; high populations, causing significant yield loss can be localized, occurring most frequently in Northeast Brazil.

Geographic regions of the Americas were identified and prioritized using GIS support, to assist in targeting specific areas for exploration. Homologous maps based on agrometeorological data and microregional classification comparing Africa and the Neotropics were prepared as one of the major targets for biological control in those areas of Africa where the CGM was causing economic damage.

A total of 87 phytoseiid species were collected and stored: 25 are new or unrecorded species; 66 were collected from cassava (**Table 4**). The current predator mite reference collection held at CIAT conserves primarily those related to phytophagous mites found on cassava. A taxonomic key on the species associated with cassava is being prepared with Brazilian colleagues. The CIAT-Brazil collection is a true reference collection with accompanying database and can be readily used for species description. Explorations also identified several insect predators of cassava mites, especially the staphylinid *Oligota minuta* and the coccinellid *Stethorus* sp. After extensive lab and field studies of this predator complex, it was generally agreed that the phytoseiid predators offer the best potential for controlling mites, especially when occurring in low densities. The phytoseiid development cycle is shorter than that of the CGM and *Tetranychus* mites. In studies at CIAT with the species *Neoseiulus anonymus*, the egg-to-adult development period at 25 and 30°C was 4.7 and 4.0 days, respectively (Bellotti, 2002). This is approximately half the development period for the CGM and *T. urticae* at those temperatures. Survey data also revealed that CGM densities were much higher in Northeast Brazil than in Colombia, but the richness of phytoseiid species was greater in Colombia.

Field data from experiments in Colombia demonstrated that a rich phytoseiid species complex could reduce CGM populations and prevent cassava yield loss. When natural enemies were eliminated by applying low doses of an acaricide that did not affect the CGM population, cassava root yields were reduced by 33%. Application of an acaricide did not increase yields, indicating the effectiveness of biological control (Braun *et al.*, 1989).

A major objective of the surveys for CGM natural enemies and the substantial research that followed was to identify the key phytoseiid species controlling CGM populations and introduce them into Africa. This was a collaborative effort between CIAT and EMBRAPA in the Americas and IITA in Africa. Of the phytoseiid species identified as feeding on CGM, those most frequently collected were *Typhlodromalus manihoti* (found in >50% of the fields surveyed), *Neoseiulus idaeus, Typhlodromalus aripo, Galendromus annectens, Euseius concordis* and *Euseius ho* (Bellotti *et al.*, 1987).

More than ten species of phytoseiids were shipped from Colombia and Brazil to Africa, via quarantine in England (IIBC-International Institute of Biological Control). None of the Colombian species became established, but three of the Brazilian species did (*T. manihoti, T. aripo* and *N. idaeus*). *T. aripo*, the most successful of the three species, was released in Africa in 1993 and is found in more than 14 countries (Yaninek *et al.*,

1993). *T. aripo* inhabits the apex of cassava plants during the day and forages on leaves at night and can persist during periods of low CGM densities by consuming alterative food sources (e.g., maize pollen). On-farm trials in Africa indicate that *T. aripo* reduced CGM populations by 30-90% and increased fresh root yields by 30-37%. This represents an increase of US$ 60/ha for cassava producers (Yaninek *et al.*, 1993; Onzo *et al.*, 2005).

Table 4. Natural enemies (insects, mites/phytoseiidae and entomopathogens) of mites feeding on cassava.

Principal Species	*Predators*	*Entomopathogens*
Mononychellus tanajoa	**Insects:**	
	Stethorus tridens	*Hirsutella thompsoni*
	S. darwin	*Neozygites floridana*
	S. madecasus	*N. tanajoae*
	Oligota minuta	
	O. gilvifrons	
	O. centralis	
	O. pigmaea	
	Delphastus argentinicus,	
	Chrysopa sp.	
	Mites/Phytoseiidae:	
	Typhlodromalus manihoti	
	T. aripo	
	T. rapax	
	E. lokole	
	E. ncholsi	
	E. baetae,	
	Neoseiulus idaeus	
	Galendromus annectes	
	Euseius concordis	
	Euseius ho	
	Euseius fustis (5)	
Tetranychus canadensis	*Euseius naindaimei*	
	Amblyseius aerialis	
	Galendromus annectens	
	Typhlodromalus manihoti	
	T. rapax	
	Phytoseiulus macropilis	
	Phytoseius purseglovi	
	Typhlodromips dentilis	
Tetranychus tumidus	*Amblyseius chiapensis*	
	A. largoensis	
	A. aerealis	
	Euseius naindaimei	
	Galendromus annectens	
	Neoseiulus anonymus	
	Phytoseiulus macropilis	
	Typhlodromalus manihoti	
	T. dentilis	

Table 4. Continued

Principal Species	*Predators*	*Entomopathogens*
	T.aripo	
	T.rapax	
	Typhlodromips bellotti	
Tetranychus marianae	*Cydnodromella pillosa*	
T. mexicanus	*E useius casaeriae*	
	Galendromus annectens	
	Neoseilus anonymus	
	Phytoseiulus macropilis	
	Typhlodromalus peregrinus	
Tetranychus yusti	*Euseius ho*	
	Neoseiulus idaeus	
	Neoseilus anonymus	
	Phytoseiulus macropilis	
	Typhlodromalus manihoti	
	T. tenuiscutus	
Tetranychus kanzawai	*Neoseiulus longispinosus*	
Tetranychus urticae	*Neoseilus anonymus*	
	Galendromus helveolus	
	Phytoseiulus macropilis	
	Typhlodromalus aripo	
	T. manihoti	
	T. rapax	
Tetranychus bastosi	*Neoseiulus idaeus*	
	Neoseilus anonymus	

Numerous predator mite species (Phytoseiidae) have been observed feeding on *Tetranychus* mite species and several species have been evaluated feeding on *T. urticae*. These include *G. annecteus*, *E. concordes*, *Phytoseilus pessimilis*, *Neoseiulus anonymous*, *N. chilenensis*, *N. idaeus* and *P. macropilis*. The development time (egg to adult) for the seven species ranged from 4.2 days (*N. idaeus*) to 6.1 days (*G. annecteus*) (25ºC, 70 5% RH and 12:12 hours photoperiod) when feeding on *T. urticae*. The development time for these seven species when feeding on *M. tanajoa* ranged from 4.0 (*P. pesimilis*) to 5.8 days (*G. annecteus*). The development time during these experiments for the phytophagous species, *T. urticae* and *M. tanajoa* was 9.1 and 10.7 days, respectively. The development time of three predator species, *N. chilenensis* (4.4 days), *P. macropilis* (4.3 days) and *N. idaeus* (4.2 days) was less than one-half that of *T. urticae* (9.1 days). *N. anonymous* development time when feeding on *T. urticae* was 4.7 days, nearly one-half that of the prey species.

Adult longevity of the phytoseiid species when feeding on *T. urticae* ranged from 17.4 days (*N. idaeus*) to 54.8 days (*N. chilenensis*). When feeding on *M. tanajoa*, adult longevity ranged from 18.2 days (*N. ideaus*) to 44.1 days (*P. macropilis*). In general, the data for both species was similar.

Predation consumption studies were carried out with the phytoseiid *N. anonymous* on both prey species. *N. anonymous* consumed all four-development stages (eggs, larvae,

nymphs and adults) of *T. urticae* and *M. tanajoa*. *N. anonymous* when feeding on *T. urticae* consumed an average of 78.3 eggs, compared to only 10.3 *M. tanajoa* eggs. However, *N. anonymous* showed a higher average consumption of larvae (20.0 vs. 2.8), nymphs (9.0 vs. 5.1) and adults (21.0 vs. 4.7) when feeding on *M. tanajoa* compared to *T. urticae*. These results indicate that *N. anonymous* could play an effective role in the biological control of both prey species, especially that of *T. urticae* because of the high egg consumption.

Neozygites sp. is a fungal pathogen (Zygomycetes: Entomophthorales) found on mites throughout cassava-growing regions of the Neotropics. Isolates of *Neozygites floridana* from Brazil and Colombia, and from *M. tanajoa* from Brazil and Benin were evaluated on the CGM in Africa. Laboratory and field studies indicate that the Brazilian strain of *N. floridana* was the most virulent. Although this fungus shows considerable promise for biological control of the CGM, further research and field evaluations are needed (Delalibera *et al.*, 1992).

Exotic phytoseiid mite predators can play an important role in reducing CGM populations in Africa and *Tetranychus spp.* in Asia. However, field observations in the Neotropics indicate that they are very sensitive to disturbances in the agro-ecosystems, especially the use of pesticides. For example, when insecticides were applied at CIAT for controlling thrips, CGM populations erupted, and few phytoseiid predators were detected in the fields. Studies in Colombia showed that low acaricide doses that did not cause mortality to CGM, were lethal to phytoseiids, causing a considerable increase in mite populations and cassava yield losses (Braun *et al.*, 1989). In the Neotropics, especially on larger plantations, cassava farmers may use pesticides to control hornworm, whitefly or thrips outbreaks. This could result in mite outbreaks and yield losses if biological control is the only control measure employed, and highly susceptible cultivars are being grown.

CIAT maintains a cassava phytophagous mite and a phytoseiid predator mite collection that has been sourced from many of the cassava growing regions of the Americas, Asia and Africa. The collection contains more than 20,000 specimens and is utilized by cassava scientists for comparative taxonomic purposes. The collection is accompanied by a computerized database that allows researchers to identify the geographic location of cassava mite species and their natural enemies. It also allows us to predict the climatic parameters that might favor outbreaks or spread of phytophagous mite species and the potential adaptability of their natural enemies.

e. Recommendations for control of cassava mites

1. Stake treatment (Thiamthoxam) in endemic areas.
2. Plant at the beginning of the rainy season (to guarantee good establishment).
3. Appropriate fertilization to improve plant vigor.
4. Use resistant or tolerant cultivars where available.
5. Water sprayed under pressure will reduce mite populations.
6. Only use selective insecticides to protect natural biological control.
7. Phytoseiid mite predators are very sensitive to pesticides (even low dose applications).
8. Quarantine measures (prevent invasive species).

CLIMATE CHANGE AND CROP MANAGEMENT

In recent years pest populations have shown dramatic increases on large scale cassava plantations in southern Brazil. Crop damage resulting in root yield losses due to whiteflies, mealybugs and lacebugs have been recorded in the states of Sao Paulo, Parana and Mato Grosso do Sul. These increases in pest populations may be the consequence of climate changes in the region and subsequent changes in cassava crop management (Bale *et al.*, 2002). Southern Brazil is sub-tropical and during the months of June, July and August, referred to as "winter", temperatures were often low enough to cause a frost, resulting in crop defoliation and stem damage. In June, cassava producers would prune plants back to almost ground level and store stems in protected confines, to be used as cuttings for planting in September when the threat of frost has past. The absence of cassava foliage in the fields probably caused pest populations to dramatically decrease.

With warmer temperatures in September, there was a regrowth of the pruned plants and, in addition, the next cropping cycle was sown, using the stored stems as a source of planting material (cuttings). Populations of mealybugs, whiteflies and lacebugs, did not increase to levels causing economic damage (yield losses). The major pest of consequence was the cassava hornworm (*E. ello*); this is a highly migratory species and adult populations probably moved into the southern region from warmer northern areas.

In recent years, according to cassava producers in this southern region, temperatures during this "winter" period have been warmer with less probability of frost. This has had an effect on cassava crop management practices. Farmers no longer prune all stems back to ground level, leaving growing stems and foliage in the field. This provides a food source for the aforementioned cassava pests. The life cycle is not disrupted and active pest populations can occur during this "winter" period. An active pest population is thus available in the field when regrowth occurs in September and when stem cuttings in the subsequent crop cycle germinate and young, tender plants emerge. Pest populations, especially whiteflies, can migrate to and infest the new growth and young plants. As earlier noted (see section on whiteflies) whitefly populations increase rapidly under these conditions and high populations can cause considerable yield losses.

In addition, the warmer temperatures and more frequent rainfall have resulted in more frequent, or staggered plantings of the crop. This has resulted in having the cassava crop at varying ages in the same field or plantation. These staggered plantings provide an ideal scenario for an increase in cassava pests, especially whiteflies.

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CASSAVA PESTS MANAGEMENT IN INDIA

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ABSTRACT

Cassava is an important root crop grown in India for food, feed and industry. However, the quality and quantity of roots are severely affected by the infestation of many arthropod pests. The cassava green mite, *Mononychellus tanajoa* (Bondar), an internationally important and devastating pest, has so far not been reported in India due to strict quarantine measures. The important insect pests on cassava in India are the sweetpotato whitefly, *Bemisia tabaci* (Gennadius), the spiraling whitefly, *Aleurodicus dispersus* (Russell), and the soft scale *Aonidomytilus albus* (Cockerell).

The white fly *Bemisia tabaci* transmits and spreads cassava mosaic virus. Over 100 plant viruses in the genera *Begomovirus* (Geminiviridae), *Crinivirus* (Closteroviriidae) and *Carlavirus* or *Ipomovirus* (Potyviridae) are transmitted by this pest. The nymphs secrete honey dew while feeding and this facilitate the growth of fungus. In India this pest has been reported throughout the year. Maximum number of nymphs observed from a single leaf at the CTCRI experimental plots was 99, and it exceeded 3000 under glasshouse conditions with a temperature of 32 ± 2°C and relative humidity of 75%. *Encarsia* sps. and *Eretomocerus mundus* were reported as the natural enemies of the whitefly.

The spiraling whitefly, *Aleurodicus dispersus*, is another serious problem in cassava fields. A survey on the occurrence of this pest in Kerala and Tamil Nadu States revealed that this pest was abundant from September to May, and the intensity of infestation was high during January to April. The maximum infestation was observed in February (average 400 adults/leaf), but the intensity decreased at the onset of the monsoon rains in June. Fifty six plant species including fruit crops, horticultural crops, garden plants and plantation crops were recorded as its alternate hosts. The important predators recorded from the field are *Menochilus sexmaculatus* F., *Cybocephalus* sp. and *Scymnus quadrillus* Mots. A predator, *Encarsia meritoria,* was also collected.

The soft scale, *Aonidomytilus albus* Cockerell, is also an important pest infesting cassava stems, both in the field and when stored as planting material. Severely infested plants often fail to establish in the field. The field contamination is mainly from planting materials; hence, the use of stems that are free from scale insects is very important for the management of this pest. Storing the stems in a vertical position and keeping them under the shade of trees facilitates sufficient aeration and reduces the multiplication of scales. Tetranychid spider mites, i.e. *Tetranychus cinnabarinus* (Boisd), *Tetranychus neocaledonicus* Andre, *Eutetranychus orientalis* (Klein) and *Oligonychus biharensis* (Hirst) are also recognized as important pests of cassava in the field.

Due to the short shelf life of cassava roots, they are often processed into plain dried and parboiled chips for long-term storage. During storage, these products can be infested by a number of insect pests, particularly by coleopteran pests. The important pests are *Araecerus fasciculatus* (De Geer) (coffee bean weevil), *Tribolium castaneum* (Herb.) (red flour beetle), *Lasioderma serricorne* Fab. (cigarette beetle), *Rhyzopertha dominica* (Fabricius) (lesser grain borer) and *Sitophilus oryzae,* Linnaeus (rice weevil). These pests can effectively be controlled by periodic drying of the stored products to ensure that the moisture content is below 12%. Treatment with 3% common salt was also found effective to reduce the infestation. Irradiation at 100 Gy was very effective to suppress all stages of these pests.

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INTRODUCTION

Cassava is an important root crop, which is widely cultivated in tropical and subtropical regions. However, the yield is often affected by the depredation of arthropod pests, and rodents both in the field and under storage (Bellotti and Schoonhoven, 1978; Lal and Pillai, 1981). The most important pests encountered in India are described below.

I. Pests of Cassava in the Field

The pest complex in cassava fields is shown in **Table 1**. Sweetpotato whitefly, spiraling whitefly, chilly thrips, tetranychid spider mites, cassava scales and mealybugs are the most important pests causing damage to cassava in the field.

Bemisia tabaci (Gennadius) (Cassava/sweetpotato whitefly)

Bemisia tabaci was first described in 1889 by Gennadius in Greece as a pest of tobacco (*Nicotiana tabacum*). It is a polyphagous pest distributed worldwide in tropical, subtropical and temperate zones. Over 900 plants have been identified as its host, and 111 plant virus species of the genera *Begomovirus* (Geminiviridae), *Crinivirus* (Closteroviridae), *Carlavirus* or *Ipomovirus* (Potyviridae) have been transmitted by the pest (Jones, 2003). *B. tabaci*, *B. giffardi*, *B. grossa*, *B. hancocki*, *B. leakii*, *B. moringae* and *B. religiosa* are the seven species of *Bemisia* prevalent in India (Mound and Halsey, 1978), but only *B. tabaci* is associated with cassava. Among the 37 species of whiteflies identified, *B. tabaci* (Gennadius) is the most important and ubiquitous pest inflicting damage directly and indirectly to the plants. Storey (1936) reported the role of *B. tabaci* as a vector of African mosaic disease in cassava and this was confirmed by Chant (1957). The center of origin of *B. tabaci* was suggested as being the Indian subcontinent (Fishpool and Burban, 1994), but evidence support that it might be from Pakistan or from India (Brown *et al.*, 1995). In India *B. tabaci* was first reported in 1905 (Misra and Lamda, 1929; Reddy and Rao, 1989) and in 1919 it became a serious pest of cotton in the Punjab. An outbreak of sweetpotato whitefly was reported in the southern part of India during 1985-1987 and in the northern belt during 1987-1995 on different vegetable crops (Basu, 1995). There is a cassava-specific population of *B. tabaci* christened as 'the Indian cassava biotype' that acts as a vector for Indian cassava mosaic disease (ICMV), but the sweetpotato biotype is a non-vector of mosaic disease in cassava (Lisha *et al.*, 2003).

Climatic factors have a pivotal role in their population build up. Higher temperatures and lower humidity are the congenial conditions for their fast multiplication. Pillai and Daniel (1979) recorded lower populations of whitefly during August-September, with the lowest in August, and higher populations during February and March, with the highest in March. High reproductive potential, broad host range and resistance to insecticides are some of the constraints being faced for their management.

Several potential parasitoids have been reported suppressing its population. Among them, *Encarcia* sp. and *Erectmocerus* sp. are very common in India. Hayat (1998) reported more than 200 species of *Encarsia* from India. Although chemical pesticides are in use to manage the pest, this has been highly discouraged due to an array of reasons, including the deterioration of the population of natural enemies. The most feasible method for the management of whitefly is proper field sanitation and cultivation of resistant varieties.

Removal of crop residues and rouging of infested plants also reduces the risk of carryover populations (Thresh *et al.,* 2005).

Table 1. List of cassava pests encountered in the field in India.

Scientific name	Common name	Family	Order
Pests attacking the stems			
Aonidomytilus albus Ckll.	White scale	Diaspididae	Hemiptera
Saissetia coffeae Wlk.	Helmet scale	Cocoidae	Hemiptera
Lepidosaphes piperis G.	Pepper scale	Diaspididae	Hemiptera
Pseudococcus filamentosus Ckll.	Mealybug	Coccidae	Hemiptera
Pterolophia melanura Pasc.	Stemborer	Cerambycidae	Coleoptera
Pests attacking the stakes and seedlings			
Leucopholis coneophora Burm.	White grub	Melolonthidae	Coleoptera
Odontotermes Sp.	Termite	Isoptera	
Pests feeding on foliage			
Rhopalosiphum esculentum sp. n.	Aphid	Aphididae	Hemiptera
Bemisia tabaci (Genn.)	Sweetpotato whitefly	Aleyrodidae	Hemiptera
Tetranychus cinnabarinus (Boisd.)	Spidermite	Tetranychidae	Acarina
Tetranychus neocaledonicus Andre.	Spidermite	Tetranychidae	Acarina
Eutetranychus orientalis (Klein.)	Spidermite	Tetranychidae	Acarina
Oligonychus biharensis (Hirst.)	Spidermite	Tetranychidae	Acarina
Retithrips syriacus (Mayet)	Grapevine thrips	Tripidae	Thysanoptera
Myllocerus curvicornis F.	Grey weevil	Curculionidae	Coleoptera
Euchromia polymena Linn.	Hairy caterpillar	Amatidae	Lepidoptera
Euproctis fraterna (Moore)	Hairy caterpillar	Lymantridae	Lepidoptera
Orthacris simulans (B.)	Wingless	Acrididae	Orthoptera
Sarthrophyllia rugosa (Lin.)	Long horned grasshopper	Acrididae	Orthoptera
Pests damaging the roots			
Gonocephalum sp.	Ground beetle	Tenebrionidae	Coleoptera

***Aleurodicus dispersus* Russell (Spiraling whitefly)**

This sap-feeding insect is a native of the Caribbean islands and Central America (Russel, 1965). Adults are 2 mm long, white in color due to the powdery or waxy scales all over the body and wings. They congregate on both upper and lower surfaces, but prefer to feed and lay eggs on the lower surface of the leaf. The male is bigger than the female. Eggs are pale yellow, laid singly in a spiraling manner and are covered with white waxy substances. They are firmly attached on the leaf by a minute stalk. Egg laying starts 2-3 days after emergence and on average 110 eggs are laid by a female. Longevity of adults varies from 18-26 days with a mean of 22 days. The number of eggs per egg mass ranges from 5 to 22 with a mean of 10.6. *A. dispersus* is a polyphagous pest infesting a wide range of plants. Immature and adult stages suck sap, causing yellowish specks on the leaves and damage to the host plant. Severely infested leaves are covered with black sooty mould due to the secretion of honeydew by the whitefly, and this hinders the photosynthesis of the host plant. Premature leaf fall is one of the symptoms of a severe infestation.

The incidence of spiraling whitefly in India was first reported in 1994 at Thiruvananthapuram (Palaniswami *et al.,* 1994) and subsequently from five states in peninsular India on a variety of crops (David and Regu, 1995; Mani and Krishnamoorthy, 1999; Rajamma *et al.,* 2001; Aishwariya *et al.,* 2007). Prathapan (1996) reported 72 host plants in Kerala. A survey conducted in Kerala and Tamil Nadu revealed that the whitefly incidence was prevalent from September to May and its intensity of infestation was high during January to April (Rajamma *et al.,* 2002). The highest infestation was observed in February (average 400 insects/leaf) and the lowest in September (average 3 insects/leaf); however, the infestation declined at the onset of the monsoon (June). The team reported a total of 56 plant species belonging to 35 families, including fruit crops, horticultural crops and garden plants, and plantation crops as its alternate hosts.

The important predators recorded from the field are *Menochilus sexmaculatus* F, *Cybocephalus* sp., *Scymnus quadrillus* Mots., *Axinoscymnus puttarudriahi* Kapur, *Pharascymnus hornii* Weise and *Oligota* sp. An aphilinid parasitoid, *Encarsia meritoria*, was also reported on spiraling whitefly.

***Scirtothrips dorsalis* Hood (Chilly thrips)**

Adults are minute with fringed black wings and red eyes. Eggs are microscopic and are laid under the leaf epidermis. The incubation period is 5-6 days and the young ones crawl on the leaf for feeding. Nymphs are pale yellow and after second moult they enter a short pre-pupal stage before pupation. Adult emergence is in about five days and the total life cycle is completed in 15-18 days. Longevity of adults is 20-25 days. Both adults and nymphs feed on the under-surface of the leaf. The early infestation is characterized by yellow streaks or patches on the veins and leaf lamina. Infested leaves turn brown, brittle and eventually droop or fall.

Over 80% of the cassava plants raised in pots under glasshouse conditions at the Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram were infested by *Scirtothrips dorsalis* (Rajamma *et al.,* 2004). It is also a major pest on chillies in all parts of

India, particularly during severe weather conditions (Pruthi, 1969). Duraimurugan and Jagadish (2003) recorded 39 host plant species belonging to 19 families infested by this species. The pest is prevalent throughout the year, but populations are high during March-April. Highly infested leaves roll up and dry. *Retithrips syriacus* was also reported as a pest on cassava in Kerala (Pillai and Hrishi, 1975) and in Tamil Nadu (Subramniam *et al.*, 1977).

Tetranychid spider mites

Tetranychus telarius L., *T. neocaledonicus* Andre, *Eutetranychus orientalis* Klein and *Oligonychus biharensis* (Hirst) are the four species of tetranychid mites infesting cassava in India (Pillai, 1994). The former two, commonly known as red mites, feed on the under-surface of the leaf, whereas the latter two are upper-surface feeders. Arjunan (1975) studied the economic importance of *T. telarius* in cassava. Lal and Pillai (1976) observed the occurrence of *T. neocaledonicus* feeding on the lower-surface, and *E. orientalis* and *O. biharensis* feeding on the upper-surface of the leaf (Lal and Pillai, 1978). The appearance of yellow specks along the margins and the withering of severely infested leaves are the symptoms of mite attack. Infestation by spider mites is most severe from January to April. The intensity of infestation increases with the severity of the dry spell. Planting in November causes severe prolonged incidence during the early growth period, and the damage is more in this season than when the crop is planted in July.

The eggs of *T. cinnabarinus* are globular, transparent, creamy white, 0.17 mm long and they are laid scattered on the lower surface of the leaf, mostly along the mid-rib and lateral veins. As the eggs mature they turn into pale yellow with two prominent eyespots and the larval movements are visible at this stage. The mean egg, larval, protonymphal and deutonymphal periods are 5.3, 2.7, 3.6 and 4.9 days, respectively. Mating takes place soon after emergence and often the male helps female nymphs for quick moulting. Unfertilized eggs give birth only to males, but both sexes emerge from fertilized eggs. Fecundity ranges from 49 to 58 with an average of 52.8. Adult longevity ranges from 8 to 10 and from 10 to 20 days for mated and unmated females, respectively. The total life cycle from egg to adult varies from 11 to 20 days with a mean of 16.4 days. Sexual dimorphism is evident; males are smaller, slender, very active and move fast. Females are brick red and males are pale yellow. The sex ratio of males to females is 1:2.

The eggs of *Eutetranychus orientalis* are circular, flattened, disc-shaped and are laid in a linear fashion on the upper surface of the leaf, mostly along the main veins of the leaflet. Larval, protonymphal and deutonymphal periods including the quiescent stages are 2.0, 2.4 and 2.5 days, respectively. The total life cycle from egg to adult ranges from 10 to 14 days with an average of 12.4 days. Sexual dimorphism is present. Males are smaller, pale brown with a yellowish tinge, and the first pair of legs are long. Females are oval-shaped, pale brown with black or deep brown spots on the dorsal surface and their legs are shorter than the body. Females lay eggs throughout their life time. Unfertilized eggs give rise to males only, while fertilized eggs produce both males and females. Average fecundity of mated and unmated females is 47.4 and 27.0, respectively; longevity of male and female

is 7.9 and 7.8 days respectively, but unmated females live longer (9.8 days) than mated females. The sex ratio of males to females is 1:2.5 (Pillai and Palaniswami, 1985).

The mite populations are significantly lower in irrigated fields. Spider mites are polyphagous and the important alternate hosts are *Manihot glaziovii, Citrus aurantifolia, Gossypium* sp., *Abelmoschus esculenta, Solanum melongena, Carica papaya, Glyricidia maculata, Ricinus communis, Cassia fistula, Murraya koenigii, Pongamia glabra* and *Ipomia* spp. Among these, *M. glaziovii, G. maculate* and *Ipomea batatas* support high populations of cassava mites. Rainfall is the most important limiting factor adversely affecting the mites. Heavy rain with strong winds wash away all stages of the population.

Natural enemies of spider mites recorded from cassava fields are *Pharoscymnus hornii* Weise, *Stethorus gilvifrons* Muls., *Scolothrips indicus, Oligotta* sp. and the Phytoseiid mite, *Amblyseius longisphinosus*. Among these the most effective predator is the thrips *S. indicus*, which consume on average 33 eggs and 24 nymphs per day under laboratory conditions. However, the population of predators in cassava fields tends to be too low to suppress mites. The toxic principle, cyanogenic glucoside, present in cassava does not seem to have any impact on the development of mites in cassava; however, some resistant varieties have been identified against mite infestations. Pillai and Palaniswami (1988) screened 1200 accessions of cassava against spider mites and reported 18 resistant, 139 tolerant, 606 susceptible and 437 highly susceptible accessions.

***Aonidomytilus albus* Cockerell (Cassava scale/ White mussel scale)**

This has not been noticed as a serious problem in the field, but cassava stems under storage can be severely infested by this pest. The female is mussel-shaped, whitish to dark brown and 1.75 to 2.50 mm long. It was first recorded in India by Ananthanarayanan *et al.* (1957) in Salem. Infestations are common on stems, branches or even on leaf petioles; these occur in the dry season and are aggravated by prolonged moisture stress (Lal and Pillai, 1981). Adults and larvae are encrusted around the stem and multiply rapidly. The infested stems dry quickly and fail to establish in the field. Eggs are deposited in clusters and after oviposition their bodies shrink and shrivel. The incubation period lasts for four days and the crawler moves around in search of a new area or is dispersed by wind or animal contact. Dispersal can also be achieved through transport of the infested materials. Crawlers once settled become sedentary and the moulted skin is retained upon its body. The life cycle varies from 20-25 days. Males are winged and can fly. Stacking the stems in a vertical position and keeping them in the shade (Pillai *et al.*, 1990), and the use of pest-free planting materials are the practices that should be followed for the management of this pest. Natural enemies of scale insects commonly seen in India are *Chilocorus nigritus* F., *Chilomenus sexmaculata* F., *Scymnus* and *Stethorus* spp., and predatory thrips *Scolothrips indicus.*

***Pseudococcus filamentosus* (Cokerell) (Mealybug)**

This is not a serious pest in cassava; however, sporadic incidences have been observed. Nymphs and adults colonize under the leaf, petiole and stem and produce a

honeydew secretion which causes the growth of sooty mould. As the infested plant is very conspicuous due to these powdery white masses, they can be destroyed easily.

II. Pest of Stored Cassava Chips

High perishability is the major concern for storage of fresh cassava roots. Fresh roots cannot be stored for more than 2-6 days after harvest without quality deterioration. Rotting is associated with rapid production of high acidity, which turns the roots unpalatable and also render them unfit for subsequent processing. As the fresh roots deteriorate within a few days after harvest, they are generally processed into dry chips, flour, sago or *rawa* (semolina), which can all be stored for long periods. The processed products are intrinsically far more stable than the fresh roots. Under storage conditions, deterioration is mainly due to extrinsic factors, especially by insects and molds (McFarlane, 1982). In addition to the direct damage to stored-products, insects also play an important role in carrying fungal spores which contaminate the products. Countries where high humidity prevails are practicing re-drying of cassava periodically to avoid the infestation of microbes and insect pests. However, during storage, chips are highly vulnerable to the infestation by a spectrum of insect pests as listed in **Table 2**, and these may cause heavy losses. Infestation by pests may lead to the deterioration of the shape of the chips, and subsequently results in a powdery mass. Premkuar *et al.* (1996) observed qualitative and quantitative loss of plain dried chips due to the infestation by stored-product pests. Processed chips with less than 10% moisture content are unsuitable for the development of insect pests. The hard nature of parboiled chips, resulting from gelatinization while processing, make them also less susceptible to insect damage. Hirandani and Advani (1955) reported that in India, parboiled chips could be stored for nine months in a cellar with 3% loss in weight, and with 4-5% loss in an ordinary room. In the case of plain sun-dried chips, the losses were 10-12% and 12-14%, respectively, after only five months.

***Araecerus fasciculatus* (De Geer) (Cassava chips borer/coffee bean weevil)**

This is a polyphagous insect and a major pest in stored cassava chips in India. Adults are 3.0-4.5 mm long and are grayish-brown in color. On average 50 eggs are laid by a female. The life cycle is completed in about 30-50 days. Grubs are voracious feeders and turn the chips into a powdery mass; however, they cannot survive or breed in well-dried chips equivalent to 40% relative humidity (Rajamma and Premkumar, 1994). Similarly, they cannot survive at much higher relative humidity, as this promotes the growth of mold. On average the adults live for 70 days.

***Lasioderma serricorne* Fab. (Cigarette beetle)**

This is a serious pest on many stored products, including plain dried and parboiled cassava chips. Adults are small and oval, about 2.0-3.7 mm long, stout, brown to reddish brown in color and they tuck their heads down under the pronotum when disturbed. Eggs are laid singly in crevices. Females can lay as many as 100 eggs in their life of 25-30 days. The larvae are white and pass 4-6 instars; the later instars pupate within a thin cocoon. Development can be completed in about 25 days at optimum temperature (32.5° C) and at

70% relative humidity. Adults are strong fliers and are usually attracted to light. The beetles are ubiquitous due to their adaptation to a wide range of hosts, but temperature and humidity are the two factors limiting their distribution. The life span depends on the larval food type, temperature and humidity. A high temperature and low humidity reduces their longevity.

Table 2. Important pests of stored cassava chips in India.

Scientific name	Common name	Family	Order
Araecerus fasciculatus (DeG.).	Coffee bean weevil	Anthribidae	Coleoptera
Tribolium castaneum (Herb.)	Red flour beetle	Tenebrionidae	Coleoptera
Dinoderus minutus Fab.	Black borer	Bostrichidae	Coleoptera
Dinoderus bifoveolatus W.	Black borer	Bostrichidae	Coleoptera
Stegobium paniceum L.	Spice beetle	Anobiidae	Coleoptera
Lasioderma serricorne Fab.	Cigarette beetle	Anobiidae	Coleoptera
Rhyzopertha dominica (Fab.)	Lesser grain borer	Bostrichidae	Coleoptera
Alphitobius sp.	Black fungus beetle	Tenebrionidae	Coleoptera
Sitophilus oryzae (Lin.)	Rice weevil	Curculionidae	Coleoptera
Oryzaephilus surinamensis (Lin.)	Saw toothed grain beetle	Silvanidae	Coleoptera
Sitotroga cerealella (Oliv.)	Grain moth	Gelechiidae	Lepidoptera
Setomorpha rutella Zell.	Cloth moth	Tinaeidae	Lepidoptera
Ephestia cautella Wlk.	Fig moth	Phycitidae	Lepidoptera
Pyralis manihotalis Guen.	Meal moth	Pyralidae	Lepidoptera
Pyralis pictus Curt.	Meal moth	Pyralidae	Lepidoptera

***Rhyzopertha dominica* (Fabricius) (Lesser grain borer)**

This is an important internal and external feeder of plain dried and parboiled cassava chips. Parker *et al.* (1981) recognized this as the most destructive pest on stored cassava chips. Adults are 2-3 mm long, dark to black, with a slender and cylindrical body, and the head is hidden under the prothorax. Elytra have distinct rows of pits running their length. Eggs are laid singly on the outer side of the chips; fecundity ranges from 200 to 500. The life cycle is completed in 30 days.

***Sitophilus oryzae* (Linnaeus) (Rice weevil)**

This is a polyphagous pest infesting a number of stored products, including plain dried and parboiled cassava chips (Premkumar *et al.*, 1996; Jayaprakas and Karnavar 1999); they are distributed throughout the tropical and warm temperate areas of the world. Ever since the seventeenth century this weevil has attracted the attention of entomologists.

Dried and parboiled chips prepared from three popular varieties of cassava, i.e. M4, Sree Prakash and Sree Visakham, when provided to *S. oryzae* for their multiplication, the adult emergence was significantly less from Sree Prakash than from the other two varieties (Jayaprakas and Karnavar, 1995). The rearing medium had an influence on the vigor of the weevil. Morphological and weight differences were recorded when the rice weevil was reared on plain dried and parboiled chips (Jayaprakas and Karnavar, 1998). Weevils reared on plain dried cassava chips were heavier than those reared on parboiled chips. Larval period of the weevil in parboiled chips was more prolonged than in plain dried chips. Chips infested by stored-insect pests had a drastic reduction in starch and sugar and this was more pronounced in fully-infested parboiled chips. Total and soluble amylose contents and reducing values were not significantly affected in plain dried chips due to the infestation.

***Tribolium castaneum* (Herbst) (Red flour beetle)**

The adult is red-brown and 3-4 mm long; larvae are cream colored or pale brown and are very active. Adults live up to six months. The population growth is very rapid. Adults and grubs feed on the flour and chips that were damaged by other pests.

III. Control of Storage Pests of Cassava

Adequate drying, hygienic storage conditions and precautionary measures to prevent multiplication of pests and microbes are essential to reduce storage losses. Chips stored in gunny bags for long periods can absorb atmospheric moisture and the hygroscopic nature of chips facilitates the multiplication of pests and microbes at a rapid rate (Halliday *et al.,* 1967). Increased surface area of the sliced roots and the fragments formed during chipping are encouraging the infestation by a wide range of stored-product pests. But, chips prepared from high cyanide varieties are less prone to insect infestation (Rajamma and Premkumar, 1994). Radiation with gamma rays at a dose of 100 kGy is an alternative to manage the pests in stored cassava chips. Irrespective of age, the reproductive potential of males and females is significantly affected by the treatment with gamma rays at 30 and 50 Gy (Jayaprakas and Karnavar, 1996). The number of progeny produced by females that mated with males exposed to 30 and 50 Gy was significantly less than the progeny produced by unradiated females. The premature death of progeny was high in batches treated with 30 and 50 Gy.

A biopesticide prepared from cassava seed is also very toxic to the pest. Jayaprakas *et al.* (2000) observed over 90% mortality of *S. oryzae* at one day after treatment with a petroleum ether extract of cassava seeds. Drying cassava chips to a moisture level below 10% is recommended to reduce insect infestation. Polythene impregnated jute bag, closely woven plastic bags; metal bins etc. can be used for long-term storage. Fumigation with methyl bromide and aluminum phosphide are widely accepted for disinfestations, but keeping in view of their adverse effects on the environment and on every living being, this practice has been highly discouraged. A safe method for the management of stored pests, except *L. serricorne,* is an admixture of salt at 3 to 5 g/100 g of chips while processing (Parker and Booth, 1979), but *L. serricorne* actually prefers salted chips. The waste and residues of chips kept exposed in and around the storage place are the main media for

multiplication of pests; hence, strict sanitary measures should be adopted to avoid the infestation.

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CASSAVA DISEASES IN LATIN AMERICA, AFRICA AND ASIA[1]

Elizabeth Alvarez[2]

ABSTRACT

The importance of cassava (*Manihot esculenta* Crantz) in tropical regions of the world is growing because of an increase in both consumption of fresh cassava roots and the numerous agro-industrial uses of the crop. World cassava production totaled 224 million tonnes in 2007, with the greatest production in Africa. Like all other crops, cassava is also infected by several pathogens. Among the various diseases of cassava that limit production, Cassava Bacterial Blight (CBB), Cassava Mosaic Disease (CMD), Cassava Root Rot (CRR), Cassava Mosaic Virus (CMV), Cassava Brown Streak Disease (CBSD) and Cassava Frogskin Disease (CFSD) are the most important.

In **Latin America** (Colombia, Brazil and Venezuela), Cassava Bacterial Blight (CBB), caused by *Xanthomonas axonopodis* pv. *manihotis* is considered as perhaps the most limiting disease in cassava as it can cause a total loss of the crop. The bacterium disseminates widely through stakes from infected plants, it disperses through splashing during rainfall and by contaminated tools. Super-elongation disease, caused by *Sphaceloma manihoticola* is one of the major diseases affecting cassava in Colombia, Brazil, Venezuela and Central America. Among susceptible cultivars, this fungal disease can cause yield losses of up to 80%. The disease disseminates through infected stakes. Frogskin disease (CFSD) is considered of economic importance as it affects directly root yields, causing losses of more than 90% in some parts of Colombia. The disease is associated with a phytoplasma and has also been reported in Brazil, Costa Rica, Panamá, Perú and Venezuela. The disease has not been reported in Asia and Africa. Improved quarantine inspection is needed to prevent its introduction.

Cassava Root Rot, induced by *Phythophthora* species, can cause losses of up to 80% of total production in Colombia. The pathogen has been identified as *Phytophthora palmivora* and *Phytophthora tropicalis*. In Brazil *Phytophthora drechsleri* can cause significant damage in crops, and losses can reach 80 to 100% when susceptible cultivars are grown

In South and Central America, Cassava Common Mosaic Virus (CsCMV), a potexvirus, and Cassava Vein Mosaic Virus (CVMV) (Caulimoviridae) have been described. CsCMV was first reported in Southern Brazil and Paraguay; it has no known vector and its spread in the field is attributed to mechanical transmission. CVMV is common in the semi-arid zone of Northeastern Brazil.

In **Africa**, Cassava Common Mosaic Virus (CsCMV) has been detected only once in material assumed to have been introduced from South America where the virus is prevalent.

Cassava Mosaic Disease (CMD) is caused by several cassava mosaic geminiviruses and is recognized as the most important constraint to the production of cassava in Africa. A total of eight distinct cassava-infecting geminivirus species have now been identified. Synergism between two species of geminiviruses, the African Cassava Mosaic Virus (ACMV) and the East African Cassava Mosaic Virus (EACMV) is an important factor for initiating and promoting an epidemic. New types of geminivirus satellites in cassava from East Africa, which are associated with severe CMD, have

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been discovered. These disease complexes pose a serious threat to tropical and subtropical agro-ecosystems worldwide.

Cassava Brown Streak Disease (CBSD) is considered important in Tanzania, Uganda, Mozambique and coastal Kenia; there is still uncertainty concerning its epidemiology and mode of spread.

Cassava bacterial blight (CBB), caused by *Xanthomonas axonopodis* pv. *manihotis (Xam),* is a destructive disease in Africa and affects both yields and planting material leading to yield reductions. CBB was particularly severe in all ecozones of Benin, but is rare in Ghana. Cassava in the savanna zones of Benin was heavily diseased with an incidence of 34-84% and a high percentage of plants showed systemic symptoms, while CBB was not observed in the rainforest zone and only sporadically in the coastal savanna zone of Ghana. High incidence and severity of CBB was associated with increasing plant age and clay soils, whereas the disease was less severe when fields were intercropped or planted to cultivar mixtures

In **Asia** cassava is a commercial crop entering diversified markets.Where soils are marginal in fertility, and rainfall is uncertain, cassava has a strong adaptive advantage. Among the various diseases of cassava that limit production, CMD (in India only) and CRR are of major importance as they cause a considerable reduction in yield. CMD is widespread in almost all cassava growing areas of India and causes yield losses of up to 80% in susceptible varieties, and up to 50% in field tolerant varieties. CMD is caused by a cassava mosaic begomovirus. Another important disease is root rot caused by *Phytophthora palmivora* which is emerging as a serious threat to cassava in several industrial areas of Tamil Nadu State of India, causing up to 50% loss in endemic areas. It is also severely affecting yields in Bangladesh and is observed localized in wet areas throughout Asia. Heavy soils, excessive irrigation, poor drainage and the development of a hard pan favor the disease. Disease incidence depends on climatic factors, nutrient management and genotypes.

Cassava diseases such as super-elongation, vein mosaic and brown streak have not been reported in India or elsewhere in Asia. Plant quarantine measures need to be strictly implemented to avoid their introduction

For all these diseases, effective management strategies and healthy planting material production, are discussed, with emphasis on those diseases currently prevalent or being a major future threat in Asia.

INTRODUCTION

World production of cassava roots was estimated at 233 million tonnes in 2008. Africa was the largest producer with 118 million t on almost 12 million ha, followed by Asia with 78.7 million t on 3.97 million ha. Cassava (*Manihot esculenta* Crantz) is a significant staple, providing a basic daily source of dietary energy for almost one billion people in 105 countries. It also has numerous agro-industrial uses. Cassava grows on marginal lands, tolerates drought, and can grow in low-fertility soils. Cassava is also the most inexpensive source of starch that exists, being used in more than 300 industrial products (FAOSTAT, 2010).

Cassava is still widely cultivated under traditional management. This suggests that large numbers of farmers may be ignorant of the crop's diseases and their integrated management. Hence, several diseases threaten the sustainability of cassava production and its profitability. The principal diseases attacking the crop are:

Cassava bacterial blight (CBB; *Xanthomonas axonopodis* pv. *manihotis* or *Xam*)
Phytophthora root rots (PRR; *Phytophthora* spp.)

Superelongation disease (SED; *Sphaceloma manihoticola*)
Cassava frogskin disease (CFSD; phytoplasma Cfdp of the 16SrIII group)
Cassava mosaic disease (CMD; begomovirus complex)
Cassava brown streak disease (CBSD; an ipomovirus).
Brown leaf spot (*Cercosporidium henningsii)*
Diffuse leaf spot (*Cercospora vicosae*)
White leaf spot (*Phaeoramularia manihotis*)
Anthracnose (*Colletotrichum spp.*)

Of these, the most common diseases found in Asia, are Cassava Bacterial Blight (CBB), Phytophthora root roots, Indian and Sri Lanka Cassava Mosaic Disease (only in India and Sri Lanka), Anthracnose and Cercospora. Recently, a new, as yet unidentified disease with symptoms of Witches Broom has been observed in Vietnam and Thailand.

DISEASES CAUSED BY FUNGI

Brown Leaf Spot (*Cercospora henningsii*)

Importance

Brown leaf spot has a broad geographical distribution, being found in Asia, North America, Africa, and Latin America. It attacks naturally *M. esculenta*, *M. glaziovii*, and *M. piauhynsis* Ule (Ferdinando *et al.*, 1968; Golato and Meossi 1966; Powell, 1972). In India, *Cercospora henningsii* is an important pathogen, causing severe defoliation (Edison, 2002).

Symptoms and epidemiology

Symptoms in cassava leaves are characterized by leaf spots visible on both sides. On the leaves' upper surface, uniform brown spots appear, with defined and dark margins. On the leaves' undersurface, the lesions have less-defined margins and, towards the center, the brown spots have a gray-olive background because of the presence of the fungus' conidiophores and conidia. As these circular lesions grow, from 3 to 12 mm in diameter, they take up an irregular angular form, their expansion being limited by the leaves' major veins (**Figure 1**).

Figure 1. Leaf spots caused by Cercospora henningsii.

The veins found within the necrotic area are black. Sometimes, depending on how susceptible the variety is, an undefined yellow halo or discolored area can be observed around the lesions. As the disease progresses, infected leaves become yellow and dry before falling off, possibly because of toxic substances secreted by the pathogen. Susceptible varieties may undergo severe, or even total, defoliation during the hot rainy season.

When wind or rain carry conidia that have dropped from wounds of infected tissues towards leaves of a new planting, primary infections occur. If environmental humidity is sufficiently high, the conidia will germinate, producing branched germinal tubes that frequently anastomose (Chevaugeon, 1956; Viégas, 1941).

When lesions mature, stromata appear from which conidiophores emerge. Secondary cycles of the disease are repeated throughout the rainy season, when wind or rain carries conidia to new susceptible tissues of the plant. The fungus survives the dry season in old lesions, frequently those of fallen leaves. It renews activity with the advent of the rainy season and the growth of new leaves of the host.

Chevaugeon (1956) observed that in a cassava plant the lower leaves are more susceptible than the youngest leaves. However, certain susceptible species (e.g., *M. carthagenensis* Muell.) and *M. esculenta* cultivars can be severely attacked. Severe symptoms have been observed in young leaves, petioles, and even fruits of *M. carthagenensis*. Although plants "hardened" by unfavorable conditions appear more resistant, no significant differences in susceptibility were found between plants growing in fertile soils and those growing in poor soils (Chevaugeon, 1956).

Etiology

Cercospora henningsii, causal agent of the disease, grows in the intercellular spaces of leaf tissues, producing stromata from which conidiophores are produced in dense fascicles. The conidiophores are pale olive brown, semi-transparent, with uniform width and color, and non-branching. Sometimes, black perithecia appear, disseminated in the necrotic tissue of leaf spots and on the leaves' upper surface (Powell, 1972). The perfect state of *C. henningsii* is *Mycosphaerella manihotis* (Ghesquière, 1932; Chevaugeon, 1956).

Management and control

To reduce the severity of infection, recommended cultural practices include reducing excess humidity during planting (Golato and Meossi, 1966). Fungicides based on copper oxide and copper oxychloride, suspended in mineral oil, and applied at 12 l/ha also provide good chemical control (Golato and Meossi, 1966). The best control over the disease can be achieved by using resistant varieties. Significant differences in varietal resistance have been found in Africa (Chevaugeon, 1956; Umanah, 1970), Brazil (Viégas, 1941), and in the extensive collection of cassava varieties held at CIAT, Colombia (CIAT, 1972).

Diffuse Leaf Spot (*Cercospora vicosae*)

Importance

This disease is found where brown leaf spot predominates, that is, in the hot cassava-growing areas of Brazil and Colombia (CIAT, 1972; Viégas, 1941). The pathogen causes severe defoliation in susceptible cultivars, but in Colombia does not cause serious crop losses.

Symptoms and epidemiology

This disease is characterized by the presence of large leaf spots, with undefined margins. Each spot may cover one fifth, or more, of the leaf lobe. On the leaves' upper surfaces, the spots are uniformly brown, whereas, on the lower surfaces, spots also have grayish centers caused by the presence of the fungus' conidia and conidiophores. The spots' general appearance is similar to that of the spots induced by *Phoma* sp., although lesions induced by the latter have concentric rings on the leaves' upper surfaces (**Figure 2**).

Figure 2. Leaf spots caused by Cercospora vicosae in a cassava leaf.

Defoliation may occur in susceptible cultivars, being more severe at the end of the rainy season and/or vegetative cycle. As the disease progresses, leaves become yellow and dry before falling off.

Symptoms of this disease can be confused with those of cassava bacterial blight (CBB; see below), except that the blight lesions are noticeably aqueous.

Etiology

The fungus does not form stromata but sporulates abundantly. The conidiophores are reddish dark brown (Chupp, 1953). The fungus has been recorded as a pathogen occurring only on *Manihot* spp. Mill. As its incidence on a single plant or in a given planting is very low and apparently confined to the plant's lower leaves, its importance is relatively less.

Management and control

- Planting with healthy and resistant cultivars
- Using cultural practices that reduce humidity during planting

White Leaf Spot (*Phaeoramularia manihotis*)

Importance

This fungus is commonly found in the cold humid cassava-growing regions of Asia, America, North America, tropical Africa, and Latin America (Castaño, 1969; Chevaugeon, 1956; CIAT, 1972). In these areas, the pathogen may cause considerable defoliation in susceptible varieties of *M. esculenta*, the only known host species (Chevaugeon, 1956; Viégas, 1941).

Symptoms and epidemiology

Leaf spots caused by *P. manihotis* are smaller, with a different color, to those induced by *C. henningsii*. They vary from circular to angular, with diameters of usually 1 to 7 mm. They are normally white, but sometimes yellowish brown. Lesions are sunken on both sides, to half of the thickness of a healthy leaf blade. On the lower leaf surface, the white spots can be distinguished but they frequently have diffusely colored margins, which sometimes appear as brown-violet irregular lines, surrounded by brown or yellowish halos. The spots' centers have a velvety grayish aspect during the pathogen's fruiting (**Figure 3**).

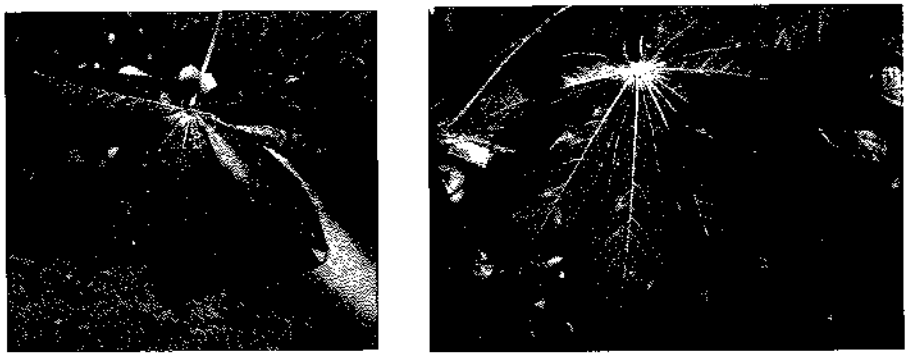

Figure 3. Leaf spots caused by Phaeoramularia manihotis.

The fungus penetrates the host through stomatal cavities and then invades the host's tissues through the intercellular spaces. When leaf spots reach 5 to 7 mm in diameter, a stroma is formed, which produces conidiophores. The disease's secondary cycles are repeated throughout the rainy season as conidia are dispersed by wind or rain splash. The fungus survives the dry season in old infected tissues and renews activity at the beginning of the rainy season and with the host's new growth.

Etiology

Phaeoramularia manihotis, the causal agent, forms thin stromata in lesions on leaves. The stromata produce conidiophores in loose fascicles that emerge through the stromata and are usually olive brown (Powell, 1972).

White leaf spot is very similar to brown leaf spot. However, brown spot usually occurs in warm but not humid areas, whereas white spot appears in cold humid areas. These differences in their geographical distribution are also observed in Africa and Latin America, and are probably the result of different responses of the respective causal agents to temperatures and humidity. The optimal temperature for germinating *C. hemingsii* conidia is 39°C, with a maximum temperature of 43°C. For *P. manihotis*, these temperatures are, respectively, 33°C and 43°C (Chevaugeon, 1956).

Management and control

The control measures recommended for this disease are similar to those for brown leaf spot. Specifically resistant varieties are unknown, but field studies suggest they exist (J. Carlos Lozano, 1979, unpublished data).

Concentric Ring Leaf Spot (*Phoma* spp.)

Importance

This fungal disease, caused by *Phoma* spp., usually appears in the cold cassava-growing areas of Colombia (CIAT, 1972), Brazil (Viégas, 1943a), Philippines, tropical Africa, and India (Ferdinando *et al.*, 1968). According to Edison (2002), this disease is an emerging problem in certain areas where cassava cultivation is intensive. During the rainy season and when the temperature is below 22°C, the disease may cause severe defoliation in susceptible varieties and almost always produces stem dieback.

Symptoms and epidemiology

The disease is characterized by the presence of large dark brown leaf spots, with usually undefined margins. These lesions are commonly found at leaf points, margins of leaf lobes, or along the central vein or other secondary veins. Initially, lesions appear as concentric rings of brown pycnidia on the leaf's upper surface (**Figure 4**). These rings are not found on old injuries because the rain drags away mature pycnidia. In these cases, the spots are uniformly brown, and are very similar to those caused by *Cercospora vicosae*. On the lower leaf surfaces, very few pycnidia occur. Hence, lesions are uniformly brown.

Under conditions of high relative humidity, lesions may be covered by braid-like chains of grayish-brown hyphae. On the lower leaf surfaces, the nervures within the lesions become necrotic, forming black bands that emerge from the spots. These spots grow, causing leaf blight. The fungus invades the infected leaf and then the petiole, which becomes dark brown as it necroses. Leaves wilt and then fall, resulting in severe defoliation in susceptible cultivars. These cultivars may present dieback during epiphytotes and even total plant death. Necrotic stems become dark brown and frequently appear covered with pycnidia.

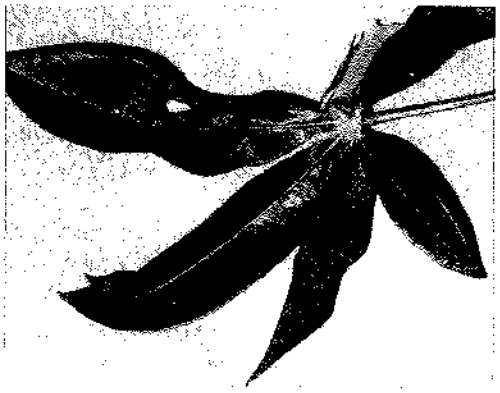

Figure 4. Leaf spots caused by Phoma sp. in cassava.

Field studies suggest that the more mature lower leaves may be more resistant than the young upper leaves. However, total defoliation, accompanied by partial or total dieback, has been observed in susceptible cultivars.

Favorable conditions for the germination of fungal spores occur at temperatures between 20° and 25°C. With artificial inoculation, infection is only achieved when inoculated plants are kept for 48 h at less than 24°C and with 100% relative humidity (J. Carlos Lozano, 1979, unpublished data). Under field conditions, this disease always occurs during the rainy season and in areas where the temperature is less than 22°C.

The fungus' survival mechanism during dry hot periods is unknown. Viégas (1943b) suggested that the fungus may produce its sexual state on infected stems and leaf residues. However, this has not yet been observed or recorded.

Etiology

The causal agent produces numerous, spherical, dark brown pycnidia, either individually or in small clusters, on surfaces of leaves or stems. Pycnidia measure 100 to 170 µm in diameter, their walls are formed by polyhedral cells; and their ostiole measures 15–20 µm. Conidiophores are short and hyaline, producing small conidia (15–20 µm) that are unicellular and ovoid or elongated (Ferdinando *et al.*, 1968; Viégas, 1943a). On lima-bean agar, the fungus forms pycnidia in profuse quantities, appearing in concentric rings.

Management and control

To date, no measures of control exist for the disease, even though it causes heavy losses in areas where environmental conditions are propitious for its development. Although no reports exist on varietal resistance, in the field in Colombia, resistance has been observed in naturally infected plantings. Chemical treatments such as carbendazim (3 g a.i./l) and benomyl (0.6 g a.i./l) during the rainy season may be equally effective in those areas where the disease is endemic.

Cassava Anthracnose (*Glomerella manihotis*)

Although cassava anthracnose has been known for a long time, it has been considered of minor importance. It is characterized by the presence of sunken leaf spots, 10 mm in diameter, that are similar to those caused by *C. henningsii*. The latter, however, appear towards the base of leaves, thus causing their total death.

The pathogen also causes young stems to wilt and induces cankers on mature stems (Irvine, 1969) (**Figure 5**). New leaves, produced at the beginning of the rainy season, are the most susceptible. The disease tends to disappear when the dry season begins (Irvine, 1969). This finding agrees with results obtained from artificial inoculations with an aqueous suspension of spores from the pathogen. Inoculation is successful if incubation is at 100% relative humidity for 60 hours. The fungus will stop invading plant tissue when the relative humidity drops to 70% (CIAT, 1972). The insect *Pseudotheraptus devastans* Distant is associated with the disease (Fokunang *et al.*, 2000), contributing to the pathogen's dissemination and increasing the severity of symptoms.

The organism causing this disease has been variously called *Glomerella manihotis*, *Colletotrichum manihotis* (Vanderweyen, 1962), *Gloeosporium manihotis* (Bouriquet, 1946), and *Glomerella cingulata* (Irvine, 1969). All these names possibly refer to one species, but this hypothesis is yet to be confirmed.

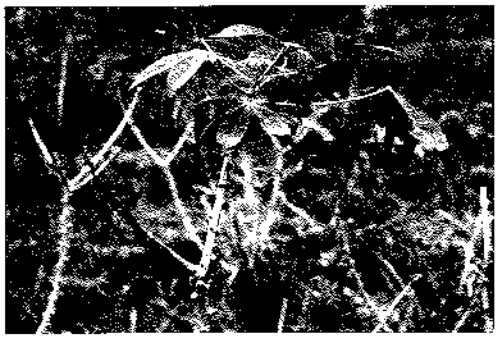

Figure 5. Leaves and stem show cankers caused by Glomerella manihotis.

Stem anthracnose caused by a *Colletotrichum* sp. was recorded in Nigeria (IITA, 1972). Green portions of the stems presented shallow oval depressions that were pale brown, but with a point of normal green tissue in the center. In the ligneous portions of the stems, lesions were round, swollen, and in bands, forming deep cankers on the epidermis and cortex, and sometimes deforming the stem. Its importance is unknown but its prevalence, occurrence, and dissemination are considerable. In Asia stem anthracnose was observed in Thailand (Alvarez, 2009, personal communication)

Dry Rot of Stem and Roots (*Diplodia* sp.)

Importance

This disease attacks stored cassava planting materials and residue stems left in the field. Its occurrence is not as common as necrosis caused by *Glomerella* spp.

Symptoms and epidemiology

The disease has two phases. The first is when root rot starts when soils are infested or when stakes from diseased plants are used. Symptoms, similar to those induced by root pathogens, consists in sudden plant death caused by root deterioration.

The second phase includes stem rot caused by systemic invasion of the fungus from the roots or by penetration through wounds. The disease is characterized by black discoloration and necrosis of the vascular bundles, which extend from the infection sites, that is, wounds in the stem. In the epidermis, they appear as blisters under which the stem's internal tissues are discolored black or dark brown. The blisters break, showing confluent masses of black pycnidia (**Figure 6**). Gum may be excreted, and partial or total wilting occurs. Dieback may also occur.

The pathogen disseminates across great distances through stakes from infected plantings. Within the same crop, dissemination is by wind and rain during fungal fructifications, use of infested tools and irrigation water, and land preparation for later plantings.

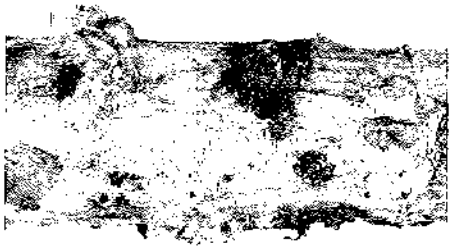

Figure 6. Stem rot in a stake infected by Diplodia sp.

Etiology

The causal agent of dry rot of stem and root is *Diplodia manihotis*. In both the host and laboratory cultures, this organism produces pycnidia that erupt through the stem or root surface, becoming confluent, stromal, and ostiolate. The conidiophores are short and simple, producing dark two-cell conidia that are slightly elongated on reaching maturity. Infection is believed to occur through wounds, and is favored by high environmental relative humidity.

Management and control

To control the disease, the cassava crop should be rotated with nonsusceptible crops such as maize or sorghum, particularly when incidence is more than 3%. Planting

stakes from healthy crops should be used and tools disinfected. Planting materials should be selected and handled carefully both before and after storage. Only viable cuttings or buds should be planted. One recommendation is to immerse cuttings in a solution of captan (3 g/l) and benomyl (3 g/l) for 5 min. Captan may be replaced by copper oxychloride.

Root Rots

Root rots in cassava are important where soils are poorly drained or where excessively rainy seasons occur. In early growth, many microorganisms are capable of inducing not only root rots in young cassava plants, but also in the storage roots of mature plants. Although several root diseases have been reported, little information exists about them. Not even the symptoms are well described.

Usually, infection kills young plants at germination or shortly afterwards. Infection in plants older than 4 months may result in partial or total wilt, depending on whether the root rot is soft or dry. Once invaded by one or more primary pathogens, infected roots may be invaded by a wide spectrum of other micro-organisms. These are usually the otherwise weak saprophytic parasites, which become capable of degrading root tissues and masking the identity of the primary causal agent. The resulting root rots therefore appear to have the same syndrome of symptoms.

Pathogens causing root rots include *Phytophthora* spp., *Fusarium* sp., *Scytalidium lignicola, Rosellinia* spp., *Sclerotium* sp., and *Fomes lignosus* (Ferdinando *et al.*, 1968; Jennings, 1970; Pereira, 1998; Viégas, 1955).

Some of these diseases often develop when cassava is planted immediately after woody crops such as coffee. Soils of such crops are infested with pathogens that attack ligneous plants such as cassava. These pathogens may be fungi or bacteria that cause root deterioration, either as the crop grows or after harvest when roots are stored.

Control measures for these diseases are similar, the best comprising cultural practices such as good drainage, selection of loose-textured soils, crop rotation, early harvest, and avoiding soils prone to flooding. Treatments with fungicides may help establish the crop, preventing root rots from attacking during the crop's first months. Ridomil® (2.5 kg/ha), applied to the soil, and foliar applications of Alliette® (0.4 kg/ha) have shown good results. Fungicides based on plant extracts, oils, and cytokinins help control soil fungi, while offering a non-polluting organic alternative. Resistant varieties have also been reported (Castaño, 1953; CIAT, 1998; Drummond and Gonçalves, 1957; Fassi, 1957; Müller and De Carneiro, 1970; Sánchez, 1998).

DISEASES CAUSED BY PSEUDO-FUNGI

Root Rots (*Phytophthora* spp.)

Importance

Root rots are a very common problem in cassava production, causing yield losses that may be as high as 80% of total production.

Distribution

Root rot caused by *Phytophthora* spp. affect cassava in different agroecological areas in Africa (Fassi, 1957), tropical America (Müller and De Carneiro, 1970), and India (Johnson and Palaniswami, 1999). In Nigeria, Cameroon, and Benin, the pathogens causing root diseases of economic importance include *Sclerotium rolfsii, Botryodiplodia theobromae, Fomes lignosus, Rosellinia necatrix, Rhizoctonia solani, Phytophthora* spp., and *Fusarium* spp. (Hillocks and Wydra, 2001).

Recent reports mention that cassava rots may cause losses between 5% and sometimes 100% in Latin America, Asia, and Africa, specifically, Colombia, Brazil (Wania Fukuda and Chigeru Fukuda, 1996; EMBRAPA, Brazil; Fernando Takatsu, 1996, University of Brasília, Brazil, personal communications), Cuba (Maryluz Folgueras, 2002, INIVIT, Cuba, personal communication), Mexico (Luis Fernando Cadavid, 2005, CLAYUCA, personal communication), India (James George, 2004, CTCRI, India, personal communication), Uganda (William Serubombwe, 2003, NARO, personal communication), Nigeria, Kenya, Indonesia, Ghana, Ecuador, and probably in many other countries.

In Asia root rots, have recently been reported in Nondindang disctrict of Buriram province, and in Khonburi district of Nakhon Ratchasima province in Thailand, both areas characterized by sandy loam soils. Varieties showing the symptoms are Rayong 5, Kasetsart 50 and Huay Bong 60 (Álvarez, 2009, personal communication). The disease was also observed at the Rayong Field Crops Research Center, affecting Huay Bong 80 (Figure 13). Cassava root rots have also been reported in Vietnam.

Figure 7. Cassava root rot symptoms have been observed in Rayong and at the Thai Tapioca Development Institute (TTDI) in Huay Bong, Nakhon Ratchasima.

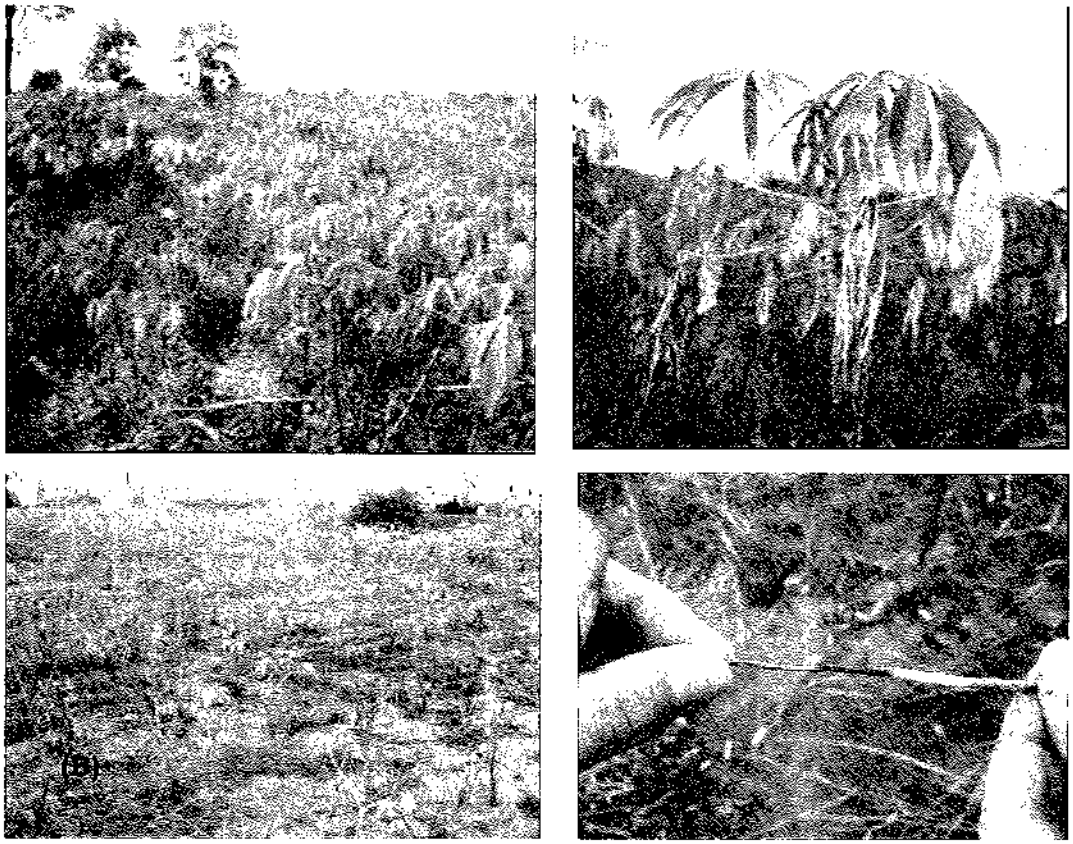

Figure 8. Cassava plants showing symptoms of root rots and wilting in Buriram province (A) and Nakhon Ratchasima province (B) of Thailand.

In India, *Phytophthora palmivora* is emerging as a serious threat to cassava in several industrial areas of Tamil Nadu, where it is endemic. Crop losses are as high as 50%. Differential reaction of cassava varieties to infection by *Phytophthora* was observed (Edison, 2002).

Symptoms and epidemiology

Phytophthora drechsleri macerates the root parenchyma, causing a penetrating odor and changing root color to cream (**Figure 9A**). *P. tropicalis* has been isolated from crops in Colombia (**Figure 9B**). In the State of Sergipe (Brazil), in 1976–1979, *P. drechsleri* was found to cause rot in the neck and roots, irreversible wilting of aerial parts, and defoliation (Souza Filho and Tupinamba, 1979) (**Figure 9C**). In contrast, *P. nicotianae* var. *nicotianae* shows little pepstatin activity. The odor is mild, with brown discoloration (Soto *et al.*, 1988). Root attack by *P. drechsleri* leads to leaves falling and branch tips drying up before the plant dies (Figuereido and Albuquerque, 1970). *Phytophthora nicotianae* also causes a similar leaf blight in cassava (Erwin and Ribeiro, 1996; Lima *et al.*, 1993).

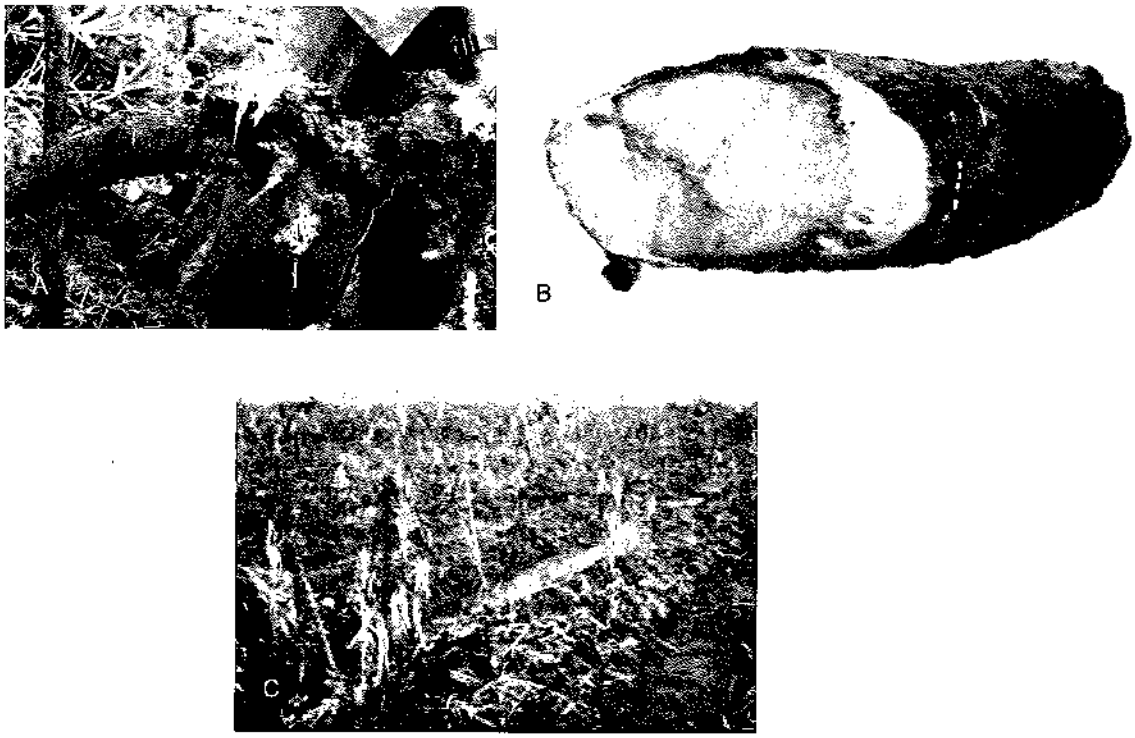

Figure 9. Root rots (A and B) and plant wilt (C) caused by Phytophthora spp.

Etiology

Farmers widely believe that root rots are caused by excess water in the soil. However, a study conducted in different edapho-climatic areas of Colombia showed that different *Phytophthora* spp. form the major cause of cassava root rots (Sánchez, 1998). Other pathogens also causing root rots include:

Fomes lignosus
Sclerotium rolfsii
Armillariella mellea
Fusarium spp.
Rhizoctonia sp.
Rhizopus sp.
Rosellinia necatrix (Lozano and Booth, 1979)
Pythium chamaehyphon (GenBank accession AY745748; CIAT, 2004)

Eleven species of *Phytophthora* have been reported as causing root rot. These are:

P. arecae (Coleman) Pethybridge (Alvarez *et al.*, 1997b)
P. capsici Leonian (Lima *et al.*, 1993)

P. citricola (CIAT, 1999, 2000)
P. cryptogea Pethybr. & Lafferty
P. drechsleri Tucker (Figueiredo and Albuquerque, 1970; Muller and De Carneiro, 1970)
P. erythroseptica Pethybridge (Fassi, 1957)
P. meadii (Barragán and Alvarez, 1998)
P. melonis (GenBank accession AY 739021; CIAT, 2000; 2004)
P. nicotianae Breda de Haan var. *nicotinae* (Dastur) (Soto *et al.*, 1988)
P. palmivora (Johnson and Palaniswami, 1999 ; Álvarez *et al.*, 2002)
P. tropicalis (GenBank accession AY 739022; CIAT, 2000; 2004)

The genetic diversity of these pathogens is broad and was determined through studies in Colombia with 80 isolates obtained from roots, young stems, and soils from 19 municipalities. These studies included the pathogen's pathogenicity, virulence, morphology, and molecular analysis of the internal transcribed spacer (ITS) region of the pathogen's ribosomal DNA. Eleven genetic groups were identified through PCR-RFLP (Alvarez *et al.*, 1997a; 1997b; 2000; Sánchez, 1998). *Phytophthora tropicalis* was identified through sequencing of the ITS region of ribosomal DNA and isoenzymes, showing it to be genetically similar to *P. capsici* (CIAT, 2000). An isolate was obtained from cassava roots in Barcelona, Quindío, Colombia.. *P. palmivora* was isolated from cassava roots at CIAT, Valle del Cauca, Colombia.

Integrated Disease Management

The integrated management of root rots includes the use of varietal resistance and/or cultural practices.

Varietal resistance.

A principal tool for managing root rots caused by various *Phytophthora* species is the use of varietal resistance. Various examples exist of the successful adoption of cassava clones resistant to *Phytophthora* spp. In 1990, the Brazilian Agricultural Research Corporation (EMBRAPA) and the Agricultural Research Center for the Humid Tropics (CPATU) released two cassava clones resistant to root rots: cvs. Mae Joana (IM-175) and Zolhudinha (IM-158). Both clones came from the State of Amazonas and are planted in the várzea ecosystem (a type of floodplains) of northern Brazil. The adoption of these clones, together with the application of appropriate cultural practices, increased root yields by more than 80% in this region (Lozano, 1991a).

With the MD-33 and Pao clones, high yields and resistance to root rot caused by *P. drechsleri* were obtained (Mendonça *et al.*, 2003). Pereira (1998) reported resistance to *P. drechsleri* in seven cultivars from a group of 31 evaluated. Barragán and Alvarez (1998) reported 15 resistant genotypes from a group of 60 elite genotypes evaluated. In 2003, Llano reported six individuals from a family of 126 genotypes, with high resistance to *P. tropicalis, P. palmivora*, and *P. melonis*. Although harvesting roots 14 months after planting resulted in increased yield it also demonstrated a higher incidence of root rots, thus showing that root rot incidence varies according to clones and harvest time.

In a participatory research study, indigenous communities of the Colombian Amazon adopted cassava clones resistant to *Phytophthora* spp. (Llano and Alvarez *et al.*, 2008; Llano *et al.*, 2001). These clones were selected in the laboratory (harvested roots) and greenhouse (stems) from 700 genotypes provided by EMBRAPA and CIAT.

To obtain reliable information on the genetics of such a complex disease, Takatsu and Fukuda (1990) concluded that standardized methods were needed for inoculating and evaluating resistance to each cassava root rot pathogen. CIAT and the National University of Colombia in Palmira identified cassava clones resistant to *P. nicotianae* var. *nicotianae* by first inoculating bulked roots of plants that were 10 to 12 months old. They then added a suspension of the fungus to a nutritive solution in which 45 day-old seedlings were growing. Seedling roots were colonized by the pathogen. The inoculated roots were evaluated in terms of the percentage of the pathogen's colonization of cortical and parenchymatous tissues.

Inoculated bulked roots demonstrated variation in the severity of symptoms, depending on whether they came from resistant or susceptible clones. The inoculation method was easier to carry out, less expensive, and with faster results than the seedling method. No correlation was found between the two inoculation methods (López and Lozano, 1992).

Cassava seedlings planted in soil were also evaluated. The soil had previously been inoculated with a suspension of each of zoospores, oospores, or chlamydospores applied separately (Lima *et al.*, 1993). Each inoculum type caused wilt and seedling death.

In 1995, Lima and Takatsu (1995) published the reactions of 13 cassava clones that had been stem-inoculated with three isolates of *P. drechsleri* in the greenhouse. The isolate with the most virulence was inoculated into roots in the field. To inoculate roots without harvesting them, inoculum was deposited in a small wound. The correlation between inoculated plants in the screenhouse and roots inoculated in the field was +0.24.

In other studies (Loke, 2004), several biochemical and morphological markers, and leaf resistance were identified for preselecting clones for resistance to *P. tropicalis* in cassava populations, based on (1) reduced area of the parenchyma with the presence of scopoletin in roots after harvest; (2) a high relationship between iron and manganese; and (3) resistance in leaves 72 hours after inoculation. Scopoletin is a coumarin that is found in very low concentrations in fresh roots but which increases considerably after harvest. This substance is easy to quantify in roots, using ultraviolet light, and is related to the cassava root's susceptibility to postharvest physiological deterioration.

Loke (2004) also demonstrated the benefits of using an index of resistance to *P. tropicalis* that includes molecular markers. The objective of this index is to select genotypes with durable resistance, based on a large diversity of resistance or defense mechanisms.

Several studies to identify the genetic base of resistance to *Phytophthora* have been conducted. A correlation of +0.31 between resistance during (in the peel, both epidermis and subepidermis) and after penetration (in the parenchyma) was observed for 25 cassava clones. This finding indicated that these forms of resistance are moderately associated (Corredor, 2005; Loke, 2004). Alvarez *et al.* (2003c), Llano *et al.* (2004), and Loke (2004) evaluated the cassava K family (150 F_1 individuals from the cross TMS 30572 × CM 2177-2), inoculating root fragments. Nineteen QTLs were identified as associated with resistance to different species of *Phytophthora* and *Pythium*, three of which explained between 8.3% and 11% of phenotypic variance.

Those QTLs that were expressed were also found to vary from one cropping cycle to another, depending on prevailing environmental conditions. Minor genes were demonstrated as controlling resistance to *P. tropicalis, P. melonis*, and *P. palmivora*, with a high genotype-by-environment interaction existing. Although the population showed differences within its genetic base for resistance to *Phytophthora*, levels of resistance were not sufficiently high for use in improvement programs. Hence, identifying contrasting parents for the disease would be useful, as well as developing new populations for determining QTLs (Llano *et al.*, 2004; Loke *et al.*, 2004).

To identify genomic sequences in cassava that are homologous with genes of resistance to diseases of different plant species, two cassava families were evaluated for their resistance to *P. tropicalis* (GenBank accession AY 739022), *P. melonis* (GenBank accession AY 739021), and *P. palmivora*, all causal agents of root rot. Two strategies were used to search for genes for resistance: (1) hybridization with probes for maize and rice, using RFLP; and (2) amplifying conserved regions of DNA, using the degenerate primers NBS and Pto kinase. Three cassava clones resistant to *P. tropicalis* and *P. palmivora* were used, obtaining clones that were sequenced and homologized with known genes of resistance.

With hybridization, cassava demonstrated very low homology with the monocotyledon genes tested. Twenty-eight NBS and 2 Pto kinase clones were obtained, of which 14 showed homologous sequence with resistance gene analogs (RGAs) and NBS-LRR (GenBank accessions: AY730038, AY730040, AY730041, AY737490, AY745762, AY745763, AY745764, AY745765, AY745766, AY745767, AY745768, AY745769, AY745770, and AY745771). Four of these showed an open reading framework (ORF) with conserved motifs in the nucleotide-binding site (NBS) region, which means they were considered to be RGAs. Altogether, three classes of RGAs were identified, none of which showed association with resistance to *Phytophthora* (Llano *et al.*, 2004).

Cultural practices

The best cultural practices for the integrated management of root rots are summarized below:

Selecting an appropriate, well-drained, and moderately deep soil. If the land is flat and soils are clayey, planting should be done on ridges.

To catalyze resistance, fertilizers should be applied in drench form, using potassium sources, and/or as foliar sprays, using potassium phosphites.

If rot incidence reaches 3%, the cassava crop should be rotated with grasses, at least once a year.

Eradicating diseased plants by removing infected roots from the field and burning them.

Selecting healthy plants to obtain clean seed. Where the farming area is infested, then stakes should be treated with metalaxyl at 0.3 g a.i./l.

Treating stakes in hot water at 49°C for 49 min is an alternative to chemical treatment (Alvarez *et al.*, 2003d).

Immersing stakes in a suspension of *Trichoderma harzianum* and *T. viride* at 2.5×10^8 spores/l, and later applying the same suspension in drench form (CIAT, 2006; 2007). Biological control of rots with isolates of *T. harzianum* and *T. viride* is promising (Bedoya *et al.*, 2000; CIAT, 2006; 2007; Edison, 2002). Field trials in different agroecological zones of Colombia have shown that soil inoculated with strains of these types of *Trichoderma* will increase cassava yield (CIAT, 2001; 2006; 2007). Isolates of *Trichoderma* spp. were selected on the basis of *in vitro* antagonism, production of secondary metabolites that inhibit *Phytophthora* spp., and bioassays in screenhouses.

To identify practices of disease management that are feasible for indigenous communities in the northwestern region of the Amazon (Colombia), participatory research trials were established, with the women farmers making the evaluations. Soil amendments were incorporated. These were ash, organic matter (dry leaves), and a 1:1 mixture of both materials. Dosage was 200 g/plant. Cassava was also intercropped with cowpea (*Vigna unguiculata*), and planting stakes were selected from the middle part of healthy plants.

In these trials, cassava yields increased by 446% with applications of the ash and organic matter mixture. Where only ash was used, yields increased by 272%. Stake selection increased yield by 366%. Compared with traditional management, these practices reduced root rots by 100% (incorporation of the ash and organic matter mixture), 99% (association with cowpea), 94.2% (ash only), and 89.7% (stake selection) (Llano and Alvarez, 2008).

DISEASES CAUSED BY BACTERIA

Cassava Bacterial Blight (CBB) (*Xanthomonas axonopodis* pv. *manihotis*)

Importance

Cassava bacterial blight (CBB) is regarded as one of the most limiting diseases of cassava production, as it can cause total crop loss in affected areas.

During the 1960s and 1970s, this disease caused major damage to the cassava crop. However, the application of integrated management programs, introduction of quarantine

measures in some countries, and identification and planting of resistant varieties have led to its satisfactory control (Hillocks and Wydra, 2001; Lozano, 1986).

Distribution

Cassava bacterial blight has been known in Latin America since 1912, when it was reported in Brazil (Kemp, 2000). It spread to the cassava-growing regions of Africa and Asia in the 1970s (Boher and Verdier, 1994; Bradbury, 1986). In Latin America, the disease has been reported from most of the cassava-growing regions of Bolivia, Brazil, Colombia, Cuba, the Dominican Republic, Mexico, Panama, Trinidad and Tobago, and Venezuela (Cajar, 1981; Fukuda, 1992; Languidey, 1981; Lozano and Sequeira, 1974; Rajnauth and Pegus, 1988; A. Rodríguez, 1979; S. Rodríguez, 1992; Sosa, 1992; Trujillo *et al.*, 1982).

In Asia, CBB has been observed during the rainy season in Thailand (**Figure 10**) as well as in many other countries but it is seldom very severe (Álvarez, 2009, personal communication). The disease was first observed in Taiwan before 1945 (Leu, 1976), and has since been reported from Malaysia, Indonesia, Thailand (Booth and Lozano, 1978, Alvarez and Bellotti, 2009), Vietnam (Alvarez and Bellotti, 2009) and India (Cherian and Mathew, 1981).

Figure 10. Cassava Bacterial Blight (CBB) symptoms observed on cassava leaves of cv. Rayong 5 in Thailand.

Symptoms and epidemiology

Symptoms characteristic of CBB are small, angular, aqueous-looking leaf spots found on the lower surface of the leaf blade. Or symptoms may be leaf blight or brown leaf burn, wilt, dieback, and a gummy exudation in infected young stems, petioles, and leaf spots (**Figure 11**). The vascular bundles of infected petioles and stems are also necrotic, appearing as bands of brown or black color. Symptoms occur 11 to 13 days after infection

(Lozano and Booth, 1979). Some susceptible varieties present dry and putrid spots around necrotic vascular bundles (Verdier, 2002).

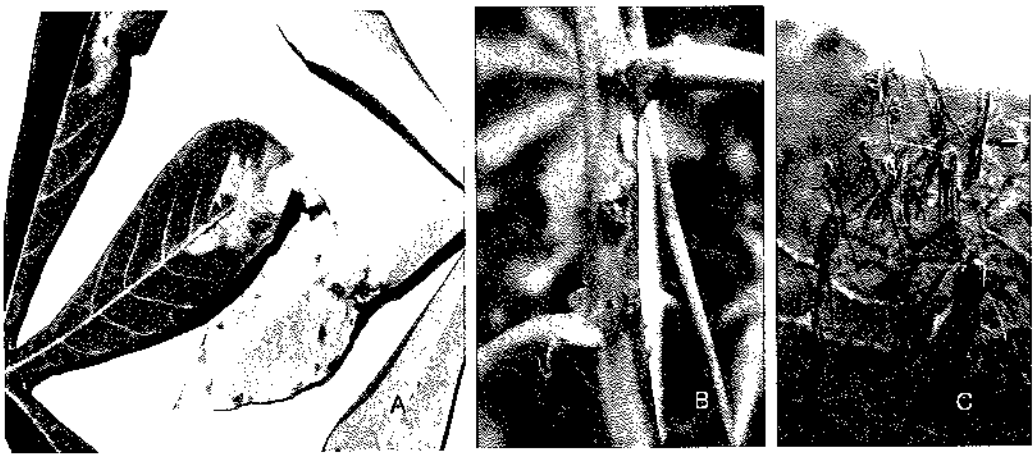

Figure 11. Symptoms of cassava bacterial blight, induced by the bacterium Xanthomonas axonopodis pv. manihotis: (A) angular leaf spots and leaf blight, (B) exudate on stem, and (C) plant wilt.

The bacterium disseminates widely through stakes from infected plants, from one cropping cycle to another, and from one area to another. Within the crop, the principal means of dispersal are water splash from rain and contaminated tools. The movement of people and animals within the crop, especially during or after rain, may also help disperse the pathogen (Lozano, 1973).

Although the pathogen survives poorly in soil, this can be a source of inoculum if it is contaminated, as well as irrigation water, although in reduced proportions. The bacterium can survive epiphytically on many weeds, which serve as sources of inoculum if control is inadequate. Insects spread the disease over short distances.

The severity of CBB becomes greater when temperatures fluctuate widely between day and night. Hence, the disease is not important in areas of stable temperatures such as the Amazon Region, where the cloud cover does not permit marked fluctuations in temperatures.

Etiology

The causal organism, *Xanthomonas axonopodis* pv. *manihotis* (*Xam*), is a Gram-negative bacterium that is shaped like a slim cane. It is mobile by means of a polar flagellum. Its cells are not encapsulated, and the bacterium does not form spores.

The organism penetrates the host through stomas and wounds in the plant's epidermis. Infection is systemic, moving through the stems and petioles in xylem vessels and possibly also the phloem.

Xam can be detected, using the polymerase chain reaction (PCR), which amplifies a DNA fragment of 898 bp. This methodology permits detection to as low as 300 cfu/ml in leaves and stems infected by CBB (Verdier *et al.*, 1998). When Verdier and Mosquera (1999) used the specific probe P898, they detected the bacterium in raw extracts of infected leaves and stems, and in cassava fruits and sexual seed. According to Verdier *et al.* (1993), pathogen diversity is narrow in Africa but broad in South America, cassava's center of origin.

Restrepo *et al.* (1996) reported that the diversity of the Colombian strains is very broad, at both pathogenic and genetic levels. Diversity is also high in Brazil (Restrepo *et al.*, 1999) and Venezuela (Verdier *et al.*, 1998).

Previous studies also revealed geographical differentiation among pathogen populations, according to ecozone. Evidence also exists of pathotypes moving within and between regions, probably because of movements of infected planting materials. In Colombia, analysis of pathogenic characteristics of *Xam* strains collected in three ecozones led to the definition of different pathotypes specific to each ecozone (Restrepo, 1999).

An analysis, using the AFLP technique, of the genetic variability of 85 *Xam* isolates from Brazil, Colombia, Cuba, and Venezuela distinguished three groups: (1) a cluster at a similarity level of 0.6 and formed of isolates from different localities in Colombia; (2) a cluster at 0.7 and comprising 81% of the Venezuelan isolates included in this study, and 4 Brazilian isolates; and (3) a cluster at 0.4 and formed by most of the Brazilian isolates, 3 isolates from Venezuela, 1 from Cuba, and 3 from Colombia. In this last group, clustering below the 0.4 similarity level also occurred, indicating great genetic variability within the Brazilian sites, possibly related to the equally high level of genetic diversity observed for the host plant (Sánchez *et al.*, 1999). When new pathogen strains are introduced into a given area, the genetic diversity already found within the pathogen population is increased, thereby favoring the development of new pathotypes (Restrepo, 1999).

Integrated disease management

To control the disease, integrated management should be carried out, involving varietal resistance, cultural practices, and biological control.

Varietal resistance

The genetic control of CBB is the most efficient and economic method for the farmer, but the cassava cropping cycle is long, with a very low production of planting materials. Hence, the time involved in producing resistant varieties is very long. At CIAT, resistant varieties are identified through evaluations in the Eastern Plains and the Atlantic Coast, where the disease is acute and endemic. They are also evaluated in the greenhouse, under controlled conditions, with temperatures at 30 C and relative humidity at 95%.

In several greenhouse studies, plants of different cassava varieties were inoculated with 39 isolates from different regions of Colombia, Venezuela, and Brazil. Fifteen genotypes were identified as having high to intermediate resistance to CBB, i.e. scoring between 1.0 and

2.5 on a scale of severity from 1.0 to 5.0. These varieties included MEsc Fla 039, MEsc Fla 021, MBra 383, MCol 2066, CM 3311-4, CM 7772-13, and SM 1779-8 (CIAT, 1999; 2000; 2001; 2002b; 2003b).

Between 1995 and 2007, about 6400 cassava genotypes were evaluated in Villavicencio in the Eastern Plains of Colombia for their field resistance to CBB. Of these, 117 were identified as having partial resistance (CIAT, 2001; 2002b; 2003b; 2006; 2007).

In a 10 × 10 diallelic study, carried out in Villavicencio, with 45 families and 30 plants per family, the cassava genotype CM 4574-7 was identified as having high general combination ability. Its progenies showed increased resistance to CBB and Super elongation disease (SED) (Calle *et al.*, 2005).

Tolerant varieties also exist such as MBra 685, MBra 886, ICA Catumare, ICA Cebucán, ICA Negrita, Vergara (CM 6438-14), CM 4574-7, and Chiroza. However, the disease has increased in severity in ICA Catumare, for which adequate selection of clean seed was not performed (Alvarez and Llano, 2002). Several genotypes have also been identified as having resistance to several pathotypes of the bacterium (Alvarez *et al.*, 1999).

Zinsou *et al.*, (2004) recommended the cassava genotype TMS 30572 for farmers in Benin, because of its high yield and relatively stable resistance to CBB across different environments. Kpémoua (1995) showed that resistance to *Xam* is associated with the production of phenolic compounds and the reinforcement of cell walls in the vascular system during early infection.

To determine the genetic control of resistance, 150 F_1 individuals of the cross TMS 30572 × CM 2177-2 were inoculated with the pathogen and evaluated for resistance under controlled conditions in the greenhouse. Five different *Xam* strains from the world's major cassava-growing areas were used in the study. Genetic analysis identified six genomic regions that control resistance to all *Xam* strains. One region controlled >60% of resistance to each of the strains CIO-1 and CIO-136. Two regions accounted for >70% of resistance to strain CIO-84. Another 80% of resistance to strains CIO-136 and ORST X-27 could be explained by 3 loci for each strain. (Jorge et al. 2000).

In three instances, the same genomic regions controlled resistance to two strains. A marker was obtained by Southern hybridization of a PCR amplification product from cassava, using heterologous primers designed from conserved regions of the *Xanthomonas* resistance gene in rice (*Xa21*). The region it marked explained 60% of phenotypic variance for resistance to strain CIO-136. A backcross population, derived from crossing members of the mapping population, has been developed and will provide more recombinations for fine mapping towards cloning resistance genes, and for studying intra-locus and inter-loci genetic interactions (Jorge *et al.*, 2000).

A molecular genetic map of cassava was recently constructed from an F_1 cross of non-inbred parents. RFLP, AFLP, EST, SSR markers were used to map resistance to CBB. The F_1 cross was evaluated with *Xam* strains under both field and greenhouse conditions.

Nine quantitative trait loci (QTLs), located on linkage groups B, D, L, N, and X, explained the phenotypic variance of the crop's response to *Xam* in the greenhouse.

Jorge *et al.* (2001) reported eight QTLs associated with resistance to CBB, and found changes in the expression of QTLs from one cropping cycle to another in the field, which could be related to changes in the pathogen's population structure. A QTL, located in linkage group D, was conserved over two cropping cycles and in resistance evaluations in the greenhouse. In a previous study, Jorge *et al.*, (2000) showed that 12 different QTLs control resistance to five *Xam* strains.

Hurtado *et al.* (2005) detected the molecular marker, microsatellite SSRY 65, that could select resistant genotypes in a cassava family corresponding to the cross CM 9208-13 × MNga 19. Furthermore, the authors identified two RGAs of the NBS class through amplification with PCR, using two primers designed by Llano (2003). These RGAs could identify plant individuals that were resistant to the bacterium.

One approach to assessing cassava genetic diversity involves the structural analysis of genotypes resistant to CBB. Multiple correspondence analysis of AFLP data, using two primer combinations for cassava genotypes resistant and susceptible to two strains of *Xam,* elucidated the genetic structure of cassava germplasm resistant to CBB (Sánchez *et al.*, 1999). Results revealed a random distribution of resistance or susceptibility, suggesting that resistance to CBB has arisen independently many times in cassava germplasm.

Phenolic compounds have been implicated in the resistance of cassava (*Manihot esculenta*) to xanthomonads. Cassava cultivars MCol 22 and CM 523-7 were inoculated with *Xam* and *X. cassavae*. CM 523-7 was susceptible to both pathogens, whereas MCol 22 was susceptible to *Xam* and resistant to *X. cassavae*. In the resistant interaction, no disease symptoms were observed in leaves. Bacterial growth was greatly reduced, and cell wall-bound peroxidase activity increased twofold, probably related to lignin deposition (Pereira *et al.*, 2000).

Preformed putative defenses include copious latex production, which contains protease, β-1,3 glucanase, and lysozyme activities. ESTs from a latex cDNA library revealed a constitutive expression of many defense-related genes including chitinase, glucanase, and PAL. A cDNA-AFLP analysis of cassava leaves suffering a hypersensitive response to *Pseudomonas syringae* pv. *tomato* revealed that 78 genes, new to cassava, had expressed differentially. Homologs of a metalloprotease, glucanase, peroxidase, and ACC oxidase were all found to be upregulated. Pathogenicity determinants of *Xam* are being studied in the disruption of the *gum* biosynthesis gene (its EPS is produced copiously in plants) and the *pel* gene (pectate lyase appears as a single isoform) (Kemp *et al.*, 2001).

RGAs were amplified as a means of elucidating the putative genes involved in cassava's defense response. For the cDNA-AFLP technique, of about 3600 cDNA fragments screened, 353 fragments were specific to a resistant variety. Sequence analyses showed significant homology with resistance genes, NPK-1 related proteins, senescence-related proteins, and other known proteins involved in disease resistance reactions.

Using degenerate primers, 12 classes of RGAs were identified in cassava. Screening a cassava cDNA library (root and leaf) with class-specific RGA probes also led to the identification of 16 expressed gene clones. Sequence analysis of clone L16 confirmed the constitutive expression of a protein that shares characteristics with previously reported resistance genes (Restrepo *et al.*, 2001).

López *et al.* (2004a) identified 6046 unigenes and characterized a group of genes putatively involved in cassava's defense response to *Xam* infection. López *et al.* (2004b) identified the *RXam1* gene, homolog of *Xa21* from rice, in a 3600-bp DNA fragment. The gene is induced in the resistant variety (MBra 685), 72 hours after infection by *Xam*.

Cultural practices

The following practices are recommended:

Use of healthy planting materials obtained from disease-free crops, plants derived from meristem culture, and by rooting buds and/or shoots

Treating stakes by immersing them for 10 min in a solution of cupric fungicides such as copper oxychloride or Orthocide® (captan) at 3 to 6 g/l

Immersion in extract of citrus fruit seeds (Lonlife)

Heat treatment of stakes (Alvarez *et al.*, 2008; CIAT, 2007), using hot water at 49 C for 49 min. Incidence of CBB in untreated stakes was 37%, but dropped to 7% when treated with hot water. It dropped further to 0% when stakes were pretreated at 49 C for 10 min, 24 hours before being treated with hot water for 5 hours. Treatment with hot water did not, in practical terms, affect stake germination, reducing it by only 18% in the most prolonged treatment (Ramírez *et al.*, 2000). The induction of enzymes that activate under stress conditions is probably responsible for conserving high stake germination, even after prolonged treatment in hot water.

Lozano (1986) also mentions the following practices for managing the disease:

Planting at the end of rainy periods
Crop rotation with grasses
Planting barriers of maize to prevent dissemination by wind
Improving soil drainage
Weed control
Fertilizers, mainly sources of potassium
Eradicating diseased plants
Preventing the movement of people, machines, and animals from infected lots to healthy lots
Eliminating infected materials after harvest by burning branches and stems
Incorporating harvest residues into the soil

In field studies conducted in Benin and Togo by Wydra *et al.* (2001), locally and regionally well-adapted control measures for CBB were identified such as:

Using locally preferred resistant varieties
Intercropping with locally used crops
Amending soils with local materials
Fertilizer applications and recommendations on phytosanitary measures carried out to reduce disease

Complementary studies elucidated some mechanisms of resistance at the biochemical and genetic levels and molecular host-pathogen interactions.

New methods for detecting *Xanthomonas campestris* pv. *manihotis* (*Xcm*), using immunological and genetic techniques, were developed. Research results were partly verified under African conditions such as testing the cassava genome mapping population for reaction towards African strains to identify genetic markers and/or resistance related genes.

Biological control

Spraying with suspensions of *Pseudomonas putida* reduced the severity of damage caused by CBB, while cassava yields increased significantly (CIAT, 1985). However, this practice has not been adapted for farming conditions.

DISEASES CAUSED BY PHYTOPLASMAS (previously known as mycoplasma-like organisms or MLOs)

Witches' Broom

Importance

This disease, known as *superbrotamiento* in Spanish, has been reported in Brazil, Venezuela, Mexico, and Peru (**Figure 12**). Although its incidence is not significant, the percentage of witches' broom in affected plantings is much higher than that of other diseases caused by American phytoplasmas. Crop losses can reach 80% (Lozano *et al.*, 1981). In Asia a new cassava disease was observed at Quang Ngai, Vietnam (**Figure 13**). Typical symptoms similar to witches' broom are widespread in southern Vietnam, in Plangyao, Chacheoengsao, Thailand and also in the Philippines (**Figure 14**). The disease may seriously affect yields and the availability of clean planting material

Symptoms

Several symptomatologies exist:

1. Plants exhibit dwarfism and an exaggerated proliferation of buds; shoot proliferation and/or usually rachitic branches growing from single stake. Sprouts have short internodes and small leaves, but do not show deformation or chlorosis.

2. Proliferation of weak spindly sprouts on the stakes.
3. Stakes produce only a few dwarf and weak spindly sprouts that never reach normal size.
4. When the affected cassava is uprooted, the roots are thinner and smaller, with rough-textured skins, and drastically reduced starch content.

Figure 12. Symptoms of Witches' Broom disease in cassava (Photo: B. Pineda)

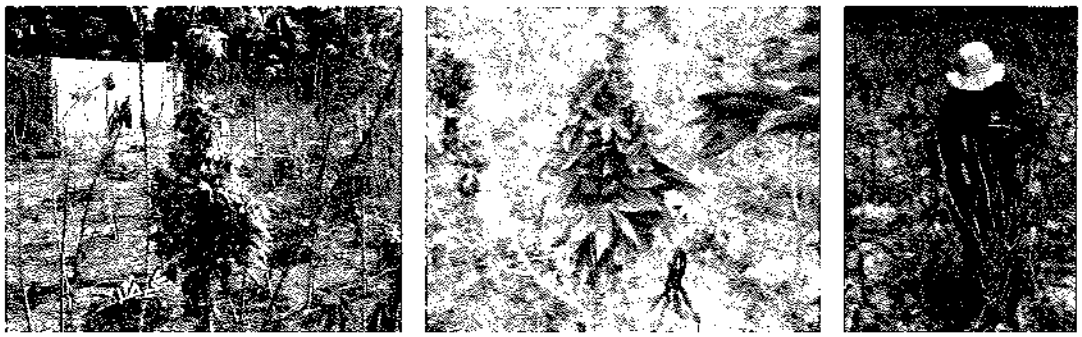

Figure 13. Plants with exaggerated bud proliferation; shoot proliferation and/or unusually rachitic branches growing from single stake; and shoots with short internodes and small leaves that show no deformation or chlorosis were observed in Vietnam. (Photo: J.F. Mejia)

Figure 14. Disease symptoms observed on cassava plants in the Philippines.

Etiology

The disease is transmitted mechanically and by the use of stakes from diseased plants (Lozano *et al.*, 1981).

The transmission of cassava phytoplasmas by *Cuscuta* sp. into pink vinca was 100% positive. Symptoms appeared three weeks after implanting the host parasite into pink vinca in growth chambers at 18-20 C. No transmission was achieved with the insect *Scaphytopius fuliginosus*, even three months after exposure to feeding, whether cassava to cassava, cassava to vinca, or vinca to vinca (Valencia *et al.*, 1993).

In Vietnam, disease recognition was carried out in the country's central and southern regions (Quang Ngai and Dong Nai provinces). Samples for diagnosing phytoplasmas were collected in southern Vietnam at Hung Loc Agricultural Research Center and from a farmer's plot in Dong Nai province, both sites being about 60 km from Ho Chi Minh City. In the samples collected in Thailand and Vietnam, phytoplasmas were detected. Results of diagnosis confirm the association of symptoms (high bud proliferation shoots with short internodes, and small leaves) with phytoplasmas.

Phytoplasmas were detected in roots, small leaves, and leaf veins showing symptoms. In the samples from Thailand and Vietnam no phytoplasmas of the 16SrIII group (reported in America) were found. However, we have evaluated only samples from the eastern and southern regions of these two countries, respectively. These results need to be confirmed. Through molecular tests based on the 16Sr gene, we were able to conclude that differences exist among the phytoplasmas detected in eastern Thailand and in southern Vietnam (Alvarez and Mejia, 2009).

Management

For disease prevention, using healthy planting materials and eliminating diseased plants in the field are recommended (Lozano *et al.*, 1981). The disease is reduced by selecting stakes from healthy plants. Restrict the movement of cassava planting stakes,

especially from infected areas and restrict the movement of related species such as jatropha. Varietal resistance also exists.

DISEASES CAUSED BY VIRUSES

Cassava Mosaic Disease (CMD)

Importance

Cassava mosaic disease (CMD) was first described in 1894 in what is now Tanzania. The disease was later reported in many other countries of East, West, and Central Africa. It is now known to occur in all cassava-growing countries of Africa and adjacent islands, forming the major constraint to cassava production on this continent. Losses may be as high as 88% in susceptible varieties and 50% in varieties tolerant in the field (Edison, 2002; Obonyo *et al.*, 2007). Calvert and Thresh (2002) reported disease incidence as being between 21% and 84% in 13 African countries, with the highest value in Kenya.

The disease also appears in India and Sri Lanka (Hillocks and Thresh, 2000), where it is gradually reaching alarming proportions in the cassava-growing states, causing losses as high as in Africa (Edison, 2002). Overall incidence of CMD is highest in the two main cassava-growing states in India: Kerala (23%) and Tamil Nadu (30%). It also appears in Andhra Pradesh (<1%) and Karnataka (5%), which are outside the main cassava-growing areas (Calvert and Thresh, 2002).

Symptoms

Symptoms begin in leaves as chlorotic areas intermixing with normal green tissue and creating a mosaic pattern and leaf distortion, leading to defoliation and severe stunting. In severe cases, leaves are reduced in size, twisted, and deformed (**Figure 15**). Plant height, stem diameter, petiole length, and leaf size are significantly reduced (Edison, 2002). Plants are stunted and young leaves abscise (Hillocks and Thresh, 2000). Symptoms are masked during hot dry months, making the identification of diseased plants impossible (Edison, 2002).

The disease is spread through infected planting materials or a vector, the whitefly (*Bemisia tabaci* Gennadius). It can also be transmitted through grafting.

Etiology

Cassava mosaic disease is caused by a begomovirus. An unusually virulent recombinant strain – the East African cassava mosaic virus of Uganda (EACMV-Ug) – was associated with the severe CMD pandemic in East and Central Africa in the 1990s (Edison, 2002; Obonyo *et al.*, 2007). Studies have identified several distinct but similar viruses: the African cassava mosaic virus (ACMV), East African cassava mosaic virus (EACMV), Indian cassava mosaic virus (ICMV), and South African cassava mosaic virus (SACMV).

Recently, EACMV-UG occurred most frequently in the northernmost part of Angola (Uige Province) immediately to the south of the Bas Congo region of the Democratic

Republic of Congo, already known to be affected by the pandemic. These findings significantly broaden the known geographical extent of the CMD pandemic and draw attention to the urgent need for the large-scale deployment of resistant cassava varieties, which have been used to reduce losses in pandemic-affected regions of East Africa (Lava Kumar *et al.*, 2009)

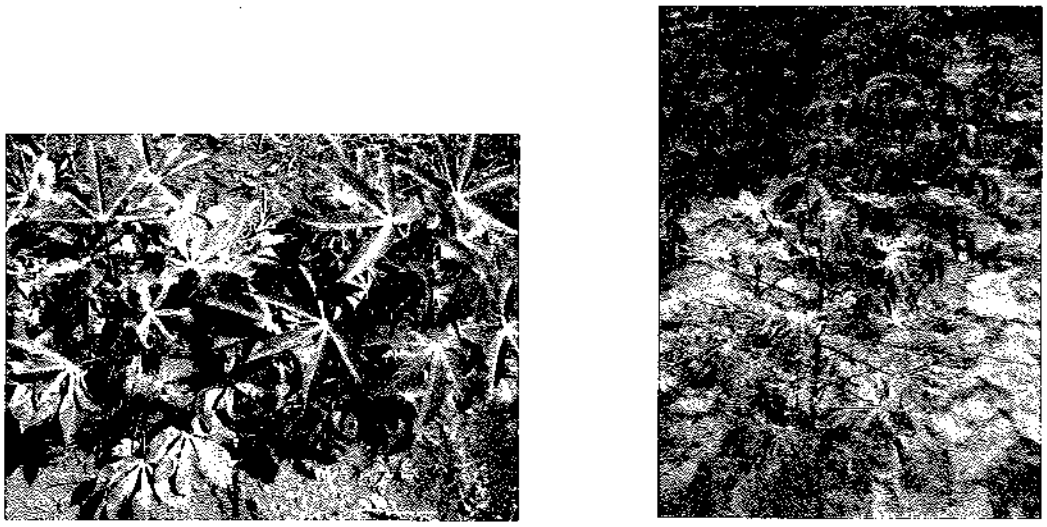

Figure 15. Cassava mosaic disease (CMD) in Burundi (left) and Tanzania (right). (Photos: R. Howeler)

In India, CMD is caused by the ICMV. This virus has been purified and was found to belong to the geminivirus group. Particles measure 18-24 nm in diameter. The rate of the virus's spread and crop losses depend on the time of infection, varietal susceptibility, climatic factors, and vector populations (Edison, 2002).

Antiserums of adequate titer strength can successfully detect even latent infections (Edison, 2002). Primer pairs, specific for ACMV and EACMV-Ug, are used to amplify fragments of DNA A of cassava mosaic geminiviruses (CMGs) (Obonyo *et al.*, 2007).

A multiplex PCR was also developed for the simultaneous detection of ACMV and the East African cassava mosaic Cameroon virus (EACMCV) in cassava with CMD (Alabi *et al.*, 2008). In Burindi most of the samples of cassava leaves exhibiting severe symptoms of CMD were found to be co-infected by three different begomoviruses (ACMV + EACMV + EACMV-UG), multiple infections with begomoviruses within a same plant can drive to important evolution of the virus species and strains. (Busogoro *et al.*, 2008). A study on the molecular variability and distribution of cassava mosaic begomoviruses in Nigeria showed that ACMV was the dominant virus, forming 80% of all samples. The EACMCV was detected in single (2%) and mixed infections (18%) with the African cassava mosaic virus DNA A (ACMVA) (Ariyo *et al.*, 2005). ACMV showed little

variation in its genomic sequence in Côte d'Ivoire, while EACMV is more genetically diverse because of frequent recombinations of its two components (i.e. EACMV and EACMV-Ug) (Pita *et al.*, 2001).

Studies on variability first showed that the EACMV-Ug virus arose from a recombination event between ACMV and EACMV. Mixed virus infections were frequent, resulting in a synergistic interaction (Legg and Thresh, 2003); this aspect of the cassava-CMD pathogen system has to be taken into consideration for a successful implementation of plant genetic resistance to control CMD.

Integrated disease management

Management comprises:

Use of field-tolerant cassava varieties like H-97, H-165, and Sree Visakham in India.

Selection of disease-free meristem-derived planting materials, followed by clonal multiplication with periodical screening and rouging of newly infected plants.

Disease-free planting materials should be selected before the beginning of the hot dry season. These materials can be multiplied on a large scale at higher altitudes where whitefly populations are small or nonexistent.

Raising plants in the nursery at closer spacing before transplantation into the main field to prevent the primary spread of the disease in the main field.

Adherence to strict phytosanitary practices such as timely harvesting, prompt disposal of crop residues, and eradication of self-sown plants and weeds that may harbor both the disease and vectors (Edison, 2002).

Resistance to CMD has been successfully incorporated into high-yielding cultivars of acceptable quality. CMD-resistant materials have been evaluated, and many promising clones have been selected in various countries in tropical Africa and India (Hahn *et al.*, 1980). Levels of resistance have been effective in those countries. Currently, the seven cassava varieties highly recommended for cultivation in areas affected by cassava brown streak disease (CBSD; see below) and CMD of Tanzania are 'Kiroba', 'Kigoma Mafia', 'Nachinyaya', 'Kalulu', 'Kitumbua', 'Namikonga', and 'Naliendele'. In 2007, Zanzibar released another four new cassava varieties that are tolerant of CBSD, resistant to CMD, and which meet consumer preferences in markets (Manyong and Abass, 2007).

Even so, while some farmers could obtain CMD-resistant varieties, adoption rates are very low. Strong multiplication and dissemination efforts are required to encourage the adoption of CMD-resistant varieties (Obonyo *et al.*, 2007).

Little use is made of insecticides to control the whitefly vector, but such measures are inappropriate anyway for a widely grown subsistence crop. Only limited attention has

been given to other possible control measures such as the use of intercropping, crop disposition, or manipulation of planting date to decrease risk of infection (Thresh and Otim-Nape, 1994, cited by Hillocks and Thresh, 2000). Such measures merit consideration in the current search for integrated means of control that would make the most effective use of phytosanitation and resistant varieties (Hillocks and Thresh, 2000).

Cassava Brown Streak Disease (CBSD)

Importance

The disease was first reported and distinguished from cassava mosaic disease (CMD) in Tanzania during the 1930s. Soon after, the whitefly, *Bemisia tabaci* (Gennadius), was suggested as a possible vector. Successful transmission of CBSV by *B. tabaci* between cassava plants was achieved only recently in 2004 (Maruthi *et al.*, 2005). . Surveys for CBSD found the disease to be endemic in all East African coastal cassava growing areas, from Kenya to the Ruvuma River that marks the border between Tanzania and Mozambique. It was reported to be widespread in coastal Kenya and in Mozambique where it was prevalent. Recent surveys have confirmed that the disease occurs throughout the coastal strip of Lake Malawi. Symptoms resembling those of CBSD have been reported from Bas-Congo and Kinshasa provinces of the Democratic Republic of Congo, but the virus has not been confirmed by diagnostics. The reasons for the restricted occurrence of CBSD, despite the distribution of *B. tabaci* throughout Africa and the considerable movement of cassava planting materials, remain unknown. Early studies led to the observation that CBSD could be found inland from the East African coast up to an altitude of 1,000 m above sea level (masl). Surveys conducted during the 1990s appeared to support that view. Although cassava is widely grown at altitudes above 1,000 masl in Tanzania, Malawi, and Mozambique, CBSD has not been reported from these areas. A nationwide survey of Tanzania in 1993 and 1994 showed CMD and *B. tabaci* in all parts of the country, but CBSD was found only in the lowlands bordering the Indian Ocean and Lake Malawi. Wherever the disease has been reported to be endemic, occurrences were confined to altitudes below 1,000 masl, and incidence increased with decreasing altitude. However, it has been known for some time that CBSD symptoms can be expressed at altitudes greater than 1,000 masl when infected cuttings have been planted. This occurred in Uganda when infected material was taken from Tanzania in 1934, but the disease was eradicated by destroying all plants showing symptoms. From that time until 2004, CBSD has not been prevalent in Uganda, although CBSD-like symptoms were observed on a few cassava plants at one site in central Uganda in 1994 (Alicai *et al.*, 2007).

Symptoms

Symptoms of the disease are first seen as discoloration of the cassava leaves along the veins (**Figure 16**). In severe cases, the whole leaf looks blotchy with yellow-light green spots. The lower leaves are usually most affected but leaves are not deformed. In roots, symptoms may be external or internal or, sometimes, both. External symptoms include constrictions in the roots and/or pits in the surface bark. Underneath the bark the cortex is necrotic (**Figure 16**). Internal symptoms are yellow to brown corky patches in the root pulp under the root cortex. Sometimes, blue to black streaks appear. Often, roots look healthy on

the outside until they are cut open, when the streaks become evident (Manyong and Abass, 2007).

In the more susceptible varieties, purple to brown lesions on the exterior surface of young green stem tissues may be observed. On stripping off the outer bark, the lesions can be seen to penetrate the cortex. Necrotic lesions appear in leaf scars after leaves are shed through normal senescence.

Root symptoms usually develop after foliar symptoms. The period between infection and the onset of root necrosis seems to be cultivar dependent. In some cultivars, root necrosis does not develop in infected cuttings until more than 8 months after planting, despite the earlier presence of clear foliar symptoms. In the most susceptible cultivars, where planting materials have derived from infected stock, root necrosis can become apparent at five months after planting (Hillocks and Thresh, 2000).

Figure 16. Symptoms of cassava brown streak disease (CBSD) on leaves (left) in Tanzania and roots (right) in Uganda (Photos: R. Howeler)

Etiology

Leaf samples showing typical CBSD symptoms were sent to UK for electron microscopy whereby virus particles were detected. The particles were elongate, flexuous filaments 650–690 nm long that contained "pin-wheel" inclusions, typical of potyviruses. The exact etiology of the disease remained a matter of speculation until the coat protein gene of CBSV was recently cloned and sequenced at the University of Bristol, UK. The virus has since been shown to be an ipomovirus, a whitefly-transmitted potyvirus (G. Foster 1997, unpublished data; Hillocks and Thresh, 2000).

Very little information is currently available on the variability of different CBSV isolates. Only a few isolates have been examined, and these cannot be considered to be representative for CBSV in East and Central Africa as a whole. However, the University of Bristol team examined CBSV isolates from three varieties obtained in Tanzania and Mozambique. The isolates each elicited different symptom types in herbaceous indicator

plants, but comparisons of sequences revealed only 8% differences in nucleotides and 6% differences in deduced amino acids (Legg and Thresh, 2003).

Integrated disease management

The basic approach to controlling CBSD is to select planting materials from symptomless mother plants. The stock's health needs to be maintained by continued selection and roguing of any infected individuals that appear at sprouting. The success of this approach depends on the amount of disease in surrounding cassava and the rate of dissemination. The mechanism for dissemination is unknown for CBSV and the practicality of virus-free planting materials cannot yet be predicted. However, this measure may be worthwhile for areas with low disease pressure.

For areas with high disease pressure such as the Tanzanian coast and much of Mozambique, the release of virus-free planting materials needs to be combined with deployment of cultivars with some form of resistance. Local cultivars such as 'Nachinyaya' in southern Tanzania that apparently tolerate infection and are slow to develop root necrosis could be used. Surveys conducted in Tanzania have indicated that other cultivars also show varying degrees of resistance to or tolerance of CBSV (Hillocks and Thresh, 2000). .

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STATUS OF CASSAVA MOSAIC VIRUSES OCCURRING IN INDIA

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ABSTRACT

Cassava (*Manihot esculenta* Cranz) was introduced into the state of Kerala, India, during the 18th century as a food crop. In 2008 it was grown in an area of 269,900 ha in India with an annual production of 9,053,900 tonnes, used for both human and animal consumption, as well as for processing into starch. Among the biotic factors limiting the production of cassava in India, cassava mosaic is severe, widespread and economically most important. The disease is widely distributed due to the indiscriminate use of infected planting material (stem cuttings), and can cause yield losses of 20-80% depending upon the varieties and severity of infection. The disease is transmitted by the cassava biotype of whitefly *Bemisia tabaci*. The causal viruses, i.e. the *Indian cassava mosaic virus* (ICMV) as well as the *Sri Lankan cassava mosaic virus* (SLCMV) are prevalent in major cassava growing areas of Kerala and Tamil Nadu. Although the occurrence of ICMV was known already during the late 1980s, the presence of SLCMV is known only since 2004. The specific primers for the detection of both these viruses have been developed and a multiplex PCR protocol has also been standardized for the detection of ICMV and SLCMV in cassava. Host range studies showed that ICMV and SLCMV could be transmitted to more than 39 plant species belonging to the Solanaceae family through sap inoculation. The coat protein and the replicase gene of ICMV and SLCMV have been cloned and sequenced. Restriction analyses of the coat protein gene of SLCMV using different restriction enzymes indicate the variability among the isolates. The replicase gene of ICMV has been cloned in pBI 121 and transformed into tobacco (*Nicotiana tabacum* cv White Barley) and cassava, variety H-226. Transgenic plants of cassava with the replicase gene of the ICMV have been developed and are being evaluated for CMD resistance under Transgenic Glasshouse conditions. Apart from transgenic technology, other conventional approaches like virus elimination through meristem culture, combined with chemotherapy are being practiced for the production of virus-free planting materials. The meristem-derived plants are indexed for the presence of virus through ELISA and PCR. Work done on the use of antiviral plant extracts, namely *Boerhavia diffusa* and *Mirabilis jalapa*, and the planting of barrier crops such as maize or pigeon pea for the management of CMD in India, is also discussed in the paper.

INTRODUCTION

Tropical roots and tubers (cassava, sweetpotato, yams and aroids) are the third most important food crops in the world after cereals and legumes. These crops make significant contributions to income generation, sustainable development and household food security in developing countries. Their flexibility in cultivation under mixed farming systems contributes to the versatility of the crops. They are planted by millions of people in the tropics, and are also identified to be the major source of carbohydrates for the populations of the world in the next decades (Scott *et al.*, 2000). Among the tropical root and tuber crops grown in India, cassava (*Manihot esculenta* Crantz) is first with respect to area, production and productivity.

Cassava was introduced to Kerala State of India during the 1840s by the Shri Visakham Thirunal Maharaja of Travancore. Later on the crop spread to nearby states, namely Tamil Nadu, Karataka and Andhra Pradesh. It is a staple food for most of the

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marginal and small farmers and tribal peoples in Kerala, and is popular as an industrial crop in Tamil Nadu, Maharastra and Andhra Pradesh. Similarly, in Tamil Nadu and Andhra Pradesh more than 1000 starch-based industries are utilizing this crop as raw material for producing starch, sago and different by-products.

The Central Tuber Crops Research Institute, established under the aegis of ICAR in 1963, is one of the premier institutes working exclusively on tropical root and tuber crops. Cassava is one of the major mandatory crops of the Institute and over the last four decades the Institute has generated several useful technologies in cassava, which have benefited small and marginal cassava growing farmers, and starch and sago industries through R & D projects. The cassava varieties H-226 and H-165, developed by the institute during the 1970s, are still popular, occupying about 80% of the cassava area of Tamil Nadu. Recently, in the year 2006, a mosaic-tolerant cassava variety, namely Sree Padmanabha, has been released in the state of Tamil Nadu.

Cassava Mosaic Disease in the Indian Subcontinent

More than 30 diseases caused by fungi, bacteria, viruses and MLO (Mycoplasma – like organism) are known to attack cassava the world over. However, few diseases are economically important. Like any other vegetatively propagated crop, cassava is also more prone to systemic diseases carried through propagation material. Among the various diseases which affect the cassava crop, cassava mosaic disease (CMD) has emerged as one of the most serious limiting factors all over the world, resulting in annual yield losses estimated at one billion pound sterling (Fargette *et al.*, 1988). The first report of CMD in the Indian subcontinent was documented by Abraham (1956), and later on an elaborate report was published by Alagianagalingam and Ramakrishnan (1966). A similar disease in Sri Lanka caused by a different begomovirus, called *Sri Lankan Cassava Mosaic Virus* (SLCMV), was later reported by Austin (1986). The CMD reported from India and that reported from Africa were considered to be the same all along. However, findings of Harrison *et al.* (1987) and Malathi *et al.* (1987) indicated that the disease occurring in India is caused by a distinct virus which differs from the African Cassava Mosaic Virus (ACMV) with respect to serological analysis. Hence, the disease occurring in India was termed the Indian cassava mosaic disease (ICMD), caused by the *Indian cassava mosaic virus* (ICMV). The first clone of *Indian cassava mosaic virus* (ICMV-Ker) was obtained by Hong *et al.* (1993), and subsequently Saunders *et al.* (2002) cloned SLCMV. The DNA A and DNA B component of ICMV shares 65% and 30% nucleotide sequence identity with *African cassava mosaic virus* (ACMV) DNA A and DNA B, respectively. Patil and Dasgupta (2005) reported the presence of SLCMV in southern India through differential polymerase chain reaction (PCR) studies, and developed a distribution map of ICMV and SLCMV. Subsequently, several ICMV and SLCMV isolates from southern India were cloned and their biodiversity and infectivity were studied (Dutt *et al.*, 2005; Patil *et al.*, 2005; Rothenstien *et al.*, 2006). Only one incidence of ACMV in India was reported (Anitha Jose *et al.*, 2007); however, no further isolation could be made.

Presently the cassava mosaic disease is widespread, both in Kerala and Tamil Nadu, and is spreading to southern Andhra Pradesh and Maharastra. The symptoms are chlorotic areas intermixing with normal green tissue which gives a mosaic pattern. In severe cases the leaves are reduced in size, twisted and distorted. The yield loss due to

CMD in India is up to 88% in case of highly susceptible varieties, and up to 50% in case of field-tolerant varieties (Malathi *et al.*, 1985; Edison, 2007). The major reason for the widespread occurrence of CMD is mainly due to the indiscriminate use of infected planting materials. A few highly susceptible cultivars are not being cultivated by the farmers anymore and are not seen nowadays. The variety H-226, a popular variety in the industrial belt of Tamil Nadu, is 100% infected; however, the yield loss due to the disease is only 17 to 20% because of the good agronomic practices provided by the local farmers. Though CTCRI is producing virus-free cassava, there is no systematic arrangement for the distribution of virus-free planting materials to farmers.

CMD is one of the major problems receiving attention by researchers in India over the last three decades. Work done over the years include: surveys and surveillance of CMD, symptomatology, pathogen detection, yield loss estimation, transmission, epidemiological studies, various management strategies, development of virus-free planting materials through meristem culture and single node techniques, etc. In recent years, the work has focused mainly on molecular diagnostics and the identification of the viruses/strains involved, understanding the biodiversity of the viruses, virus elimination in planting materials, integrated disease management, development of CMD-resistant cassava through traditional breeding and transgenic approaches.

Diagnostics

Cassava mosaic geminiviruses causing cassava mosaic disease belong to the family Geminiviridae. The virus particles are paired geminate particles having 16-18 nm diameter and a single stranded DNA as their genome (Malathi *et al.*, 1985; Hong *et al.*, 1993) Most of the presently cultivated cassava varieties in India are infected with ICMV or SLCMV but the yield loss incurred is less compared to cassava mosaic in Africa caused by ACMV or EACMV. Infected cassava plants express a range of symptoms which depend on the virus species/strain, environmental conditions, and the sensitivity of the cassava host. The most typical symptoms consist of a yellow or pale green chlorotic mosaic of leaves, commonly accompanied by distortion and crumpling. In the infected plant, the young and emerging leaf has chlorotic areas which appear as specs on the leaf lamina. Gradually they enlarge and intermix with normal green tissue to give rise to a typical mosaic pattern. This pattern may be sparsely present or spread throughout the lamina. Chlorotic areas may be bright yellow or pale green in color. Affected leaves are reduced in size, misshapen, twisted and distorted to give a shoe string appearance. In severely infected plants all the leaves will be reduced in size or deformed, and this result in stunting with a bushy appearance. Infected plants usually express symptoms, unless the plant has only recently been infected (symptoms typically appear 3-5 weeks after infection) or conditions are unfavorable, as during periods of drought when most leaves are shed. Resistant varieties that are infected may "recover" i.e., begin to produce symptomless leaves during the later stages of crop growth, and particularly during hot, dry weather. But even so, careful observation usually detects symptoms on lower leaves (Storey and Nichols, 1938; Malathi *et al.*, 1985). No marked synergistic effect on symptom severity was observed in cassava plants infected with SLCMV and ICMV.

Cassava mosaic viruses are transmitted by mechanical inoculation from cassava to 38 species of *Nicotiana*, *Datura stramonium*, *Manihot esculenta*, *M. glaziovii*, *Nicandra physalodes*, *Petunia hybrida* (Malathi and Sreenivasan, 1983; Mathew and Muniyappa,

1993; Anitha Jose *et al.*, 2008). *Jatropha curcas*, a plant used as fence on the bunds around cassava fields, and nowadays popularized for biofuel, is also known to be infected with ICMV and SLCMV. Mechanical inoculation to *Nicotiana benthamiana* will differentiate the infection of SLCMV or ICMV. In the case of SLCMV infection, we can see severe stunting, leaf distortion, reduction in leaf size and crinkling, but ICMV infection exhibits only mild mottling and leaf crinkles. Serological as well as nucleic acid-based methods are routinely employed in India for detection of cassava mosaic viruses.

a. Serological assays

Gemini virus infecting cassava was first purified in 1977 (Bock *et al.*, 1977) and it lead to the production of antiserum to detect the cassava mosaic virus through gel diffusion tests (Bock *et al.*, 1981), by DAS-ELISA (Sequeira and Harrison, 1982) and immune-sorbent electron microscopy (ISEM) (Roberts *et al.*, 1984). Since the polyclonal antibodies did not clearly distinguish the variations and strains among the cassava mosaic viruses, a panel of monoclonal antibodies were produced against ACMV, EACMV and ICMV and these are now used to differentiate them by triple antibody sandwich ELISA (TAS-ELISA) (Thomas *et al.*, 1986; Swanson and Harrison, 1993; Ogbe *et al.*, 1997; Ogbe, 2001). CMD diagnosis was routinely done in India (CTCRI) with TAS-ELISA using both polyclonal and monoclonal antibodies (SCR58 and SCR60) of ICMV obtained from IITA, Nigeria, and detected the virus infection from plant samples tested (Makeshkumar *et al.*, 2001). However, these monoclonal antibodies will not differentiate the infection of SLCMV or ICMV, as it produces reactions to both viruses. ICMV was also detected through a dot blot immune-binding assay (DIBA) and tissue blot immuno-assay (TBIA), though the sensitivity was less compared to TAS-ELISA. The efforts made in India could not yield good quality polyclonal antisera against ICMV or SLCMV due to the inherent difficulty in transmission of the virus, purification of the virus and virus titre. In recent years efforts are being made to express the coat protein gene of the ICMV and SLCMV in bacterial expression vector to produce antisera.

b. Nucleic acid based methods

PCR-based protocols for the specific detection of ICMV and SLCMV have been developed (Patil *et al.*, 2005; Makeshkumar *et al.*, 2006). PCR-based diagnostics make use of specific PCR primers designed from full length sequences of DNA A. In case of PCR-based diagnosis of cassava mosaic virus infection in India, among the several primers designed (primers targeted for coat protein gene (CP), Replicase (Rep) and movement protein (MP)) and tested for their efficiency, it was found that the CP primer was best even though all the primers detected the viral infection in the test plants. The presence of ICMV in different parts of cassava plants, namely bud, stem, bark and pith, were detected through PCR using CP specific primers. The ICMV was also detected from cassava plants by immuno capture PCR using CP specific primers (Makeshkumar *et al.*, 2005). Presently, multiplex PCR is being employed for specific detection of both ICMV and SLCMV in cassava. (Dutt *et al.*, 2005; Manivasagam *et al.*, 2006) using two primers having different forward primers specific to SLCMV and ICMV and a common reverse primer amplifying a fragment encompassing 5'(five prime) end of AC1 region and intergenic region. Makeshkumar *et al.* (2007) reported the detection of SLCMV and ICMV through multiplex PCR from cassava samples collected from Tamil Nadu and Kerala.

Nucleic Acid Spot Hybridization (NASH) was also employed for detection of ICMV in Indian cassava cultivars. The biotinylated coat protein gene probe specific to ICMV was prepared and was able to detect ICMV in different cassava cultivars. A strong hybridization signal was observed when the concentration of virus was high, especially in the susceptible and tolerant varieties, namely H-165, H-226, Sree Sahya, Sree Visakham, Sree Jaya, Sree Prakash and Sree Vijaya. The virus could be detected from the apparently healthy symptomless cassava plants as well as in the meristem-cultured plants (Hegde *et al.*, 2005) indicating that meristem culture alone may not be sufficient to eliminate the virus from infected cassava plants. Meristem culture in combination with thermotherapy or chemotherapy is essential for virus elimination in case of cassava.

A faint hybridization signal was observed when the CMD-resistant line MNga-1 was tested through NASH. This indicates that MNga-1 is not immune to ICMV but multiplication of the virus within the plant is restricted and symptoms are not expressed by the plants.

Biodiversity of Cassava Mosaic Viruses

A survey was carried out to study the variability of cassava mosaic viruses occurring in different districts of Tamil Nadu and Kerala (CTCRI 2007; 2008). Out of 59 cassava mosaic affected samples collected from different districts in Kerala, when subjected to multiplex PCR, nine samples showed the presence of ICMV, 46 samples showed the presence of SLCMV, and four samples had both ICMV and SLCMV infection. Out of 30 CMD samples collected from Tamil Nadu, 21 samples showed the presence of ICMV whereas nine samples had SLCMV infection. Rothenstein *et al.* (2006) analyzed the viral DNA A components of CMD samples collected from Tamil Nadu and Kerala and sequenced eight representative samples. The majority (7 out of 8) DNA sequences obtained were more closely related to SLCMV than ICMV. Only one sequence collected from Kerala was related to ICMV. The diversity of the SLCMV-like sequences was rather low compared to the variability of African viruses associated with CMD. Based on DNS sequence data all these isolates were classified as isolates of SLCMV or ICMV and their phylogenetic analyses revealed the recombination events between ancestors of ICMV and SLCMV.

Management of CMD

The geminiviruses and their whitefly vector responsible for CMD have been studied intensively and much attention has been given to the development of possible control measures in Africa (Thresh and Cooter, 2005) as well as in India (Edison *et al.*, 2007). Planting disease-resistant varieties is the best option for management of any disease. However, most of the popular cassava cultivars in India are already infected and susceptible. The repeated indiscriminate use of infected planting material, non-availability of resistant varieties and no systematic program for distribution of virus-free planting materials to farmers have resulted in the widespread prevalence of CMD in India. Two decades of breeding for resistance to CMD or selection for resistance in germplasm has resulted in the identification of a resistant variety, which has been released as Sree Padmanabha for Tamil Nadu State (Unnikrishnan *et al.*, 2006; Abraham *et al.*, 2006).

Based on findings on disease incidence, spread, their effect on growth and production, integrated management practices have been recommended with emphasis on the health status of the planting material and phytosanitory measures. Various approaches for management of cassava mosaic have been explored. Use of meristem-derived plants, spraying of antiviral plant extracts like *Boerhavia diffusa* and *Mirabilis jalapa (*Hegde *et al.*, 2004*)*, use of barrier crops like maize and pigeon pea (Hegde *et al.*, 2004), application of plant growth promoting rhizobacteria like *Pseudomonas* species for induction of resistance to CMD (Hegde *et al.*, 2008) have been tested for management of cassava mosaic with partial success. The integrated management recommended at present includes:

Selection of disease-free planting material

Use of field-tolerant varieties like H-97, H-165 or the resistant variety Sree Padmanabha

Use of disease-free meristem-derived planting material, followed by multiplication by periodic screening and rouging of infected plants

Adherence to strict phytosanitory measures, such as timely harvest and prompt disposal of crop residues, eradication of self-sown plants and weeds, which may harbor the disease and vectors

Disease-free planting material can be multiplied on large scale at higher altitudes where the whitefly population is low or nil.

Though these management practices are recommended, there is no systematic arrangement for replacement of infected cassava plants and supply of healthy planting materials to farmers. Unlike other high-value horticulture crops like banana, no private firms have come forward for large-scale *in-vitro* production of disease-free cassava plants on a commercial scale.

Development of Transgenic Cassava

Growing resistant varieties is one of the best options for management of any disease. Development of disease-resistant varieties through genetic engineering is rapid and makes it possible to introduce the desired gene in the traditional cassava varieties which are susceptible to CMD but are otherwise liked by the farmers. Currently, two major research institutes, namely the Donald Danforth Plant Science Center (St. Louis, USA) and the Swiss Federal Institute of Technology (Zurich, Switzerland), in collaboration with several African countries and other laboratories are using different biotechnological approaches to develop mosaic-resistant transgenic cassava. In India work on the development of transgenic cassava has been initiated recently (Makeshkumar *et al.*, 2006). Initially, the regeneration of the Indian cassava cultivars was found difficult but later regeneration protocols for most of the popular Indian cassava cultivars were standardized. Cassava varieties H-226 and Sree Prakash were found to be ideal genotypes for the development of transgenic cassava in India as they were easily responding to induction of friable embryogenic callus (FEC) and had better regeneration efficiency compared to other cultivars (Sheela *et al.*, 2006). Replicase gene (AC1) of ICMV was cloned in pGEM-T Easy vector as a candidate gene for developing pathogen-derived resistance against ICMV infection. Sequencing of the AC1 gene showed that it had 1055 nucleotides, which encoded for 351 amino acids. Full-length AC1 gene constructs were made in pBin19 plant

transformation vector and mobilized to *Agrobacterium tumefaciens* strain LBA4404. Through Agrobacterium-mediated gene transfer methods, these constructs were introduced into cassava hybrid H-226 using cotyledons as explants. Transformants were selected by increasing the concentration of paramomycin from 10 mg/l to 25 mg/l. Analysis of incorporation of the AC1 gene in transgenic cassava lines were confirmed through PCR using *nptII* and AC1 primers and Southern analysis (Prakash Krishnan *et al.*, 2007). The transgenic cassava plants were hardened and are being maintained in a containment facility for further challenge inoculation with ICMV. If the plants resist challenge inoculation, they will be further multiplied for field trials. Further improvement for enhanced expression of transgene (Rep) is being worked out. Efforts are also made to use siRNA technology to develop transgenic mosaic-resistant cassava.

Future Thrust on Cassava Mosaic Research

Phasing out the infected materials and replace these with healthy planting materials, utilization of inherent biodiversity and wild relatives, development of quick and reliable diagnostic kits, strengthening of molecular biological research for obtaining an in-depth understanding of the cassava mosaic disease development, and the development of mosaic-resistant cassava are some of the future thrust areas.

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THE USE OF MOLECULAR MARKERS TO IDENTIFY AND BREED FOR RESISTANCE TO AFRICAN AND INDIAN CASSAVA MOSAIC DISEASE

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ABSTRACT

Cassava mosaic disease (CMD) is the most reported causal factor responsible for severe yield losses of cassava in Africa and India. CMD, a viral disease, transmitted by the white fly *Bemisia tabaci*, is caused by at least six African and two Asian cassava mosaic geminivirus (CMG) species. The inherent dynamism of the causal viruses to recombine into more virulent forms, coupled with the heterozygous background of the crop, makes breeding for CMD resistance difficult in cassava improvement programs.

Molecular markers are effective genomic tools in breeding for resistance to this disease through gene tagging and the identification of different sources of CMD resistance. The application of molecular markers in breeding at CIAT in the past few years through bulk segregant analysis and genetic mapping, has facilitated the identification of genes from different sources associated with CMD. These are the CMD1 gene from a *Manihot glaziovii* source, CMD2 from a landrace TME3, and CMD3 from an elite IITA clone TMS97/2205. Four flanking markers – two each of simple sequence repeat (SSR) and sequence characterized amplified regions (SCARs) – linked to the CMD2 gene, have been intensely used in a marker-assisted selection (MAS) scheme to introgress resistance into elite genomic backgrounds in CIAT for germplasm shipment to Africa and India. The use of CMD2 markers through MAS has so far resulted in the development of over 150 CMD resistant elite genotypes in four countries in Africa. The three sources of CMD resistance are presently being deployed in gene pyramiding to increase favorable alleles for CMD resistance in elite breeding populations. The discovery of different resistance genes through molecular markers is permitting the systematic pyramiding of these genes into single genotypes towards the development of durable resistance in efforts to combat the rapid evolutionary capacity of the virus to evolve as a recurrent threat to food security in Africa and South Asia.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the fourth most important tropical crop worldwide. Cassava, a tropical plant with tuberous roots, is not only a valuable source of food in many parts of Africa, but the starch obtained from the roots has wide industrial applications. Africa accounts for most of the cassava root harvest worldwide with more than half of the world's total production (FAOSTAT, 2008), followed by Asia and Latin America – the center of origin for *Manihot* species.

One of the most important constraints to cassava production is cassava mosaic disease (CMD), which is the most widespread cassava disease of economic importance and is the most reported causal factor responsible for severe yield losses in Africa and South Asia. The CMD pandemic led to widespread food shortages and famine related deaths in

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East Africa in the 1990s with yield losses as high as 100% in some epidemic situations. CMD is transmitted by a whitefly (*Bemicia tabaci*) vector, which occurs in Africa and India.

Cassava mosaic disease is caused by begomoviruses and it includes at least six African and two Asian cassava mosaic geminivirus (CMG) species. These are the *African cassava mosaic virus* (ACMV), *East African cassava mosaic virus* (EACMV), and *South African cassava mosaic virus* (SACMV) (Berrie *et al.,* 2001; Bock and Woods, 1983; Hong *et al.,* 1993), and the *Indian cassava mosaic virus* (ICMV) (Swanson and Harrison, 1994). Among the cassava mosaic geminiviruses, the principal species are the ACMV, EACMV and the ICMV. Cassava is the most common natural host of the viruses, followed by its relative wild species *M. glaziovii* Muller von Argau (Ogbe *et al.,* 2006).

Cassava mosaic viruses are disseminated and perpetuated from one cropping season to another by the use of infected cuttings as planting material. Disease severity generally depends upon the host genotype, and is usually more severe on susceptible than on resistant genotypes (Hahn *et al.*, 1980; Jennings, 1994; Thresh and Otim Nape, 1994). Double infection of cassava with EACMV and ACMV has been documented in Tanzania (Harrison *et al.,* 1997), Cameroun (Fondong *et al.,* 2000) and Cote d'Ivoire (Pita *et al.,* 2001) with most plants exhibiting severe disease symptoms.

The rapid evolution of the virus has continued to be a serious threat to food security in those areas where the crop is a staple food. The inherent dynamism of the causal viruses has been demonstrated by the occurrence of a recombinant hybrid of the two principal species (ACMV and EACMV), which was identified and shown to be associated with an unusually severe and rapidly spreading epidemic. The consequent devastation of production of the cassava crop, and the observation of similar recombination events elsewhere, has demonstrated the inherent danger posed to man by the capacity of these viruses to adapt to their environment and optimally exploit their relationships with the whitefly vector, plant host and human cultivator (Legg and Fauquet, 2004).

Cassava improvement continues to tap genetic variation through conventional breeding (including the use of wild species) and biotechnology, through manipulation of genes for the development of new cultivars that resist prevailing diseases and pests, especially CMD. Host plant resistance is the best strategy for controlling the disease. *Manihot glaziovii* was the first known source of resistance to the disease and classical genetic analysis confirmed the polygenic nature of the *M. glaziovii* source of resistance. This resistance which was deployed in breeding programs in Africa and Asia where the disease occurs was thought to be polygenic with a recessive component and difficult to manipulate in breeding programs. While wild relatives are important sources of genes for pest and disease resistance in cassava (Hahn *et al.*, 1980a; Hahn *et al.*, 1980b; Chaviarriaga *et al.*, 2004), the need to reduce or eliminate undesirable donor genome content and linkage drag can lengthen the process, making it unrealistic for most breeders, and a more daunting task to achieve.

With the discovery of the molecular basis of genetic improvement of crops, molecular markers have rapidly gained importance in the study of genes and genomes. Molecular markers are valuable breeding tools that have rapidly increased our knowledge of traits that are difficult to manipulate genetically, and have rapidly facilitated the identification of a great number of genetic factors responsible for the heritable variation in traits, including pests and diseases.

The CMD pandemic expansion is a continued threat to production gains recorded through breeding successes in recent decades. However, the long time frame required for cassava breeding means that molecular markers could be used to accelerate breeding activities and to develop efficient strategies to address the constant threats this disease poses to Africa and Asia. This paper reports on current progress and trends in the use of molecular markers to efficiently breed for CMD resistance in Africa and Asia and the implications for cassava development.

Breeding Cassava

Cassava is a monoecious and highly heterozygous crop. The worldwide breeding objectives for cassava are broad, which implies that a large and variable number of characteristics would be required to achieve them. Improved populations are being created into which exotic germplasm from several sources could be introgressed, while retaining the desirable gene complexes already present, and allowing sufficient inbreeding for the expression and elimination of recessive ones (Hahn *et al.,* 1979; Hershey, 1984). It was desirable to minimize inbreeding and to restore heterozygosity fully to avoid inbreeding depression (Kawano *et al.,* 1978).

The vegetative multiplication rate of cassava is low. From one plant, 5-10 cuttings typically can be obtained, although this figure varies widely by genotype. This situation implies a lengthy process to reach the point where replicated evaluations across several locations can be conducted. It takes therefore about 5-6 years from the time the botanical seed is germinated until the evaluation/selection cycle reaches the regional trial stage, in which several locations can be included, and an additional few years before varieties are released.

Due to repeated cassava mosaic disease (CMD) pandemics, breeding has tended towards development of varieties with CMD resistance (Thresh and Cooter, 2005). Host-plant resistance to CMD is the best method of containing the disease (Akano *et al.,* 2002) and it provides the most effective control strategy and easiest approach to tackle the disease (Hahn *et al.,* 1980a; Nnodu and Ogbe, 1994; Otim Nape *et al.,* 1994) and it is the most practical long-term approach for controlling CMD. In addition, this approach offers a more durable method because it has no negative impact on the environment and the economics of adoption makes it relatively easier for farmers compared to other forms of control. The aim of breeding for resistance is to produce cultivars with improved resistance that persists under a wide range of environmental conditions. Different strategies have been used in breeding for CMD resistance in Africa and Asia. This includes introgression of resistant genes from wild species into cassava using interspecific crosses, followed by backcrossing.

Diallel crosses and recurrent selection have also been used to improve and develop resistant varieties (Hahn *et al.*, 1989).

Disease resistance breeding is a rather slow and cumbersome process, owing to the biological constraints of a heterozygous vegetatively propagated crop. **Table 1** illustrates a typical selection cycle in cassava. The table shows the different stages required to complete a selection cycle and the kind of selection pressures that are generally applied (Ceballos *et al.*, 2007). A cassava breeding scheme starts with the crossing of elite clones. The botanical seed obtained by the different types of crosses (Kawano, 1980) are planted. The first selection is conducted in the second year in the nurseries, with plants derived from botanical seed while the second stage of selection is the clonal evaluation trial (CET). At the seedling nursery (SN) and CET stages, primary emphasis is placed on CMD as well as other pests and diseases in the first two years. Selected clones from CET are evaluated in the Preliminary Yield Trial (PYT), which is a replicated trial. With the initiation of replicated trials, the emphasis of selection shifts from high heritability traits to those of low heritability such as yield from PYT to advanced yield trials (AYT) and the regional or uniform yield trials (RT or UYT). The clones that show outstanding performance in the RTs are selected and tested on farmers fields before release. The scheme ends with a release of a new variety that takes a time frame of 8-10 years. The development and release of CMD resistant and high yielding varieties is time consuming. Because cassava is propagated by cuttings, the virus easily builds up in the planting materials, and plants without moderate resistance could succumb to the disease after a long period of exposure to the virus. Therefore, CMD evaluation is continued long into the breeding scheme. However, with the aid of molecular markers, resistant materials could be easily identified and this may help reduce the evaluation period for the disease.

Table 1. Cassava selection in breeding programs.

Year	Activity	Number of genotypes	Plants per genotype
1	Crosses among elite clones	Up to 100,000	
2	F1: evaluation of seedlings from botanical seeds (strong selection for CMD in Africa and Asia)	17,500 – 100,000	1
3	Clonal Evaluation Trial (CET)	1,800 – 3,000	6-12
4	Preliminary Yield Trial (PYT)	100 - 300	20-80
5	Advanced Yield Trial (AYT)	18-100	100-500
6-8	Regional Trials (RT)	5-30	500-5,000

Source: *Ceballos et al., 2004.*

CMD Effects on Introduced Germplasm

The germplasm of the original importations to Africa was inevitably narrowly based. Research over the years has aimed to broaden the genetic base of cassava in Africa and Asia by introducing Latin American (LA) germplasm. Due to the absence of the virus in Latin America, the International Center for Tropical Agriculture (CIAT) could not breed for CMD resistance in the absence of the pathogen. Resistant elite germplasm transferred from IITA to CIAT were initially used to breed for CMD resistance. However, due to the

polygenic source of inheritance for this source of inheritance, resistance was difficult to achieve. Consequently, germplasm introduced from Latin America into Africa and Asia was highly susceptible to cassava mosaic disease. The effects of CMD were often so devastating that most national programs concentrated on breeding for resistance to it. For example, over 20,000 seedlings introduced from Latin America to Nigeria under IITA-CIAT collaborative projects between 1990 and 1994 (Okogbenin *et al.,* 2007) were found to be highly susceptible to CMD, minimizing its usefulness in African cassava-breeding programs. The implication of this was that useful germplasm from the Americas could not be used directly for breeding in Africa and Asia. This initial setback justifies the need to seek molecular approaches to map genes for resistance for marker-aided introgression and selection for CMD resistance in breeding programs.

Genetic Mapping for CMD Resistance

The application of molecular markers in breeding has facilitated the identification of genes associated with important traits, including CMD resistance.

Host plant resistance was first identified in third backcross derivatives of an interspecific cross between cassava and *M. glaziovii.* The female parent, TMS 30572 of the first genetic cassava map population has this source of resistance. Several Nigerian cassava landraces showing strong resistance to CMD have been identified which are being used for CMD resistance breeding in the National Root Crops Research Institute (NRCRI), Nigeria, and at IITA . Classical genetic analysis confirmed the polygenic nature with a recessive component of the *M. glaziovii* source of resistance and a major dominant gene control for a new resistance source found in TME3, a landrace (Akano *et al.,* 2002).

These two sources of CMD resistance were used for gene tagging studies to identify the genes and the genomic regions involved in the control of resistance to CMD. A bulk segregant analysis (BSA) approach identified markers linked to both sources of resistance (Fregene and Puonti-Kaerlas, 2002). An SSR marker, SSRY40, on linkage group D of the genetic map of cassava was found to be associated with CMD resistance for the *M. glaziovii* source, and explains 48% of the phenotypic variance of CMD resistance; it was designated CMD1. The dominant CMD resistance gene from the land race was designated CMD2 and explains about 70% of the phenotypic variance; it is flanked by RME1 and NS158 (at distances of 4 and 7 cM, respectively) (**Figure 1**). RME1 is a SCAR marker, while NS158 is an SSR marker. The dominant gene offers a rapid means to quickly transfer resistance from parents to progeny in the breeding scheme.

Fine mapping studies were made to identify more markers within the genomic region for multiple marker selection for alleles associated with the gene. Genetic mapping has identified four markers which are RME1, RME2 (SCAR markers), NS158 and NS128 (SSR markers). These markers are closely associated to CMD2 and are being deployed for use in MAS. Activities for the positional cloning of the CMD2 gene has been initiated involving the construction and screening of TME3 BAC library, fine mapping and chromosome walking (Isabel Moreno *et al.,* unpublished data). Fine mapping of the CMD2 gene region has identified two additional tightly linked markers to the CMD2 gene (Isabel Moreno *et al.*, unpublished data)

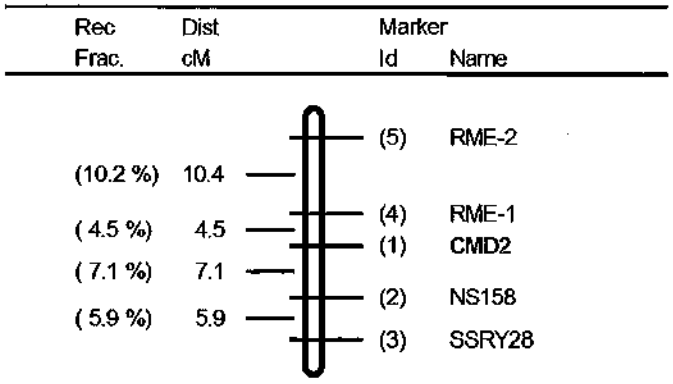

Figure 1. Genetic mapping of the CMD2 gene and associated molecular markers. RME1 and RME2 are SCAR markers, while NS158 and SSRY28 are SSR markers.

The dominant nature of CMD2 and its effectiveness against a wide spectrum of viral strains makes its deployment very appealing for protecting cassava against the actual or potential ravages of CMD. CIAT in collaboration with cassava breeding programs in African NARs has been exploiting the CMD2 gene via MAS to deploy useful germplasm from Latin America to Africa and India, and recently many resistant cultivars have been developed through this process (Okogbenin *et al.*, 2007).

MAS for CMD Resistance in the Development of New Varieties

Cassava genetic improvement can be made more efficient through the use of easily assayable molecular genetic markers (MAS) that enable the precise identification of genotype without the confounding effect of the environment, thereby increasing heritability.

An ideal target for MAS is breeding for disease resistance in the absence of the pathogen. This is the case for disease resistance to cassava mosaic disease (CMD) in the Americas, where the disease does not occur. Cassava originates in Latin America which is the center of diversity for the crop and where good sources of useful germplasm are available for the genetic improvement of the crop worldwide. The utility of such germplasm in Africa and Asia, essentially and of necessity, requires that they are improved for CMD resistance. Breeding for CMD resistance was difficult based on conventional breeding approaches in the absence of the pathogen in Latin America. The polygenic nature of the disease resistance initially deployed made it extremely difficult to effectively breed for CMD resistance. Consequently, large quantities of cassava seeds (in hundreds of thousands) were shipped to breeding programs in Asia and African NARs, which often ended being devastated by CMD. In IITA, after five years of evaluation of over 20,000 genotypes, none was selected for uniform or regional yield trials (Okogbenin *et al.*, 2007) **(Table 2).** The discovery of the single dominant gene (CMD2) has made it possible to transfer CMD resistance efficiently with molecular markers closely linked to the gene.

Molecular markers that allow selection of segregating progenies that carry the resistance to CMD have been successfully utilized (Fregene *et al.,* 2006) in breeding programs in Africa.

Table 2. The number of Latin American genotypes selected at various stages of the IITA breeding scheme at Ibadan, Nigeria, from 1990 to 1994.

Trial	1990	1991	1992	1993	1994
Seedling nursery	5400	5300	3514	3800	2018
Clonal evaluation trial		538	253	117	572
Preliminary yield trial			9	10	26
Advanced yield trial				2	2
Uniform yield trial					0

Source: *Okogbenin et al., 2007.*

Although evaluation for CMD resistance in sub-Saharan Africa is relatively easy and most areas have sufficient disease pressure to permit moderate to high heritability of resistance, the need for modest-sized breeding populations make MAS for CMD resistance a powerful tool to accelerate cassava improvement in Africa. A MAS project was initiated under the Generation Challenge Program (GCP) involving CIAT, Nigeria, Ghana and Uganda. Under this project, MAS for CMD resistance was used to transfer useful germplasm from Latin America to Africa. Considering that Latin American germplasm are susceptible to the disease has efficiently assisted breeding programs in Africa to receive useful cassava germplasm from Latin America. Germplasm for beta carotene, high dry matter, yield, good architecture and vigor incorporated with CMD resistance have been successfully deployed in Africa. Currently, SSR and SCAR markers are being used to select for CMD resistance in Africa and Asia. MAS based on the markers associated with the CMD2 gene revealed 68% efficiency, and this is expected to improve with the discovery of more closely linked markers.

In vitro cultures of elite lines combining useful traits of interest with CMD resistance were selected with molecular markers for the *CMD2* gene in Latin America for shipment to Africa. Through MAS, a first shipment of 156 genotypes which were pre-selected for the gene at CIAT, was evaluated in Nigeria between 2004 and 2006. The introgression of the *CMD2* gene resulted in high CMD resistance under African field conditions. In Nigeria and Ghana, elite cassava genotypes combining CMD resistance, good dry matter content and high yield, are being evaluated at advanced stages in the breeding scheme. In Nigeria, 14 genotypes (**Tables 3 and 4**) are being evaluated in farmers fields prior to their release, while another set of 42 genotypes are presently in regional yield trials (**Table 5**). Ghana is also evaluating eight elite lines developed through MAS at the Advanced Yield Trial stage. Severity of CMD is rated on a scale of 1 to 5 (1= no symptoms, implying high resistance; 5 = high susceptibility). Results have shown that genotypes expressing CMD2 gene resistance show zero or mild symptoms during most of the growth season. Even in instances where genotypes show relatively moderate symptoms with severity score of 3, such genotypes rapidly outgrow the disease and show little or no symptoms at harvest, and generally tend to have a mean severity index of less than 2. MAS for CMD has efficiently assisted breeding programs in Africa and Asia to receive useful

cassava germplasm from Latin America. **Table 6** shows a summary of CMD shipments to Africa and Asia. This has greatly improved the potential value of LA germplasm for Africa, and has led to enhanced prospects of elite LA genotypes being released as improved varieties in Africa. It is not only of immense benefit for Africa, but it has in addition opened up opportunities for marker-assisted breeding for CMD resistance in Latin America as a pre-emptive step against the frightening prospect of the accidental transfer of the disease to the New World.

Table 3. Highest and mean CMD score over an 8-month period in 2007 at Umudike, Nigeria.

Accession	Mean CMD score	Highest CMD score
AR15-5	1.11	2
AR1-82	2.06	3
AR37-108	1.72	3
CR12-45	2.11	3
CR14A-1	1.72	3
CR26-1	1.33	3
CR36-2	1.17	2
CR36-5	1.17	2
CR42-4	1.61	3
CR52A-25	1.44	3
CR52A-41	1.33	2

Table 4. Harvest data of cassava clones in a uniform yield trial in 2007 at Umudike, Nigeria.

Clone	Root yield (tons/ha)	Top yield (tons/ha)	Harvest Index
AR9-12	44.00	15.50	0.74
CR36-2	28.29	30.10	0.49
CR52A-9	24.26	19.61	0.55
CR11A-20	21.45	18.64	0.56
AR12-57	21.27	20.80	0.52
AR38-89	18.63	16.07	0.50
CR59A-3	18.43	14.22	0.57
AR9-19	18.13	15.75	0.53
CR8A-20	17.85	17.64	0.51
CR59-4	17.46	19.07	0.44

Table 5. Disease scores of advanced lines in yield trials in 2007 at Umudike, Nigeria.

		Highest severity scores				
	Accessions	CMD	CBB	CAD	CGM	CM
MAS lines	AR14-4	1	2	3	3	1
	AR15-5	1	3	3	3	1
	AR26-1	2	2	3	4	1
	AR9-45	2	2	2	3	1
	AR9-46	2	2	2	4	1
	AR9-5	1	2	3	3	1
	CR13-1	2	2	2	3	1
	CR20A-2	2	2	3	3	1
	CR24-9	1	2	3	3	1
	CR25-4	1	2	2	4	1
	CR35-10	1	2	4	4	1
	CR35-14	1	2	3	4	1
	CR41-10	1	2	3	3	1
	CR41-7	1	2	3	4	1
	CR45-10	1	2	3	3	1
	CR52A-1	1	2	3	3	1
	CR52A-37	1	2	3	3	1
	CR52A-4	2	2	3	3	1
	CR52A-6	2	2	3	4	1
	CR8A-22	1	2	3	4	1
	AR12-4	2	2	3	4	1
	AR12-57	1	2	3	4	
	AR14-10	2	2	3	4	1
	AR38-89	1	2	3	4	
	AR6-1	1	2	3	4	1
	AR9-12	2	2	3	3	1
	AR9-19	1	2	3	3	1
	AR9-48	1	2	3	4	1
	AR9-63	2	2	3	4	
	CR20A-6	2	3	3	4	
	CR24-7	1	2	3	3	1
	CR34-6	1	2	3	4	1
	CR36-2	1	2	3	3	1
	CR41-8	-	-	-	-	-
	CR44-6	1	2	3	4	1
	CR49-2	2	2	3	3	1
	CR52A-2	1	2	3	4	1
	CR52A-22	1	2	3	3	1
	CR52A-31	1	2	3	4	1
	CR52A-9	1	1	3	4	4
	CR59-4	1	2	3	4	1
	CR59A-3	1	2	3	3	1
Checks	Local	4	3	3	3	1
	NR8082	4	2	3	4	1
	TMS30572	3	2	3	4	1

CMD = Cassava mosaic disease; CBB = cassava bacterial blight; CAD, cassava anthracnose disease, CGM = cassava green mite; CM, cassava mealybug

Table 6. Summary of CMD shipments from CIAT to Africa and Asia.

Country	Trait[1)]	Genotypes	Date sent
Tanzania	CMD + CGM	530	November 2003, April 2004
Nigeria	CMD+CGM+RQ	765	March 2006
Uganda	CMD+CGM	530	March 2006
Ghana	CMD+CGM+RQ	765	March 2006
Kenya	CMD+CGM+DM	850	October 2005
Ethiopia	CMD+CGM+DM	480	October 2005
Mozambique	CMD+CGM+RQ	150	October 2008
South Africa	CMD+CGM	80	September 2005
India	CMD+CGM	530	May 2005
Thailand	CMD+CGM	50	March 2008

[1)] CMD = cassava mosaic disease; CGM = cassava green mite; RQ = root quality traits; DM = dry matter.
Source: *M. Fregene, unpublished data.*

Markers associated with resistance to CMD are currently being used to reduce the population size in breeding programs. Through MAS, genotypes shipped from CIAT to NARs have reduced from hundreds of thousands as previously in the 90s to a few hundreds of genotypes by 2005. The advantage of MAS is that it enables the breeder to eliminate at an early stage CMD-susceptible genotypes, which in the case of the heterozygous CMD-resistant landraces is 50%. This halves the cost of disease evaluations and increases the efficiency. Using MAS for CMD alone could therefore reduce the size of field trials by 50 percent.

With the aid of MAS, effective selection for CMD resistance can be achieved, and the first two years, which principally target CMD screening in the breeding scheme, could be reduced or eliminated in breeding programs. Through rapid multiplication of genotypes selected via MAS, sufficient planting materials could be generated quickly for yield trials conducted for 2-3 years. There is thus a massive gain in time considering the length of the growing cycle of cassava and the expense involved in the evaluation process under conventional breeding. The selection of progenies based on genetic values derived from molecular marker data substantially increases the rate of genetic gain, especially if the number of cycles of evaluation or generations can be reduced (Meuwissen *et al.,* 2001). With the aid of markers, the breeding scheme time frame could be reduced by 20-40%. **Figure 2** describes the scheme for MAS as it is being used in Africa under the CP project with a timeframe of 6-7 years.

New sources of CMD Resistance

Due to the dynamic evolution of the virus, especially in view of the emergence of new recombinants of the virus, there is a need to identify new sources of resistance and pyramid genes in an effective way to build durable disease resistance. For example, EACMV-Ug is an interspecific recombination of DNAs of ACMV and EACMV in Uganda (Zhou *et al.,* 1997); the widespread pandemic in Uganda, which caused 90 to 100% yield

losses (Otim Nape *et al.*, 2000), resulted from mixed infections of ACMV and EACMV-Ug.

Host-pathogen relationships are dynamic, usually resulting in a breakdown in host resistance as a result of changes in pathogen populations over time. The use of a single dominant gene/locus-based resistance strategy, as with CMD2, might lead to a vulnerability to resistance breakdown (Legg and Fauquet, 2004). A genotype developed for resistance to a particular race of a pathogen under a given set of circumstances may not be resistant to another race of the same pathogen under different circumstances. Considering the time and resources required for development of resistant varieties it is important to develop varieties carrying as many different genes for resistance as possible. The discovery of additional genes representing new sources of resistance will rapidly allow for the pyramiding of these genes into single genotypes, thus enhancing the development of durable resistance to the disease. This offers the best approach for combating the rapid evolutionary capacity of the disease to evolve as a recurrent threat to food security in Asia and Africa. The pyramiding of genes, known only by indistinguishable phenotypes, requires molecular marker aided breeding.

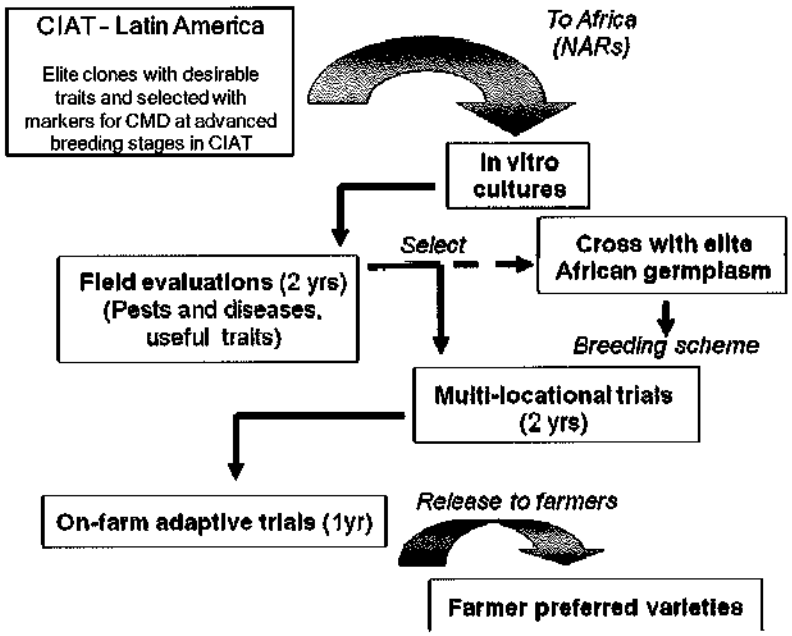

Figure 2. A marker assisted selection (MAS) cassava breeding scheme for exotic elite germplasm deployed in breeding programs in Africa.

Molecular markers have facilitated the discovery of the CMD1 and CMD2 genes, and efforts have been further made to identify additional genes. Under the genotyping

support service of the GCP, NRCRI evaluated F_1 families segregating for CMD resistance with molecular markers with a view to identifying additional sources of CMD resistance. Preliminary results based on 530 SSR markers using BSA, identified TMS 97/2205 as having resistance different from CMD1 and CMD2 genes. The histogram showing CMD segregation in the cross TMS97/2205 x NR8083 is shown in **Figure 3**. The new gene from TMS97/2205 has been denoted as CMD3, and SSR marker NS 198 was found to be significantly (P = 0.015) associated with this resistance. Genetic distances as computed with Mapmaker, shows that the genetic distance between NS198 and CMD3 is 47.5 cM. TMS 97/2205 is highly resistant to CMD in several CMD pressure zones in Nigeria (Egesi *et al.*, 2007). TMS 97/2205 has been used in crosses with eleven elite cassava lines having the CMD2 gene as part of systematic efforts in the breeding scheme to pyramid CMD resistance genes for durable and stable resistance to a broad spectrum of viruses.

Extensive screening of germplasm for CMD resistance is still on-going with a view to identify more sources of CMD resistance in breeding programs. Egesi *et al.* (2007) reported the resistance profile of IITA elite clones evaluated in different agro-ecologies in Nigeria at three sites (Ishiagu, Otobi and Umudike). Results from this evaluation have identified some highly resistant genotypes (**Table 7**). However, information or evidence are currently lacking to indicate if they represent new sources of resistance. High CMD resistance in cassava genotypes are indistinguishable phenotypically for the different resistance genes, and molecular markers will be needed to further analyze these genotypes.

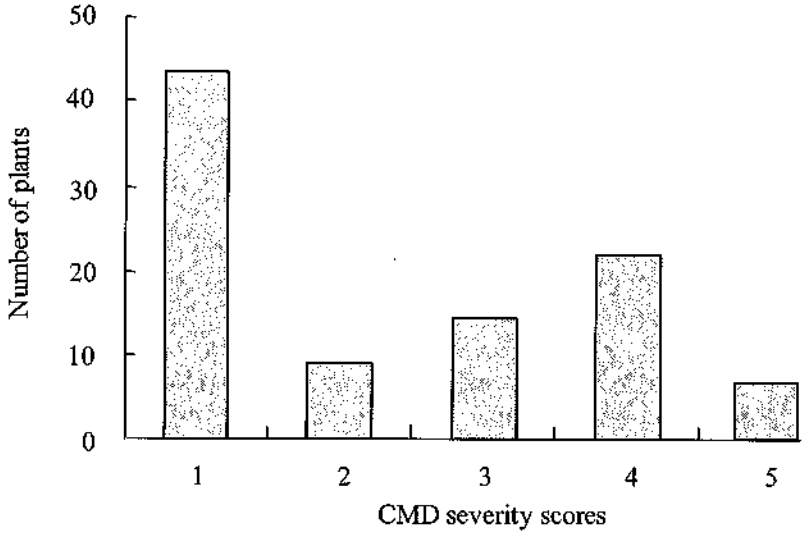

Figure 3. Segregation for CMD resistance in the cross TMS 97/2205 x NR8083.

Table 7. Resistance status of selected improved cassava genotypes with cassava mosaic disease resistance as determined by the rank-sum classification method based on their responses in three locations in 2003 and 2004.

	Ishiagu		Otobi		Umudike		Rank sum classification			
Genotype	AUDPC	a	AUDPC	b	AUDPC	c	d	e	f	Group
TMS 98/0581	4.21	5.00	6.65	13.00	6.58	4.00	22.00	-39.50	-1.30	R
TMS 99/3073	4.21	5.00	6.65	13.00	6.95	5.50	23.50	-38.00	-1.25	R
TMS 97/4763	4.21	5.00	6.65	13.00	7.01	7.00	25.00	-36.50	-1.20	R
TMS M98/0040	7.33	19.00	4.15	1.50	6.95	5.50	26.00	-35.50	-1.17	R
TMS 98/0505	8.08	24.00	4.15	1.50	5.45	2.00	27.50	-34.00	-1.12	R
TMS 97/0211	4.21	5.00	6.65	13.00	7.33	10.00	28.00	-33.50	-1.10	R
TMS 97/4769	6.58	14.00	6.02	6.00	7.33	10.00	30.00	-31.50	-1.04	R
TMS 99/2123	4.21	5.00	6.65	13.00	7.70	12.00	30.00	-31.50	-1.04	R
TMS M98/0068	4.21	5.00	6.65	13.00	7.89	13.00	31.00	-30.50	-1.00	R
TMS 97/0162	6.58	14.00	4.71	3.00	8.27	15.00	32.00	-29.50	-0.97	R
TMS 98/0002	4.21	5.00	6.65	13.00	9.20	17.00	35.00	-26.50	-0.87	R
TMS 96/0523	4.21	5.00	6.65	13.00	9.58	18.00	36.00	-25.50	-0.84	R
TMS 96/1632	4.77	10.00	6.65	13.00	8.08	14.00	37.00	-24.50	-0.81	R
TMS 98/2101	4.21	5.00	6.65	13.00	9.77	20.50	38.50	-23.00	-0.76	R
TMS M98/0028	6.58	14.00	5.84	5.00	9.77	20.50	39.50	-22.00	-0.72	R
TMS 97/4779	5.33	12.00	6.65	13.00	8.83	16.00	41.00	-20.50	-0.67	R
TMS 97/2205	7.21	17.50	7.77	26.00	4.95	1.00	44.50	-17.00	-0.56	R

a, b, c: genotype rankings at Ishiagu, Otobi and Umudike, respectively; †Grand mean of the rank-sums (G); d: Rank-sum (a + b + c) for each genotype at each site; e: deviation from the grand mean (G) of the rank-sums (e = (d – G)/standard deviation); f: standardized mean of deviations.
R = resistant; MR = moderately resistant; MS = moderately susceptible and S = susceptible.
Source: *Egesi et al., 2007*

SUMMARY AND CONCLUSIONS

The use of DNA-based markers in breeding is primarily based on the heritability of a trait and the amount of genotypic variance explained by the marker. Where heritability is zero or low, as in CMD in the New World tropics, breeding for CMD resistance through MAS has facilitated the transfer of useful germplasm from the center of diversity in Latin America to Africa and Asia. Even where heritability is moderate or high, selection by markers is helping to identify different sources of genes for CMD and other traits that are indistinguishable by phenotype, thereby creating opportunities to rapidly pyramid these genes. This would be difficult to achieve in classical breeding, which oftentimes is also time consuming. Such molecular tags for the different sources of CMD resistance can be used inexpensively and rapidly to identify desirable genotypes early in the breeding cycle, thereby eliminating the need to evaluate large numbers of plants phenotypically; it also obviates the confounding effects of the environment.

The success of MAS for CMD resistance breeding has opened new vistas in the application of markers in breeding programs at NARs in Africa and Asia. The remarkable

progress recorded with MAS for CMD resistance is rapidly expanding the capacity of NARs in Africa and Asia in the area of molecular breeding to embrace other activities in the genetic improvement of cassava. These activities include the use of markers in the introgression of useful genes for pests and diseases, and other traits from wild relatives and exotic germplasm into the adapted gene pools; it also allows for the identification of genotypes that carry minimal amounts of flanking donor parent genome around the gene of interest for faster backcrossing, thus reducing the length of time required to achieve this.

Through the support of the Generation Challenge Program (GCP) under the cassava breeding community of practice project, NARs in Africa are rapidly integrating field-based breeding strategies with MAS activities in breeding for resistance to pests and diseases, and for root quality traits. This is expected to result in more efficient breeding with rapid product delivery and increased productivity of value-added cassava, resulting in improved livelihoods and quality of life for resource poor farmers and consumers who mainly depend on cassava for their daily source of food.

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CASSAVA LEAF PRODUCTION RESEARCH CONDUCTED IN THAILAND

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ABSTRACT

Cassava tops (leaves, petioles and young stem) are a good source of protein for animal feeding. If only 10% (0.4 million tonnes) of imported soybean meal in the animal feed industry were substituted by cassava leaf meal, the country could save 900 million baht or 21 million US dollars a year. Research concerning the use of cassava leaves in the past mainly concentrated on the utilization of cassava tops to partially substitute for soybean meal in the feeding of animals, including dairy and beef cattle, swine, and poultry. To achieve a package of technologies for cassava leaf production and utilization, experiments to identify suitable varieties and cultural practices have been conducted since 2002. In addition, experiments to develop techniques for cassava leaves for animal feed making has been conducted since 2005. The technologies have also been transferred to dairy and cattle farmers and cassava growers since 2005.

The results so far indicate that the best varieties/lines for cassava leaf production are KU 50, Rayong 72, Rayong 5, CMR41-61-59 and CMR41-111-129. These varieties/lines yielded 7.0-15.9 t/ha dry tops and 11.3-36.9 t/ha fresh roots. The optimum plant spacing was either 30x30 cm, 60x60 cm or double rows at 30x30 cm and 60 cm between those double rows. The recommended rate of fertilizer is 375 kg N, 109 kg P_2O_5 and 281 kg K_2O/ha, applying a commercial fertilizer formula 15-7-18 at the rate of 521 kg/ha at planting and after the 2nd and 4th leaf harvest, and urea at the rate of 156 kg/ha after the 1st and the 3rd harvest. Alternatively, a fertilizer rate of 425 kg N, 142 kg P_2O_5 and 141 kg K_2O/ha, using a mixture of 187 kg/ha 15-15-15 and 125 kg/ha of urea/ha applied at planting and after every leaf harvest is recommended for some areas. Cutting the plant tops at about 20 cm above the ground at 2-3 month intervals was found to be the best practice.

An experiment on making animal feeds indicate that when chopped cassava leaves were dried for 3-4 days in the sun, the moisture content was reduced to less than 10% and this resulted in good quality and good-smelling cassava hay, or good-quality cassava meal after grinding. Both products could be stored for 7 months when they were in plastic bags. Chopping cassava leaves and letting them wilt overnight caused a remarkable reduction in HCN content of about 69 to 80%. Subsequent sun drying for two days reduced the HCN content to a safe level for animal feed of 30 mg/kg dry weight. Further drying to the safe moisture content for storage (lower than 10%) was necessary for later use. Air-drying reduced the HCN content at a faster rate than sun-drying under hot weather conditions during April to June. For cassava leaf silage making, chopping the leaves into small pieces is more important than the kind of additive used. The chopped cassava leaves that were wilted overnight, when mixed with one of the additives, such as cassava chips or molasses at 5%, by weight, then ensiled in plastic bags for one month, provided good quality silage that could be kept for five months. Cassava root silage could be made by cutting the roots into small slices and letting these dry overnight followed by ensiling in plastic bags for a month. The cassava roots mixed with 25-50% chopped leaves before ensiling produced good quality silage. Plastic containers with firmly closing lids can also be used for cassava leaf and root ensiling. Dairy and cattle farmers in some areas are now adopting the cassava leaf utilization on their own farms.

INTRODUCTION

Cassava is one of the most important crops grown in Thailand. In 2007, the planting area of the country was 1.2 million ha with root yields of 26.4 million tonnes. Because cassava can grow well even under infertile soil and drought conditions, the crop is

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grown throughout the country. The main planting area is in the Northeast, followed by the Central Plain and the North, with the areas of 0.66, 0.36 and 0.18 million ha, respectively. Thailand has also been the biggest world exporter of cassava root products, mainly in the forms of starch, chips and pellets, for more than 30 years. The value of the exported products is about US$ 834 million or baht 30,000 million per year. Beside cassava roots which are a carbohydrate (energy) source for many industries, including food and feed, the leaves are a good source of protein for feeding to various kinds of animals, including pigs, poultry, beef and dairy cattle. If cassava leaf meal were to substitute only 10% (0.4 million tonnes) of imported soybean meal as the protein source for animal feed, the country could save 25 millions US$ per year (Juttupornpong, 2000). Cattle are also one of the important animals produced in Thailand. In the year 2007, there were 9.26 million heads of beef and dairy cattle produced in the country. About 66% of these cattle were raised in the same main planting area of cassava, the Northeastern and the Central Plain regions. High feed cost and insufficient grass land are important constraints for animal production. Therefore, cassava leaves could potentially be used as a protein source for cattle production.

RESEARCH ON CASSAVA LEAF PRODUCTION IN THAILAND

Previous Research

From the experiments conducted by many researchers in universities and research institutes in Thailand (Limsila *et al.*, 2002; Martwana *et al.*, 2009) we can conclude the following:

1. Cassava leaf production research focused on the partial use of cassava leaves as a protein source for animal feed, especially for dairy and beef cattle.
2. Fresh cassava leaves contain a high level of hydrocyanic acid (HCN), which can cause the death of animals. Cassava hay made by drying the chopped or non-chopped cassava tops under sunlight for a few days will greatly reduce the levels of HCN.
3. Cassava tops can be used either from those collected at root harvest or those harvested at 2-4 month intervals.
4. Cassava top yields and nutritive value varied according to variety, soil fertility, fertilizer application, plant spacing and frequency of harvesting.

Although research on cassava leaf production for animal feed in Thailand was initiated more than 30 years ago, the results have not been widely used. Recently, as the price of animal feed increased and grazing pastures are limited, cassava leaf production and utilization for animal feed may became more important. However, further development of technologies for cassava leaf production and utilization for animal feed is still needed, especially concerning effective techniques to reduce the HCN content to safe levels for animal feeding.

Research since 2002

To achieve a package of technologies for cassava leaf production, trials on factors affecting cassava leaf production have been conducted since 2002. In addition, trials on techniques for using cassava tops for animal feed have been conducted since 2005. The technologies have also been transferred to the users since 2005. The experiments on various technologies for cassava leaf production indicate that cassava varieties or breeding

lines KU 50, Rayong 72, Rayong 5, CMR 41-60-24 and CMR 41-111-129 are the best, producing dry top and fresh root yields of 7-16 and 11-37 tonnes/ha, respectively. The optimum plant spacing was found to be either 30x30 cm, 60x60 cm or double rows at 30x30 cm and 60 cm between those double rows. The optimum cutting interval was 2½-3 months. The optimum cutting height was 15-20 cm above the ground. The recommended fertilizer rate is 375 kg N, 109 kg P_2O_5 and 281 kg K_2O/ha by applying commercial fertilizer formula 15-7-18 at 521 kg/ha at planting and after the 2nd and the 4th leaf harvests, and urea at the rate of 156 kg/ha after the 1st and the 3rd harvests. Alternatively, 425 kg N, 142 kg P_2O_5 and 141 kg K_2O/ha, is also recommended, using a mixture of 187 kg/ha of commercial fertilizer formula 15-15-15 and 125 kg/ha of urea/ha at planting and after every leaf harvest (Limsila *et al*, 2005; Martwana *et al.*, 2009). Trials on the development of techniques for using cassava tops for animal feed making and the transfer of these technologies are detailed in this paper.

METHODS AND RESULTS

Development of Techniques for Cassava Hay (dried cassava tops) Making

Experiment 1. Study on cassava hay and cassava hay meal storability

To monitor the storability of cassava hay and cassava hay meal, an experiment was conducted in 2006, using cassava tops of variety Rayong 72 (R27) cut at 20 cm above the ground at three months after planting (MAP). Experimental treatments were arranged in a 2x2 factorial in a completely randomized design (CRD) with four replications. Factor 1 were dried cassava leaf products, i.e. cassava hay and cassava hay meal. Factor 2 were storage containers, i.e. plastic bags and re-used fertilizer bags.

Cassava tops were chopped into small pieces (about 2-3 cm in length) and then sun-dried until the moisture content had dropped to below 10% to produce cassava hay. Half the amount of the cassava hay was ground by the rice husk grinder to produce cassava hay meal. Both products were individually put in each of the two containers mentioned above, and then the containers were tied up firmly and stored under shade for seven months. Samples of the products were taken to determine the moisture content and the physical quality, i.e. color, texture, odor and fungi appearance at 0, 2 and 7 months of storing.

Chopped cassava tops, sun-dried to reduce the moisture content to safe levels for storage (10%) within 3-4 days, provided good quality cassava hay and cassava hay meal after grinding. Both products can be stored in re-used fertilizer sacks and plastic bags for 2 and 7 months, respectively (**Table 1**). For storing cassava hay and cassava hay meal through the rainy season (June-December), plastic bags were better for preventing moisture re-absorption than the re-used fertilizer sacks. Therefore, the products stored in plastic bags could remain in good quality for longer periods than those kept in re-used fertilizer sacks, which became rotten and were invaded by fungi when they reabsorbed moisture from the air, especially after rain.

Table 1. Moisture content and physical quality of cassava hay and cassava hay meal as affected by storage containers and storage period at Khon Kaen Field Crops Research Center in 2006.

Storage containers/cassava hay products	0 month after storage		2 months after storage		7 months after storage	
	moisture (%)	physical quality	moisture (%)	physical quality	moisture (%)	physical quality
Re-used fertilizer sack						
Cassava hay	8.0	small pieces and good smell of dried leaf, yellowish-green color with no mold	11.2	small pieces and good smell of dried leaf yellowish-green color with no mold	8.8	small pieces of dried leaf, dark brown color, with smell and appearance of mold
Cassava hay meal	8.0	rice bran-like particles, good smell of dried leaf, yellowish- green color with no mold	10.0	rice bran-like particles, good smell of dried leaf, yellowish -green color with no mold	9.3	rice bran-like particles, dark brown color with smell and appearance of mold
Plastic bag						
Cassava hay	8.0	small pieces and smell of dried leaf, yellowish-green color with no mold	8.2	small pieces and smell of dried leaf, yellowish-green color with no mold	8. 2	small pieces, brown color of dried leaf with neither smell nor mold found
Cassava hay meal	8.2	rice bran-like particles, good smell of dried leaf, yellowish -green color with no mold	8.4	rice bran-like particles, no smell, yellowish -green color with no mold	8. 5	rice bran-like particles, dark brown color with neither smell nor mold found

Experiment 2. Effects of drying period on cassava hay quality

To monitor cassava hay quality as affected by drying, an experiment was carried out in 2007. Experimental treatments were arranged in a 2x9 factorial in CRD with three replications. Factor 1 consisted of cassava varieties R72 and Kasetsart 50 (KU50). Factor 2 consisted of drying periods, i.e. 0 [1/] (at harvest), 0 [2/] (after chopping and spreading to wilt over-night), and after 1, 2 3, 4, 5, 6 and 7 days.

Cassava tops of both varieties cut at three MAP were chopped into small pieces and wilted overnight, followed by drying in the sun for seven days. Samples of cassava tops from all treatments were taken to determine their moisture contents, HCN content, protein content and physical quality, such as odor, texture and color.

Results in **Table 2** show that after chopping and wilting overnight the HCN content of cassava tops was markedly reduced by 69-80% from the initial HCN of 673-679 mg/kg dry weight at harvest. Subsequent sun drying for 1-2 days was good for immediate feeding to animals as the cassava hay was still soft with high moisture content and green color and was safe with respect to HCN toxicity. Kanto and Juttupornpong (2005) reported that the safe HCN level for animal feed was 30 mg/kg dry weight. However, cattle being ruminants

can withstand much higher HCN levels than other animals. The safe level of HCN intake for cattle is below 2 mg/kg of body weight, but it may vary depending on the age of the cattle and the type of feed intake as well (Majak and Cheng, 1984). Further sun-drying until the moisture content had dropped to the safe level for storage (<10 %) was required when the feed had to be stored for later use (**Table 2**).

Table 2. Effects of variety and drying period on moisture content and hydrocyanic acid content in cassava hay at Khon Kaen Field Crops Research Center in 2007.

Drying period (days)	Moisture content (%)		Hydrocyanic acid (HCN) content (mg/kg dry wt)	
	R72	KU50	R72	KU50
0 [1/]	80.5 a	80.3 a	679 a	673 a
0 [2/]	76.0 b	74.0 b	208 b	125 c
1	46.8 d	63.6 c	94 d	89 d
2	14.0 e	13.9 d	38 e	23 f
3	6.6 g	9.5 e	19 f	22 f
4	6.4 g	7.0 ef	13 f	19 f
5	6.2 g	4.9 f	13 f	21 f
6	6.6 g	5.8 f	13 f	21 f
7	7.0 fg	6.3 f	13 f	21 f

[1)] at harvest [2/] after chopping and letting the leaves wilt overnight (17-18 hrs.).
Drying had no effect on the protein content (ranging from 20-22%)

Note: Means of moisture content or HCN content followed by the same letter are not significantly different at 5% level by DMRT

Experiment 3. Effects of variety, preparation and drying methods on cassava hay quality

A trial was conducted in 2007, using a 2x2x2 factorial in CRD with three replications as an experimental design. Factor 1 consisted of cassava varieties R72 and KU50. Factor 2 consisted of chopping and non-chopping of cassava tops. Factor 3 consisted of sun-drying and air-drying.

Cassava tops of both varieties harvested at three MAP were either chopped into small pieces or not chopped, followed by drying under sunlight or under shade for eight days. Samples of cassava tops were taken to determine their moisture content and HCN content before drying and each day after drying.

The method of preparation of cassava tops, the variety and drying method had interacting effects on the rate of reduction of the HCN and moisture contents in cassava hay. Since varietal differences were small and found just only at some period of drying, therefore interacting effects of drying methods and the method of preparation of cassava tops averaged over varieties are presented. Chopping cassava tops of both varieties and then air drying reduced the HCN content at the fastest rate, followed by chopping the cassava tops and then sun-drying. Non-chopping cassava tops of both varieties before drying was not suitable for cassava hay making as the HCN content and moisture content remained rather high throughout the trial (**Figure 1**).

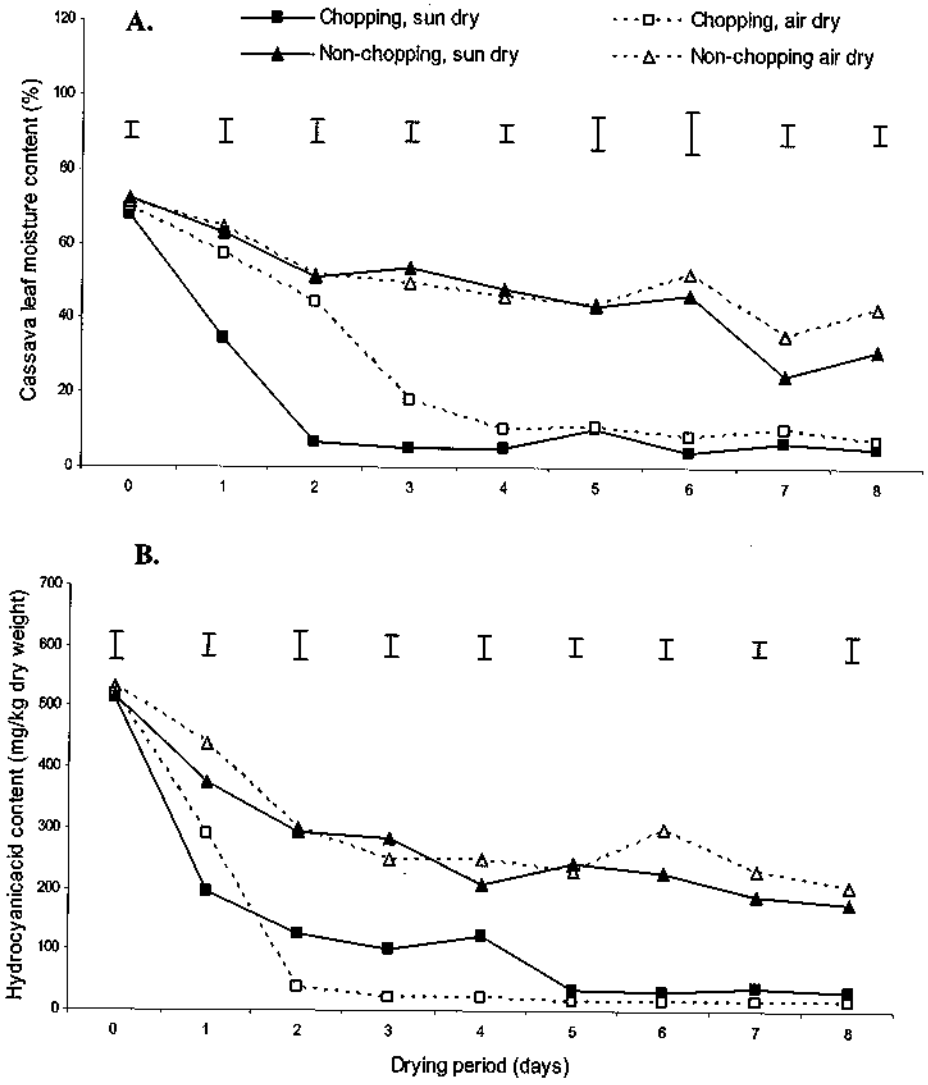

Figure 1. Effects of cassava top preparing methods and drying methods (averaged over varieties Ry72 and KU50) on (A) moisture content and (B) hydrocyanic acid content of cassava hay at Khon Kaen Field Crops Research Center in 2007. (I=LSD $_{0.05}$)

Development of Techniques for Cassava Top Silage Making

Experiment 1. Effects of cassava tops preparation and kinds of additives on quality of cassava top silage

A trial was conducted in 2005, using cassava tops of varieties R72 and KU50 harvested at three MAP. Experimental treatments were set up in a 2x7 factorial in CRD

with three replications. Factor 1 consisted of cassava tops preparation methods, i.e. crushing or chopping. Factor 2 consisted of kind or amount of additives used, i.e. cassava dry chips at 5%, cassava chips at 10%, molasses at 5%, molasses at 10%, or rice bran at 5%, rice bran at 10%, or salt at 5% by weight.

Cassava tops of both varieties were chopped into small pieces or pressed to break the shoot parts by the wheels of a tractor and then spread out to wilt overnight. The cassava tops were ensiled by mixing with different kinds or amounts of additives as mentioned above. The cassava tops mixed with ingredients were put and pressed firmly in plastic bags to eliminate air. The bags were tied up and stored under shade. Silage quality was evaluated in terms of physical quality i.e. color, texture, smell and fungi contamination at one month intervals after ensiling. In addition, moisture content, HCN content and protein content were also evaluated at the same time.

Only the cassava top preparation methods affected the cassava top silage quality. Ensiling the chopped cassava tops of both varieties by mixing with one of the additives provided the best quality silage, according to the silage standard from the Forage Crops and Animal Nutrition Division (Panichpon *et al.*, 2004); a smell like fermented fruit, a firm texture, yellowish-green color, no mold and pH 3.8-4.2. The silage possessed good physical quality during 1-5 months after ensiling (**Table 3**) and also had good chemical quality with a safe level of HCN as determined at 1 month. Protein lost in the ensiling process was minimal as indicated by the volatile-basic-nitrogen value (**Table 4**), which was below 5% (Narmsarmsi, 2003). Crushing by tractor was not a suitable method of cassava top preparation for silage making as the silage was severely rotten at two months after ensiling (**Table 3**).

Table 3. Physical quality of cassava top silage of varieties R72 and KU50, as affected by top preparation methods and additives at Khon Kaen Field Crops Research Center in 2005.

Cassava top preparation methods/kinds and concentrations of additive (% by weight)	Physical quality of cassava top silage during 1-5 months after ensiling	Physical quality of cassava tops silage at 6 months[1/]
	Odor, texture and color [1/]	
Chopped cassava tops mixed with one of the additives, i.e. salt 5%, molasses 5 or 10%, cassava chips 5 or 10%, rice bran 5 or 10%	Smell like fermented fruit, firm texture, brown color with no fungus (kinds of additives used and varieties did not affect the silage quality)	rotten >50%
Crushed cassava tops mixed with one of the additives, i.e. salt 5%, molasses 5 or 10%, cassava chips 5 or 10%, rice bran 5 or 10%	Smell like fermented fruit and fungi, brown color, rotten with fungus contamination 10-20% at 1 month, and rotted >50 % at 2 months (kinds of additives used and varieties did not affect the silage quality)	-

[1/] silage color was darker after longer storage

Table 4. Effects of cassava top preparation methods and additives used on the chemical characteristics of cassava top silage after one month of ensiling at Khon Kaen Field Crops Research Center in 2005.

Cassava top preparation /kinds and concentrations of additive used (% by weight)	Moisture content (%)	Protein content (% DM)	pH	VBN[1)] (% total nitrogen)	HCN (mg/kg fresh weight)
Chopped cassava tops					
5 % salt	78.0	16.7	4.0	1.6	25-40
5 % molasses	75.2	20.0	3.9	2.6	25-40
10 % molasses	78.4	19.3	3.9	2.1	25-40
5 % cassava chips	73.4	17.9	4.4	3.0	25-40
10 % cassava chips	72.1	15.6	4.2	1.9	25-40
5 % rice bran	74.0	15.2	4.3	4.0	25-40
10 % rice bran	72.6	18.7	4.4	4.2	25-40
Crushed cassava tops					
5 % salt	77.3	20.1	4.4	2.7	-
5 % molasses	76.0	21.8	4.9	2.2	-
10 % molasses	77.3	12.5	4.0	2.1	-
5 % cassava chips	75.5	18.9	4.8	6.4	-
10 % cassava chips	76.4	16.1	4.4	3.8	-
5 % rice bran	74.5	23.1	4.7	1.4	-
10 % rice bran	72.0	20.1	4.8	2.8	-

[1)] Volatile Basic Nitrogen; > 20% = bad, 10-20% = fair, 5-10% = good, < 5% = excellent

Experiment 2. Effects of ensiling containers on quality of cassava top silage

A trial was carried out in 2006, using cassava tops of R72 harvested at three MAP. The experimental design used was CRD with four replications. Experimental treatments consisted of five different ensiling containers i.e. clear plastic bag, dark color plastic bag, black plastic bucket with a cover lid, black plastic bucket with a bag of water used instead of cover lids and plastic container with a tight fitting lid.

Cassava tops were chopped into small pieces and spread out to wilt overnight. The cassava tops were mixed with cassava chips at 5% by weight as an additive. The mixed ingredients were put and pressed firmly in different containers as mentioned above. The containers were closed either by the cover lid, bag of water or by tying, depending on the kinds of ensiling containers, followed by storing under shade for ensiling. Physical quality, moisture content and HCN content of the silage were compared at one month after ensiling.

Cassava tops ensiled for one month in a plastic container with a firmly closed lid, clear plastic bag, black plastic bag or black plastic bucket with a bag of water used instead of a cover lid provided good quality silage, which had a good smell like that of fermented fruit, a firm texture, brown color, no or little fungi and a pH of 3.8-4.2. Only the use of the black plastic bucket with cover lid resulted in serious fungal growth on top of the silage. The type of ensiling container did not affect the protein and HCN contents of the silage (**Table 5**).

Table 5. Physical and chemical qualities of cassava top silage after ensiling in different containers for one month at Khon Kaen Field Crops Research Center in 2006.

Ensiling containers	Physical quality	Chemical quality[1)]		
		pH	Protein content (%)	HCN content (mg/kg fresh wt.)
1. Clear plastic bag	Fermented fruit-like smell, firm texture, brown color with no fungus	4.2	18.0	20-40
2. Black plastic bags	Fermented fruit-like smell, firm texture, brown color with little fungi found	3.8	18.1	20-40
3. Black plastic bucket with a cover lid	Fermented fruit-like smell, firm texture, brown color with complete fungi cover on the top surface	4.0	17.9	20-40
4. Black plastic bucket with a bag of water used as a cover lid	Fermented fruit-like smell, firm texture, brown color with little mold on top	4.0	18.6	20-40
5. Plastic container with a firmly closed lid	Fermented fruit-like smell, firm texture, brown color with no fungus appearance	4.0	18.5	20-40

[1)] pH, protein and HCN content of cassava tops before ensiling were 5.8, 19.9% and 300 mg/kg fresh weight, respectively.

Experiment 3. Development of technique on cassava root ensiling

A trial was carried out in 2007, using a 2x7 factorial in CRD design with two replications. Factor 1 consisted of ensiling containers, i.e. clear plastic bags and black plastic buckets with cover lids. Factor 2 consisted of kinds of additives added, i.e. 1% salt, 1% rice bran, 1% molasses, 10% chopped cassava tops, 25% chopped cassava tops, 50% chopped cassava tops, or no additive.

Cassava roots were cleaned, cut into thin slices ($\leq$ 2 mm thickness) and left to dry overnight followed by mixing with one of the additives mentioned in factor 2. The mixed ingredients were put and pressed firmly in clear plastic bags or black plastic buckets. The ensiling containers were then tied up or closed with cover lids and kept under the shade for ensiling. Silage quality was evaluated at one month after ensiling.

Ensiling containers and additives used had not much effect on cassava root silage quality. Cassava root silage had good quality when it was made by cutting the clean roots into thin slices and letting them dry overnight, followed by mixing with one of the additives such as 1% salt, 1% rice bran, 1% molasses, 10% chopped cassava tops, 25 % chopped cassava tops, 50 % chopped cassava tops or no additive; followed by ensiling in a plastic bag or plastic container. However, the silage made by adding chopped cassava leaves at 25 and 50% by weight tended to have the best quality as there was no liquid found in both ensiling containers (**Table 6**). When liquid is found in cassava root silage this indicates that the silage tends to have a very strong acidity when stored for longer periods.

Table 6. Quality of cassava root silage at one month after ensiling as affected by different additives and ensiling containers at Khon Kaen Field Crops Research Center in 2007.

Additives added (% fresh weight)	Clear plastic bag		Plastic container	
	pH	Physical quality	pH	Physical quality
1. no additive	3.6	Fermented smell, firm texture, light brown color with some liquid at the bottom but no mold appearance (Silage quality was not different among additives added i.e. salt, rice bran, or molasses at 1% or chopped cassava tops at 10% or no additive added)	3.6	Fermented smell, firm texture, light brown color, with some liquid at the bottom but no mold appearance (Silage quality was not different among additives added i.e. salt, rice bran, or molasses at 1% or chopped cassava tops at 10% or no additive added)
2. 1 % salt	3.6		3.6	
3. 1 % rice bran	3.6		3.6	
4. 1 % molasses	3.7		3.6	
5. 10% chopped cassava tops	3.7		3.7	
6. 25% chopped cassava tops	3.6	Fermented smell, firm texture, light brown color with neither liquid at the bottom nor mold appearance (Silage quality was not different between adding 25% and 50% chopped cassava tops as additive)	3.7	Fermented smell, firm texture, light brown color with neither liquid at the bottom nor mold appearance (Silage quality was not different between adding 25% and 50% chopped cassava tops as additive)
7. 50% chopped cassava tops	3.7		3.7	

On-farm Testing and Technology Transfer

The research team visited dairy cattle farmers in Khon Kaen province at the beginning of the project to discuss about the production situation, such as feed cost and the possibility to use cassava tops as a supplementary protein source for animal feed. Parallel with the research, discussions with the farmers were held several times to exchange ideas and transfer the technology developed as well. Suggestions and the needs of farmers were used to adjust the research plan and procedure. Animal feed products made by the technology developed included feed to dairy and beef cattle at the farmers' farm. The developed technologies were also transferred to dairy and cattle farmers and people involved in cassava utilization as animal feed via seminars, training, demonstrations, leaflets, posters and farm visits since 2005.

Some dairy and beet cattle farmers in Khon Kaen province have made cassava hay, cassava top and root silage for their own use since 2005. One dairy farmer, Phanom Farm is now considered "The learning center on the cassava utilization for animal feeding". Many groups of farmers and people involved in cassava utilization have visited Khon Kaen Field Crops Research Center and Phanom Farm to learn, practice and discuss about the production and utilization of cassava for animal feed. Now about 90% of 80 dairy farms near Phanom Farm use cassava roots and leaves to feed their animals. Some of the farmers planted cassava and bought a chopper for making animal feed. Many dairy cattle farmers in the Northeast use cassava root and top products to feed their animals in either dry or

silage forms. Some local animal feed sellers are now making and selling cassava hay and silage.

Experimental sites

The experiments were conducted at Khon Kaen Field Crops Research Center in Khon Kaen province, and the technologies were transferred to dairy and beef cattle farms in Khon Kaen province.

DISCUSSION

The results of these experiments and on-farm tests show that fresh cassava tops of commercial varieties and some breeding lines have high HCN contents that could kill animals, but that after wilting, drying or ensiling they can be safely used for animal feeding. In Thailand sun-drying is cheap and makes it easy to produce animal feed from cassava (Wanapat *et al.,* 1997), but ensiling is an alternative method, especially when drying can not be done (Nguyen Thi Hoa Ly *et al.*, 2000). Chopping cassava tops helped speed up the reduction in HCN content, especially when followed by air drying or wilting overnight. The HCN precursor, hydrocyanic glucocide, present in cassava leaves, needs enzymes to change to HCN, after which the HCN easily evaporates through the wounds or cut parts. Sun-drying of the cassava hay making trails in this study was done under hot weather conditions during April to June. Therefore, the high temperature during sun-drying may block the activities of the enzymes, resulting in high HCN contents in the cassava hay compared to that of air-dried hay. Charavanapavan (cited in Majak and Cheng, 1984) indicated that the HCN content of chopped cassava roots, dried at 60°C was reduced faster than that dried at 90-100°C, due to the enzyme activity being blocked at high temperatures. For silage, the HCN content was reduced by the hydrolysis process. However, chopping and wilting overnight before ensiling helped dramatically in the rapid reduction of the HCN content in cassava top and root silage. Anaerobic conditions and the mixing of additives as energy sources for microbial fermentation play an important role in the ensiling process. Adding a carbohydrate source at 5-10% by weight as an additive is also recommended for silage making of high protein plants to prevent rotting (Panichpon *et al.,* 2004). In the silage making trials in this study, all the additives resulted in good quality cassava top silage, but the use of cassava chips or molasses at 5% would be better to save costs. Rice bran has a high lipid content which is oxidized easily, resulting in low quality and bad smelling silage when stored long before using. Silage made by adding 5% salt also rotted when tested on-farm. As dairy cattle farmers want to know how to make cassava root silage, hence a trial was added and also tested with farmers in this study.

CONCLUSIONS

1. For cassava hay making, chopping and wilting the tops overnight, followed by sun-drying resulted in a rapid reduction of HCN. This method resulted in cassava hay that was safe for animal feeding after two days of drying. Under hot weather conditions, air-drying seemed to be better than sun-drying. Drying cassava tops to a moisture content of <10% is necessary when the hay need to be stored for its later use.
2. Cassava hay meal is a product that can reduce the bulkyness of cassava hay; it is a practical form for transportation and storage.
3. Cassava hay and hay meal could be kept for seven months in air-tight containers.

4. Cassava top silage could be made by chopping cassava tops and letting these wilt overnight followed by mixing with an additive such as cassava dry chips or molasses at 5% by weight, then ensiling in plastic bags for one month; this silage could be kept for five months.
5. Cassava root silage can be made by cutting the roots into thin slices and letting these dry overnight followed by ensiling in plastic bags for one month.
6. Sliced cassava roots mixed with 25-50% chopped leaves before ensiling provided the best quality silage.
7. Plastic containers with firmly closing lids can also be used for cassava leaf and root ensiling.
8. Using clear, dark or colored ensiling containers did not affect the silage quality.
9. Dairy and cattle farmers in some areas are now adopting the use of cassava leaves in their farms.
10. More research results on cassava leaf production and utilization for animal feeding will be available in 2010.

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USE OF CASSAVA ROOTS AND FOLIAGE IN MONOGASTRIC AND RUMINANT FEEDING

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ABSTRACT

For large and technified animal operations, including poultry and aquaculture, the troublesome management of the daily feeding program limits the extensive use of fresh cassava products. The use of dried mixtures in automatic feeding systems is the general trend in these cases. Cassava roots and/or foliage should be dried and, preferably, pelletized or extruded, to be included in commercial diets.

Information concerning the use of dried cassava products for animal feeding is quite ample in all productive species, mainly swine, poultry and ruminants. The dried products can be handled more easily and with higher accuracy than programs based on fresh or ensiled cassava.

Cassava roots and foliage are dehydrated in order to increase the total nutrient concentration and to facilitate the preservation of the finished feed. In addition, heat dehydration eliminates most of the cyanogenic components which produce toxic and deleterious effects on animal performance.

Cassava root meal is essentially a carbohydrate product with a high concentration of starch (60-65%). The metabolizable energy content of good quality root meal for poultry and swine is around 3.20 and 3.40 Mcal/kg, respectively, while the total digestible nitrogen (TDN) content is around 86%. Its main nutritional limitation is its low protein content, so that protein supplementation is required, with special emphasis on the most limiting amino-acid: methionine.

Conversely, cassava foliage meal is characterized by its high fiber and protein levels. Depending on the leaf:stem ratio and the age of the plant, the crude fiber content may range between 18 and 30%, while the protein content may vary from 16 to 28%. The best quality forage meal contains a larger proportion of leaves and young stems which can be easily obtained from plants cut back every three months. The nutritional quality decreases as the plant gets older and the leaf:stem ratio decreases due to a lower proportion of young leaves.

Though the hydrogen cyanide level in dry foliage is generally over 200 ppm, the low foliage percentage recommended for poultry and pigs usually does not present any toxicity danger; however, in some cases, the high cyanide content can affect the palatability of the diet, and, eventually, cause toxicity problems.

INTRODUCTION

The use of cassava products for animal feeding in Colombia still does not cover an important segment of the commercial production of compound feeds. There are some isolated projects where cassava dry roots are used for poultry and swine nutrition as a partial (10 to 20%) replacement of corn. The main reason for limiting the expansion of cassava as a real alternative is based on the high cost compared with imported corn from subsidized regions. The price for cassava root meal should be less than 75% of the corn price in order to compete with the standard corn-soybean diets. At the present time there are no industrial developments that can respond to this challenge in most regions of Colombia. The Eastern Plains and the north coast regions will probably become more involved in industrialized cassava developments since production costs are more competitive. The inclusion of fullfat soybeans (FFSB) will also open new possibilities for the inclusion of cassava in commercial diets, due to its excellent complement to the limiting

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nutrients in cassava. The use of cassava meal and FFSB as the main ingredients in diets for poultry and swine, simplifies the feeding programs in most of their productive stages, where there is a high need for metabolizable energy, essential amino-acids, lecithin and fatty acids.

On the other hand, small swine producers in cassava production regions are including fresh or ensiled cassava roots and starch byproducts in the daily feeding programs. Pigs (excluding piglets) and ruminants are suitable to be incorporated into feeding programs based on fresh or ensiled cassava. Due to the high moisture and low energy contents of fresh roots, the animals have to be supplied with ample amounts of chopped cassava roots and a limited amount of a dry protein supplement.

MAIN NUTRIENTS IN CASSAVA ROOTS AND FOLIAGE

The useful energy concentration in cassava and its by-products is largely affected by their moisture content. When fresh, roots contain only 30-35% dry matter and supply less than 1,500 Kcal of metabolizable energy (ME)/kg. These low ME levels limit the possibilities of using fresh cassava to feed poultry and swine during their early rearing. Once dehydrated, the roots contain up to 3,200-3,500 Kcal ME/kg. This level is adequate for the previously mentioned animal species, at all ages.

The low energy concentration is also observed in cassava foliage. The high fiber content has an important additional effect on decreasing the energy level. Fresh leaves contain less than 500 Kcal ME/kg, while dry leaf meal has 1,600-1,700 Kcal/kg. These two limitations make cassava leaves a better product for ruminant nutrition.

Root-based products (fresh root, starch or starch factory pulp) have a low crude protein (CP) level. The most limiting amino acids are, in order of importance, methionine, cystine, and tryptophan. Because of this limitation, an animal ration containing a high level of root derivatives should be supplemented with protein from other sources, and the addition of synthetic methionine is almost always required.

Foliage-based products (fresh leaves, dry leaf meal) are, on the other hand, important protein sources. However, the order mentioned for the limiting amino acids in roots, is also valid for foliage.

When swine and poultry rations have a high cassava root and/or foliage content, the addition of small levels (0.1-0.3%) of synthetic methionine is always recommended. Methionine not only plays a metabolic role as an essential amino acid, but it also plays an important part in the cyanhydric acid detoxification process, particularly when rations with high levels of bitter cassava roots or leaves are being used. Within this detoxification process, methionine provides, together with cystine, the sulfydril groups (-SH) which participate in the reactions for transforming the cyanide ion into thiocyanate.

Table 1 shows the mean values of the major nutrients in cassava roots and foliage, calculated according to their original moisture content (wet matter), as dried products (dry matter) and at environmentally balanced moisture (10%) content.

Table 1. Content of major nutrients in cassava roots and foliage calculated according to fresh matter (FM), dry matter (DM) and at environmental moisture (EM) content.

	Content (%)					
	In roots			In foliage[1]		
Nutrient	FM	DM	EM	FM	DM	EM
Dry matter	35.00	100.00	90.00	28.00	100.00	90.00
Protein	1.10	3.10	2.80	6.80	24.00	22.00
NFE	31.70	90.50	81.50	10.60	37.70	34.00
Ether extract	0.47	1.30	1.20	1.80	6.50	5.90
Crude fiber	1.10	3.10	2.80	5.80	20.60	18.60
Ash	0.70	1.90	1.70	1.70	6.20	5.60
Calcium	0.10	0.33	0.30	0.43	1.50	1.40
Phosphorus	0.15	0.55	0.40	0.08	0.27	0.25

[1)] Foliage = young leaves and stems. Stems represent less than 20% of foliage weight
[2)] NFE = nitrogen-free extract
***Source:** Buitrago, 1990.*

The nutritional composition of the foliage presents a great variation as far as its quality and quantity are concerned, because of variety and other factors associated with plant age and leaf/stem ratio. The older the plant, the lower the protein content and the higher the fiber and dry matter content (**Table 2**).

The higher concentration of leaves with regard to stems and petioles will also produce a higher protein concentration and lower fiber and dry matter concentrations, as is illustrated in **Table 3**. Typically, the leaves contain more than twice the protein of the stems. Leaves are also richer in carotene, calcium and phosphorus.

Table 2. Nutritional composition of cassava foliage meal at different harvesting times.

	Cassava foliage meal[1)]		
Main nutrients	2–3 Months	5–6 Months	More than 8 months
Protein, %	22.0	18.0	16.0
Fiber, %	16.0	20.0	26.0
Ash, %	5.5	5.8	5.8
Fat, %	5.2	5.6	5.6
Calcium, %	1.6	1.7	1.7
Phosphorus, %	0.26	0.28	0.28
TDN[2)],%	68.0	66.0	58.0
DE[2)], Mcal/kg	2.94	2.65	2.40

[1)] Third superior top (including leaves, petioles and young stems)
[2)] TDN = total digestible nutrient; DE = digestible energy
***Source:** Buitrago, 1990.*

Table 3. Nutritional composition of cassava foliage meal with different proportions of leaves, petioles and stems[1].

Nutrients, %	Leaves	Leaves and petioles	Leaves, petioles and stems
Protein	22.7	21.6	20.2
Ash	10.9	9.8	8.5
Fat	6.3	6.3	5.3
Fiber	11.0	11.6	15.2
Calcium	1.68	1.70	1.68
Phosphorus	0.29	0.24	0.28
Potassium	0.69	0.60	1.09

[1] Products with 8-10% humidity

Source: *Van Poppel, 2001.*

The results of nutritional composition analyses of roots are usually very constant, even though some minor changes associated with the variety of cassava may occur. These changes are particularly related to protein, fiber and moisture content. It is important to note that the peel represents between 15% and 20% of the total root weight and that the pulp, or central cylinder, is approximately 80% to 85%. The highest proportions of protein, fat, fiber and minerals (ash) are located in the peel. Carbohydrates are found mainly in the pulp. **Table 4** shows the nutritional differences that exist between both products. In addition, **Table 5** shows the most important differences between the whole root and the peeled root as well as detailed information about carbohydrate availability and fiber fractioning (neutral detergent fiber and acid detergent fiber).

Table 4. Nutrient content in both the cortex or peel and the pulp or central cylinder of cassava roots (fresh basis and dry basis).

	Content (%)			
	Peel		Pulp (central cylinder)	
Components	FM	DM	FM	DM
Dry matter	28.0	100.0	41.0	100.0
Crude protein	1.5	5.4	1.0	2.4
Carbohydrates	21.7	77.5	37.5	91.0
Ether extract	0.6	2.1	0.4	1.0
Crude fiber	2.5	9.0	1.1	2.7
Ash	1.7	6.1	1.2	2.9

Source: *Buitrago, 1990.*

DRIED CASSAVA ROOTS IN POULTRY FEEDING

The results of some selected experiences will be presented in the following tables, where cassava root meal is included in medium to high levels of the diet for broilers and

layers. Most of the early demonstrations were conducted with ground (meal) diets and free choice consumption. In the more recent experiences, pelletized diets were introduced as an important mechanism to improve the performance of broilers and to reduce the dusty conditions in diets with high cassava meal content.

When cassava meal replaces corn or other cereal grains in commercial operations economical considerations should consider the lower energy and protein values of cassava root meal as compared to corn. These limitations normally indicate that cassava root meal should have a cost not higher than 70 to 80% when compared to the price of corn.

Table 5. Chemical composition of whole and peeled cassava roots (dry basis).

	Content (%)	
Components	Roots with peel	Peeled roots
Dry matter	100.00	100.00
Available carbohydrates	83.80	92.40
Crude protein	3.05	1.56
Ether extract	1.04	0.88
Ash	2.45	2.00
Neutral detergent fiber	6.01	6.40
Acid detergent fiber	4.85	1.95
Hemicellulose	1.16	1.45

Source: *adapted from Agudu, 1972.*

1. Dried cassava root meal for broilers

Table 6 shows the results of an early study to measure the effect of diets where cassava meal gradually replaced corn as the energy source for broiler diets, without the adjustment of energy level. The results show a slight decrease in performance mainly associated with higher levels of cassava meal due to the reduction in metabolizable energy.

The inclusion of vegetable oil in diets with high cassava meal compensates for the lower energy and provides an improvement in performance of broilers, as is illustrated in **Table 7** where the diets contained different levels of cassava meal but similar protein and metabolizable energy concentrations. In addition, vegetable oil provides an increment in linoleic acid, which is an essential fatty acid for poultry. Total replacement of corn by cassava meal did not affect the body weight or feed conversion ratio of broilers.

The pelleting and/or extrusion processes provide additional benefits to high cassava meal diets at the different levels of cassava meal inclusion for broiler diets (**Table 8**).

Experimental work conducted at CIAT compared a commercial pelletized broiler diet based on corn and soybean meal with pelletized diets totally based on cassava root and cassava foliage meal supplemented with fullfat soybeans (FFSB). The comparison between solar dehydration and artificial dehydration of cassava roots was also included in the same study. A detailed description of the experimental diets as well as its nutritional composition for the starting (0-21 days) and finishing (21-42 days) phases is presented in **Tables 9** and **10**.

Table 6. Different levels of cassava root meal in diets for broilers[1].

	Cassava content							
	0		15 %		30 %		45 %	
Ingredients (%)	S [2]	F	S	F	S	F	S	F
Cassava root meal	0	0	15.0	15.0	30.0	30.0	45.0	45.0
Corn	59.9	64.0	42.9	47.4	26.3	30.7	9.7	14.1
Soybean meal	30.7	27.6	31.0	28.2	32.0	29.0	33.0	30.0
Fish meal	6.0	4.0	7.3	5.0	7.9	5.8	8.5	6.5
DL-methionine	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Minerals & vitamins	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Nutritional content								
ME, Mcal /kg	2.94	2.96	2.86	2.89	2.78	2.79	2.70	2.72
Protein, %	22.1	20.0	22.1	20.0	22.1	20.0	22.1	20.0
Methionine + Cystine, %	0.87	0.80	0.87	0.79	0.86	0.80	0.86	0.79
Lysine	1.26	1.10	1.33	1.26	1.39	1.22	1.44	1.28
Performance of broilers								
Final weight, kg	1.47		1.50		1.45		1.39	
Feed consumption, kg	3.33		3.39		3.48		3.29	
Feed conversion ratio[3]	2.45		2.42		2.56		2.56	

[1] 0–8 weeks broilers
[2] S = starting: 0-5 weeks; F = finishing: 5-8 weeks
[3] kg feed consumption / kg weight gain
Source: *Vasquez et al., 1977.*

Table 7. The effect of different levels of cassava root meal in iso-energetic diets on the performance of broilers[1].

	Cassava meal level (%)					
	0	20	30	40	50	58
Ingredients (%)						
Cassava root meal	0	20.0	30.0	40.0	50.0	58.0
Corn	54.0	30.0	16.0	9.0	3.9	-
Rice polishings	10.0	9.0	8.6	8.1	0	-
Fish meal	6.0	6.0	6.0	6.0	10.0	11.0
Soybean meal	27.0	31.0	35.0	32.0	32.0	27.0
Vegetable oil	-	1.0	1.4	1.9	2.0	2.0
Minerals & vitamins	3.0	3.0	3.0	3.0	2.1	2.0
Broiler performance						
Final weight, kg	2.04	2.05	2.04	2.03	2.04	2.04
Feed conversion ratio	2.61	2.59	2.64	2.61	2.56	2.53
Mortality, %	9.2	3.0	3.0	4.0	10.2	5.0

[1] 0-6 week broilers
Source: *Chou et al., 1973.*

Table 8. The effect of different levels of cassava root meal in pelletized iso-energetic diets on the performance of broilers[1].

	Cassava meal level					
	0	10	20	30	40	50
Ingredients (%)						
Cassava root meal	0	10.0	20.0	30.0	40.0	50.0
Wheat	53.9	48.9	38.9	28.8	18.3	6.1
Corn	16.2	10.5	9.5	9.0	9.0	10.0
Soybean meal	16.3	14.8	13.8	12.8	11.6	11.1
Fish meal	5.0	6.8	8.9	10.5	11.4	12.5
Meat meal	3.0	3.0	3.0	3.1	4.3	5.0
Vegetable oil	3.1	3.9	3.9	3.9	3.6	3.5
DL-methionine	0.11	0.12	0.15	0.18	0.20	0.23
Minerals & vitamins	2.4	2.0	1.9	1.7	1.6	1.4
Nutritional composition						
ME, Megajoules/kg[2]	13.7	13.5	13.8	13.9	13.9	13.8
Protein, %	19.3	19.7	20.0	19.4	19.4	19.8
Broiler performance						
Final weight, kg	2.31	2.39	2.30	2.31	2.31	2.30
Feed consumption, kg	4.45	4.49	4.39	4.59	4.38	4.62
Feed conversion ratio	1.92	1.88	1.91	1.99	1.90	2.01

[1] 0-7 week broilers

[2] 1 Mcal = 4.19 Mjoule.

Source: *Stevenson and Jackson, 1983.*

Table 11 illustrates the overall performance of broilers until 42 days when the trial was finished. All groups consuming cassava products and FFSB obtained similar or better weight gains and feed conversion ratios when compared to the control group with corn and soybean meal. The consumption of the balanced feed was not affected by the inclusion of high levels of cassava meal during the starting and finishing production phases.

Performance results demonstrate the feasibility of preparing broiler feeding programs totally based on cassava root meal as the main energy source and limited levels of cassava foliage meal as a partial protein source, as long as FFSB is included to provide the deficit of energy, fatty acids and protein.

Table 9. Composition of broiler diets with maximum levels of cassava root meal and full fat soybean used in the starting phase.

Ingredients %	Control Corn+SBM[2)]	CRM + FFSB[1)]			CRM+CFM + FFSB[3)]
		Solar	Artificial drying		
			A[4)]	B[5)]	
Corn	59.37	--	--	--	--
Cassava root meal	--	45.75	45.75	45.75	40.45
Cassava foliage meal	--	--	--	--	6.00
Fullfat soybeans	12.8	30.0	30.0	30.0	30.0
Soybean meal	21.0	18.7	18.7	18.7	18.7
Palm oil	3.0	2.9	2.9	2.9	4.5
DL-methionine	0.16	0.29	0.29	0.29	0.29
Lysine	0.07	--	--	--	--
Bone meal	1.70	1.90	1.90	1.90	1.90
Ca carbonate	1.50	--	--	--	--
Salt	0.30	0.30	0.30	0.30	0.30
Vitamin Premix	0.10	0.10	0.10	0.10	0.10
Nutrient composition					
ME., Mcal/kg	3.20	3.20	3.20	3.20	3.20
Protein, %	22.0	22.0	22.0	22.0	22.0
Methionine, %	0.59	0.59	0.59	0.59	0.59
Met + Cystine, %	0.90	0.90	0.90	0.90	0.90
Lysine, %	1.26	1.26	1.26	1.26	1.27
Linoleic acid, %	2.62	3.42	3.42	3.42	3.56
Ca, %	0.91	0.91	0.91	0.91	0.91
Available P, %	0.42	0.42	0.42	0.42	0.42

[1)] Cassava root meal + fullfat soybeans
[2)] SBM=soybean meal
[3)] Cassava root meal + cassava foliage meal + fullfat soybeans
[4)] Equipment with steam heating
[5)] Equipment with propane gas heating
Source: *Gil et al., 2001*

In the treatments that included cassava root meal, the effect of artificial drying was superior to the sun-drying procedure. Both steam and gas drying equipments were equally effective for the drying process. The high temperature obtained facilitates the gelatinization of starches and the control of pathogenic germs. These two factors have probably an important influence on the superior performance of these groups when compared with the sun-drying group.

Although the diets with high percentage of cassava meal and FFSB contain high potassium levels in their final composition, it was not observed to have an adverse effect related to chicken manure and humid litters. Humidity of the manure was analyzed at

weekly intervals and no significant differences were observed. Additionally, the measure of the moisture content of the litter did not indicate differences among groups.

Table 10. Composition of broiler diets with maximum levels of cassava root meal and full fat soybean used in the finishing phase.

Ingredients %	Control Corn+SBM[2)]	CRM + FFSB[1)]			CRM+CFM + FFSB[3)]
		Solar	Artificial drying		
			A[4)]	B[5)]	
Corn	66.85	--	--	--	--
Cassava root meal	--	49.8	49.8	49.8	46.1
Cassava foliage meal	--	--	--	--	6.00
Fullfat soybeans	6.1	41.6	41.6	41.6	45.1
Soybean meal	20.7	5.2	5.2	5.2	--
DL-methionine	0.13	0.23	0.23	0.23	0.23
Lysine	0.19	--	--	--	--
Bone meal	1.60	1.90	1.90	1.90	1.90
Ca carbonate	1.10	--	--	--	--
Salt	0.30	0.30	0.30	0.30	0.30
Vitamin Premix	0.10	0.10	0.10	0.10	0.10
Nutrient composition					
ME, Mcal/kg	3.20	3.20	3.20	3.20	3.20
Protein, %	20.0	20.0	20.0	20.0	20.0
Methionine, %	0.49	0.49	0.49	0.49	0.49
Met + Cystine, %	0.78	0.78	0.78	0.78	0.78
Lysine, %	1.12	1.12	1.12	1.12	1.12
Linoleic acid, %	2.20	3.60	3.60	3.60	3.85
Ca, %	0.90	0.90	0.90	0.90	0.90
Available P, %	0.40	0.40	0.40	0.40	0.40

[1)] Cassava root meal + fullfat soybeans
[2)] SBM=soybean meal
[3)] Cassava root meal cassava foliage meal + fullfat soybeans
[4)] Equipment with steam heating
[5)] Equipment with propane gas heating
Source: *Gil et al., 2001.*

Through external measurements of the skin and by checking the chicken carcasses after sacrifice, the pigmentation of legs, skin and internal fat was analyzed. The groups with diets based on just cassava roots showed a poor pigmentation, while the group with cassava roots and foliage showed a pigmentation grade similar to that of the control group fed with diets based on yellow corn. The visual appreciation on a scale from 1 (pale) to 5 (optimum pigmentation), gave both the control and the group fed with cassava roots plus foliage meal a grade of 4, while the other groups without cassava foliage obtained a grade of 2 on the pigmentation scale.

Table 11. Results of the performance of broilers with maximum levels of cassava root meal and full fat soybean in the diet[1] during starting and finishing phases.

Ingredients %	Control Corn+SBM[2]	CRM + FFSB[1]			CRM+CFM + FFSB[3]
		Solar	Artificial drying		
			A[4]	B[5]	
Initial weight, g	39.8	39.5	39.4	39.5	39.7
Final weight, g	2.139	2.279	2.237	2.387	2.113
Feed consumption, kg	4.73	4.88	4.65	4.68	4.72
Feed conversion ratio	2.21	2.14	2.08	1.96	2.24

[1] Cassava root meal + fullfat soybeans
[2] SBM=soybean meal
[3] Cassava root meal + cassava foliage meal + fullfat soybeans
[4] Equipment with steam heating
[5] Equipment with propane gas heating
Source: *Gil et al., 2001.*

2. Dried cassava root meal for layers

The inclusion of dried cassava roots in the diets of layers has also been experimented in different comparisons where corn was gradually replaced. In several of the earlier studies there was not a precise adjustment in some of the nutrients, mainly metabolizable energy, methionine and linoleic acid (**Tables 12, 13** and **14**) which lowered the production performance.

Egg production and feed conversion ratio are affected in most cases when cassava meal replaces corn without adjustments in the diet, especially at high levels of substitution. Egg yolk pigmentation is also affected when high levels of cassava root meal are used due to the absence of xantophyl pigments in roots, in contrast with its high concentration in cassava leaves.

Once the nutrient adjustments are introduced in diets with high levels of cassava root meal, improvement in production parameters are generally obtained. The essential amino acid methionine and the energy concentration are important factors in egg production and egg size, while linoleic acid is mainly involved in egg size. **Tables 15** and **16** illustrate the effect of high levels of cassava root meal when the diets are correctly balanced in energy and methionine. The results obtained in egg production, egg size and feed conversion ratio are generally comparable with corn-soybean meal diets.

The use of fullfat soybeans (8% linoleic acid) along with cassava root meal had a favorable effect on the size, pigmentation and weight of eggs (**Tables 16, 17** and **18**).

Table 12. Performance of Leghorn layers fed with increasing levels of cassava meal[1].

Ingredients (%)			
Cassava root meal	--	29.5	59.0
Corn	59.0	29.5	--
Soybean meal	16.6	19.4	22.2
Fish meal	8.0	8.0	8.0
Coconut cake	5.0	5.0	5.0
Sand	5.7	2.9	0.13
Vitamins & minerals	5.6	5.6	5.6
Nutritional composition			
ME, Mcal/kg	2.74	2.69	2.63
Protein, %	18.5	18.5	18.5
Calcium, %	3.08	3.24	3.40
Phosphorus, %	0.72	0.83	0.94
Performance of layers			
Egg production, %	70.9	66.6	69.3
Daily feed consumption, g	103	114	116
Feed conversion ratio [2]	2.88	3.37	3.30

[1] 20-32 week layers
[2] kg feed consumption / kg eggs produced
Source: *Vasquez et al., 1977.*

Table 13. Performance of Shaver layers fed with increasing levels of cassava meal[1].

Ingredients (%)					
Cassava root meal	--	5.0	10.0	50.0	60.0
Corn	77.0	69.5	63.5	18.0	10.0
Soybean meal	10.0	13.0	14.5	19.0	9.0
Fish meal	5.0	4.5	4.0	5.0	13.0
Vitamins & minerals	8.0	8.0	8.0	8.0	8.0
Nutritional composition					
ME, Mcal/kg	3.16	3.14	3.13	3.14	3.20
Protein, %	15.2	15.8	15.7	15.3	15.2
Methionine + cystine, %	0.60	0.66	0.67	0.59	0.49
Lysine, %	0.70	0.85	0.86	0.97	1.05
Performance of layers					
Egg production, %	67.62	60.36	58.03	47.32	57.77
Weight of eggs, g	56.03	52.61	53.08	56.12	52.94
Daily feed consumption, g	94	92	93	107	98

[1] 32-42 week layers
Source: *Jalaludin and King, 1973.*

Table 14. Performance of Leghorn layers fed with increasing levels of cassava meal[1)].

Ingredients (%)				
Cassava root meal	--	10.0	25.0	50.0
Corn	62.0	50.0	32.1	2.1
Soybean meal	9.20	11.20	14.1	19.1
Rice bran	5.0	5.0	5.0	5.0
Copra meal	7.5	7.5	7.5	7.5
Fish meal	5.0	5.0	5.0	5.0
Meat and bone meal	2.5	2.5	2.5	2.5
Leucaena meal	3.0	3.0	3.0	3.0
Vitamins & minerals	5.8	5.8	5.8	5.8
Performance of layers				
Egg production, %	63.9	62.8	58.7	62.8
Weight of eggs, g	58	57	57	57
Feed conversion ratio	2.01	2.10	2.22	2.12
Yolk pigmentation[2)]	6.0	6.0	5.0	3.5

[1)] 20-48 week layers

[2)] Roche pigmentation scale

Source: *Enriquez and Ross, 1972.*

DRIED CASSAVA ROOTS IN SWINE FEEDING

Feeding practices with dried cassava roots have been extensively studied during the growing-finishing stage of pigs. Some of the most representative feeding studies have been selected in the following tables which summarize the performance results under different environmental and management conditions.

Table 19 compares sweet (less than 80 ppm HCN) and bitter (150-200 ppm HCN) varieties of cassava root meal as the main source of energy in diets for growing pigs. Although the sun drying process partially reduced the HCN content, there is still a negative effect in consumption and weight gains of the pigs. However, this effect is very marginal compared to the effect observed when the roots are fresh since all HCN remains in the tissue.

In most studies the inclusion of low HCN cassava root varieties can replace cereal grains without detrimental effects in growing-finishing pigs, even though in some trials no adjustments were made in the energy levels of high cassava diets. **Table 20** also presents information on carcass characteristics at slaughtering time. Yields of lean meat cuts were not affected and no clear differences were noticed on fat percentages, fat quality or saturation index (iodine number), although all animals showed a larger proportion of body fat proper to the crossbred pigs available at the experimental time.

The addition of cane molasses, raw sugarcane or animal fat to diets based on cassava meal as the only energy source, did not contribute to the improvement in feed

consumption or performance in growing pigs, as shown in **Table 21**. Animal fat addition decreased feed consumption and improved feed conversion ratio, due to the increment in energy density of the diet. Unexpectedly, methionine supplementation did not improve the performance of growing pigs in this study. Nevertheless, in other experiences the beneficial effect of methionine supplementation to diets containing high levels cassava diets has been observed.

Table 15. Performance of Hisex layers fed with increasing levels of cassava meal[1)].

Ingredients (%)						
Cassava root meal	--	10.0	20.0	30.0	40.0	50.0
Wheat	50.0	50.0	46.1	30.8	15.5	--
Corn	13.2	8.5	5.8	8.8	11.9	15.2
Barley	12.7	5.4	--	--	--	--
Fish meal	3.0	3.0	3.0	3.0	3.0	2.9
Soybean meal	7.9	9.9	11.9	14.2	16.5	18.8
Meat and bone meal	5.0	5.0	5.0	5.0	5.0	5.0
Animal fat	1.0	1.0	1.0	1.0	1.0	1.0
DL-methionine	0.05	0.06	0.07	0.08	0.09	0.09
Vitamins & minerals	7.2	7.1	7.1	7.0	7.0	6.9
Nutritional composition						
ME, MJ/kg	11.0	11.0	11.0	11.0	11.5	11.1
Protein, %	15.9	15.7	15.9	15.8	15.9	16.0
Calcium, %	3.2	3.3	3.3	3.3	3.3	3.3
Phosphorus, %	0.64	0.63	0.63	0.60	0.58	0.57
Performance of layers						
No. eggs in 280 days	205	203	205	215	201	196
Weight of eggs, g	55	56	55	55	55	56
Daily feed consumption, g	119	119	111	113	112	109
kg of eggs/kg of feed	0.38	0.34	0.35	0.38	0.35	0.36

[1)] 27-67 week layers.
Source: *Stevenson, 1984.*

In recent studies conducted in Colombia (CLAYUCA), the inclusion of high levels of cassava root meal has been successfully proven in finishing diets where FFSB has been also included. The total replacement of cereal grains by cassava root meal is possible once the nutritional adjustments are introduced (**Tables 22 and 23**).

Table 16. Performance of Shaver layers with increasing levels of cassava meal[1].

Ingredients (%)						
Cassava root meal	--	25.0	50.0	--	25.0	50.0
Sorghum	65.2	38.7	12.1	57.3	28.3	--
Soybean meal	11.3	14.8	18.3	--	--	--
Fullfat soybeans	--	--	--	15.3	20.0	24.7
Fish meal	7.0	7.0	7.0	7.0	7.0	7.0
DL- methionine	0.13	0.16	0.18	0.14	0.17	0.19
L-lysine	0.17	0.10	0.04	0.15	0.08	--
Corn cobs	6.6	4.9	3.2	10.6	10.1	6.8
Vitamins & minerals	9.6	9.3	9.2	9.5	9.3	11.3
Nutritional composition						
ME, Mcal/kg	2.65	2.65	2.65	2.65	2.65	2.65
Protein, %	15.5	15.5	15.5	15.5	15.5	15.5
Methionine + cystine, %	0.66	0.66	0.66	0.66	0.66	0.66
Lysine, %	0.98	0.98	0.98	0.98	0.98	0.98
Linoleic acid, %	0.78	0.51	0.24	1.92	2.01	2.10
Performance of layers						
Egg production, %	72.3	77.9	78.0	72.6	72.0	74.5
Weight of eggs, g	69	67	67	70	71	69
Daily feed consumption, g	125	133	132	122	121	120
Yolk pigmentation[2]	5.1	4.9	4.7	6.4	6.5	6.3

[1] 42-62 week layers
[2] Roche pigmentation scale
Source: *Hennesey and Ayala, 1986.*

FRESH CASSAVA ROOTS FOR PIGS

Tables 24 to **27** illustrate different feeding approaches which have been tested as viable alternatives to maximize the consumption of fresh roots and to avoid the over consumption of protein supplement without affecting the performance of animals.

In general, performance results are a little lower than those obtained with commercial corn–soybean meal diets. The main reason relates to a lower consumption of dry matter (DM) when cassava roots are fed fresh, due to the incapacity of the pig to consume larger levels of the fresh product. The high humidity and probably the effect of minimum HCN still present in sweet varieties of cassava roots may be another cause of this situation.

When the protein supplement is provided in a free choice arrangement, the animals will consume larger amounts as compensation to the reduced consumption of cassava roots.

Therefore, an over-consumption of protein (approximately an extra 20%) is presented which results in a higher cost of the total diet (**Table 24**).

Table 17. Diets for commercial layers with 15% cassava root meal and FFSB.

Ingredients %	Control corn	15 % Cassava root meal
Corn	41.1	34.1
Cassava root meal	--	15.0
Fullfat soybeans (extruded)	20.0	20.00
Soybean meal	8.1	11.60
Rice polishings	10.0	--
Wheat bran	9.1	7.60
DL-methionine	0.18	0.19
Calcium carbonate	9.60	9.30
Calcinated bone meal	1.30	1.50
Salt	0.35	0.35
Vitamins and minerals	0.30	0.30
Main nutrients		
ME, Mcal/kg	2.75	2.75
Protein, %	17.0	17.0
Methionine, %	0.45	0.45
Met + Cystine, %	0.70	0.70
Lysine, %	0.85	0.85
Calcium, %	3.90	3.90
Available phosphorus, %	0.42	0.42
Linoleic acid, %	1.74	1.37

Source: *American Soybean Association (ASA), 2000; Buitrago et al., 2002.*

Table 18. Performance of commercial layers with 15% cassava root diets[1].

	Control corn	15% Cassava root meal
Layers, No.	15,000	5,000
Daily feed consumption, g	114.0	115.0
Laying, %	78.3	79.0
Feed conversion (dozen eggs)	1.37	1.37

[1] 55-61 week laying period; Santa Anita Poultry Farm. Pradera, Valle. 1.010 masl. 26°C.
Source: *American Soybean Association (ASA), 2000; Buitrago et al., 2002*

Table 19. The effect of bitter and sweet varieties of cassava root meal on the performance of growing Yorkshire pigs[1].

Ingredients (%)	Bitter[2]	Sweet[3]
Cassava root meal	71.0	71.0
Soybean meal	25.0	25.0
Vitamins & minerals	4.0	4.0
Performance of pigs		
Daily weight gain, kg	0.56	0.62
Feed consumption, kg	1.35	1.77
Feed conversion ratio	2.43	2.86

[1] 38-58 kg
[2] CMC-84 variety with 150-200 ppm HCN
[3] 80 ppm HCN
Source: *Gómez and Buitrago, 1982.*

Table 20. Low HCN cassava meal varieties in substitution of corn for growing crossbred pigs and effect on the pigs' performance and carcass characteristics[1][2].

Ingredients (%)				
Cassava root meal	--	20.0	40.0	58.5
Corn	60.0	40.0	20.0	--
Meat meal	5.0	5.5	6.0	6.5
Sesame meal	20.0	23.0	26.0	29.0
Rice polishings	9.0	5.5	2.0	--
Cane molasses	5.0	5.0	5.0	5.0
Vitamins & minerals	1.0	1.0	1.0	1.0
Performance of pigs				
Daily weight gain, kg	0.79	0.78	0.84	0.80
Feed conversion ratio	3.50	3.60	3.30	3.30
Carcass characteristics				
Carcass length, cm	74.0	72.1	73.0	74.0
Dorsal fat, cm	3.10	3.40	3.30	2.90
Iodine number	69.3	64.5	71.3	69.3

[1] 40-82 growing- finishing pigs
[2] 40 ppm HCN in fresh roots
Source: *Chicco et al., 1972.*

Table 21. Effect of adding cane molasses, raw sugar or animal fat to diets based on cassava root meal for Landrace x Yorkshire pigs[1].

Ingredients (%)					
Cassava root meal	65.9	65.7	55.5	55.5	55.5
Soybean meal	29.4	29.4	29.8	29.8	29.8
Cane molasses	--	--	10.0	--	--
Raw sugar	--	--	--	10.0	--
Animal fat	--	--	--	--	10.0
DL-methionine	--	0.2	--	--	--
Vitamins & minerals	4.7	4.7	4.7	4.7	4.7
Performance of pigs					
Daily weight gain, kg	0.71	0.68	0.69	0.68	0.63
Daily feed consumption, kg	1.94	1.88	1.89	1.84	1.59
Feed conversion ratio	2.73	2.76	2.74	2.70	2.53

[1] 20-50 kg growing pigs. Isoproteic (16%) diets

Source: *Maner et al., 1978.*

Table 22. High levels of cassava root meal and FFSB in diets for growing-finishing pigs.

	Control diet		Cassava root meal + FFSB	
Ingredients %	Growing	Finishing	Growing	Finishing
Corn	36.70	33.80	--	--
Cassava root meal	--	--	44.93	48.10
FFSB	20.00	18.60	20.00	20.00
Sorghum	16.00	16.00	--	--
Fish meal	--	0.50	--	--
Corn bran	8.00	12.00	--	--
Soybean meal	7.60	3.40	16.71	10.90
Wheat bran	8.00	12.00	12.00	15.00
Vegetable oil	--	--	3.70	3.30
Salt	0.39	0.39	0.39	0.39
Vitamin & minerals	3.31	3.31	2.27	2.31
Main nutrients				
ME, Mcal/kg	3.31	3.32	3.36	3.34
Protein, %	18.3	17.3	16.3	16.3

Source: *Buitrago et al., 2001*

Table 23. Performance of finishing pigs fed with high level of cassava root meal and FFSB in the diets.

	Control diet	Cassava root meal + FFSB
Initial weight, kg	48.10	49.29
Final weight, kg	96.00	96.41
Daily weight gain, kg	0.75	0.74
Daily consumption, kg	2.22	2.12
Feed conversión ratio	2.96	2.89

Granjas Paraíso – Clayuca – Nutribal, Palmira, Valle, Colombia. 2002
Source: *Buitrago et al., 2001.*

Table 24. The effect of using fresh cassava roots and protein supplements in free choice supply to Duroc x Landrace growing pigs (15-50 kg)[1)] on their performance.

Supplement ingredients %				
Cottonseed meal	16.0	23.0	23.0	--
Sesame meal	18.0	25.0	--	25.0
Peanut meal	14.0	--	25.0	23.0
Fish meal	36.0	36.0	36.0	36.0
Meat meal	14.2	14.2	14.2	14.2
Lysine	0.2	0.2	0.2	0.2
Vitamin premix	0.6	0.6	0.6	0.6
Nutrient composition				
Digestible energy, Mcal/kg	2.85	2.83	2.88	2.77
Protein, %	54.2	53.9	56.0	52.9
Methionine, %	1.20	1.27	1.07	1.23
Lysine, %	3.19	3.18	3.28	3.15
Performance of pigs				
Daily weight gain, kg	0.59	0.57	0.64	0.53
Daily feed consumption:				
Fresh cassava, kg	3.24	3.24	3.15	2.98
Protein supplement, kg	0.50	0.45	0.52	0.51
Feed conversion ratio (DM)	2.66	2.63	2.44	2.79

[1)] Chopped fresh cassava roots and protein supplement offered in different feeders for free-choice consumption
Source: *Contreras, 1973.*

As a way to avoid the over-consumption of the protein supplement, it should be offered every day in controlled amounts related with the body weight of the pig. Although

the protein consumption is controlled, the total consumption of DM is still deficient due to the low cassava intake which partially affects the animal's performance (**Table 25**).

The approach to lower the protein content of the protein supplements helps in reducing protein consumption in pigs, although the consumption of fresh roots is also reduced. The total DM intake from fresh cassava roots is reduced while the supplement consumption and weight gains are improved by providing supplements with lower protein contents; this also results in a better feed conversion ratio (**Table 26**).

When bitter varieties (i.e. CMC-84) of fresh cassava roots are used, a decrease in its consumption is observed with a parallel increase in the consumption of protein supplement when it is offered *ad libitum* (**Table 27**). However, when the protein supplement is controlled to the required daily level, both the cassava and the protein supplement consumption are reduced, creating a larger deficit in the daily DM (energy) intake and a drastic reduction in animal performance.

Table 25. The effect of using fresh cassava roots and protein supplements in free choice vs. controlled supply for Duroc growing-finishing pigs (18-100 kg)[1] on their performance.

Parameter	Free choice fresh roots + protein supplement[2]		Corn-SBM Diet[3]
	Controlled supplement	Free choice supplement	
Soybean meal, %	61.50	61.50	10.59
Cottonseed meal, %	20.50	20.50	3.53
Minerals and vitamins, %	18.00	18.00	4.55
Corn, %	--	--	81.33
Daily consumption			
Fresh roots, kg	3.89	4.05	--
Protein supplement, kg	0.73	1.17	--
DM consumption, kg	2.07	2.52	2.60
Protein consumption, kg	0.372	0.564	0.459
Performance of pigs			
Daily weight gain, kg	0.79	0.83	0.84
Feed conversion ratio (DM)	2.90	3.36	3.43

[1] Chopped fresh cassava and protein supplement offered in different feeders for free-choice or controlled consumption

[2] Protein supplement with 43% protein

[3] Commercial concentrate with 16% protein

Source: *Buitrago, 1964.*

Table 26. The effect of using fresh cassava roots and protein supplements with different protein levels for Yorkshire growing-finishing pigs (19-90 kg) on their performance.

Supplement ingredients (%)			
Protein level (%)	20.0	30.0	40.0
Soybean meal	26.73	53.15	79.56
Corn	67.27	37.85	8.44
Minerals and vitamins	6.0	9.0	12.0
Daily consumption (kg)			
Fresh roots	1.79	2.74	3.37
Protein supplement	1.39	1.00	0.75
Total DM	1.92	1.94	1.97
Total protein	0.34	0.40	0.39
Pig performance			
Feed conversion ratio	0.71	0.67	0.65

Source: *CIAT, 1974.*

Table 27. Performance of Yorkshire pigs fed with sweet vs. bitter cassava roots plus a protein supplement[1)] with different protein levels.

	Sweet roots		Bitter roots[2]	
	Free choice supplement	Controlled supplement	Free choice supplement	Controlled supplement
Daily consumption (kg)				
Fresh roots	2.99	3.40	0.98	0.93
Protein supplement	0.81	0.82	1.21	0.22
Total DM	1.78	1.80	1.43	0.52
Pig performance				
Daily weight gain (kg)	0.66	0.77	0.56	-
Feed conversion ratio	2.99	2.61	2.86	-

[1)] 40% protein supplement in all treatments
[2)] CMC-84 variety with 200 ppm cianhydric acid
Source: *CIAT, 1973.*

ENSILED CASSAVA ROOTS FOR PIGS

The following information on the performance of pigs included in different feeding demonstrations with ensiled cassava, considers the use of ensiled cassava roots in a free choice supply and the controlled supply of protein supplement.

Table 28 shows the results of an experiment in which growing- finishing pigs were fed three possible feeding schemes with various parts of the cassava plant: fresh roots, ensiled roots and ensiled roots plus foliage. In all cases, the cassava products were supplemented with a fixed amount of protein supplement (38% protein) to satisfy the daily requirements.

From the performance results it may be concluded that the silage process of cassava roots is a valid alternative to be considered as a mechanism to preserve the nutritional characteristics of the fresh cassava roots. The high perishability of the fresh roots may be overcome through the inexpensive practice of anaerobic ensiling, which also facilitates the feeding management practices for the small and medium size producer.

Table 28 shows that there was a very similar response in weight gains and feed efficiency when pigs were fed with fresh roots as compared with ensiled roots on a equivalent DM basis. However, the inclusion of cassava foliage to the ensiled product negatively affected the consumption of the silage which is reflected in lower weight gains and poorer feed conversion ratios. The lower consumption of the silage of both roots and foliage may be related to the lower palatability of leaves and stems, even at the low level of 10% inclusion.

Table 28. The effect of using fresh cassava roots compared with ensiled cassava roots and foliaje for Yorkshire x Landrace growing-finishing pigs (18-98 kg).

	Ensiled roots[1)]	Ensiled roots+foliage[2)]	Fresh roots
Supplement ingredients (%)			
Corn	10.9	10.9	10.9
Cottonseed meal	78.1	78.1	78.1
Vitamins & minerals	11.0	11.0	11.0
Daily consumption (kg)			
Ensiled cassava roots (and foliage)	3.84	3.05	--
Fresh cassava roots	--	--	4.04
Protein supplement (38%)	1.01	1.01	1.01
Total protein	0.38	0.38	0.38
Pig performance			
Daily weight gain (kg)	0.77	0.64	0.75
Feed conversion ratio (DM)	2.92	3.17	3.09

[1)] Only chopped roots
[2)] Chopped roots, leaves and stems
Source: *Buitrago et al., 1978.*

The information presented in **Table 29** illustrates the possibility of including different ingredients as protein supplements to cassava silage in growing-finishing pigs. Excluding the high fish meal supplement, where the consumption was reduced, the pigs' performance when using these alternatives compare favorably with pigs fed commercial balanced diets.

Table 29. The effect of feeding ensiled cassava roots with different protein supplements to Yorkshire growing-finishing pigs (16-90 kg) on their performance.

	Ensiled roots plus protein supplement				Corn-SBM diet
Supplement ingredients (%)					
Soybean meal	44.0	--	88.0	--	8.5
Cottonseed meal	44.0	48.5	--	97.0	8.5
Fish meal	--	48.5	--	--	--
Sorghum	--	--	--	--	78.0
Minerals & vitamins	12.0	3.0	12.0	3.0	5.0
Protein level (%)	41.0	47.0	44.0	52.0	15.5
Daily consumption (kg)					
Cassava root silage	2.85	3.01	3.10	2.98	--
Protein supplement	0.86	0.67	0.73	0.60	--
Control diet	--	--	--	--	2.06
Performance of pigs					
Daily weight gain (kg)	0.59	0.55	0.59	0.50	0.56
Feed conversion ratio (DM)	3.27	3.31	3.24	3.50	3.31

Source: Buitrago et al., 1978.

The addition of 2% common salt (**Table 30**) to the cassava root silage showed a beneficial effect on feed conversion ratio, without affecting the weight gain of pigs. The same experiment demonstrates that silage stored for long periods (more than six months) does not affect the production performance of pigs. The ensiled product progressively decreases in moisture content, which is reflected in improved feed conversion ratios.

Table 30. The effect of feeding ensiled cassava roots with different storage time and added salt to Yorkshire growing-finishing pigs (22-95 kg) on their performance.

Age of silage	Salt addition	Silage consumption	Supplement consumption[1)]	ADG[2)]	FCR[3)]
> 6 Months	-	3.30	0.78	0.63	3.34
	2 %	2.87	0.78	0.62	3.10
< 6 Months	-	3.45	0.78	0.63	3.46
	2 %	3.20	0.78	0.63	3.27

[1)] 40 % protein supplement with the following composition: 44% soybean meal, 44% cottonseed meal, 12% minerals & vitamins
[2)] Average daily weight gain
[3)] Feed conversion ratio
Source: *Buitrago et al., 1978.*

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DEVELOPMENT AND PRACTICAL USES OF CASSAVA AS FEED FOR LIVESTOCK

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ABSTRACT

Energy and protein sources are of prime importance for ruminant feeding as they stimulate microorganisms in the rumen and enhance the productive functions of the animals. Cassava roots in the form of dry cassava chips or pellets, used as an energy source, and dried cassava leaves or cassava hay as a protein source, have been used successfully in ruminant rations, due to their high rumen degradable energy and by-pass protein, respectively. Using higher levels of cassava chips in the diets could enhance supplementation of urea as an non-protein nitrogen source. The use of cassava could provide year-round feed, resulting in high yields and good quality of meat and milk, and hence, contribute to a more lucrative dairy, beef cattle and buffalo production system, especially for small-holder farmers. Moreover, there are many available feed resources in the tropics which can potentially be used in ruminant feeding, particularly the development of food-feed systems (FFS). A very practical FFS system is the intercropping of cassava with leguminous crops such as *Phaseolus calcaratus*, *Vigna unguiculata* etc, which resulted in improved soil fertility while providing food for humans and feed for livestock on a year-round basis.

INTRODUCTION

Livestock production in tropical areas plays a crucial role, which extends beyond its traditional supply of meat and milk. Livestock are used for multiple purposes as draft power, means of transportation, capital, credit, meat, milk, social value, hides, and are a source of organic fertilizer for seasonal cropping. Livestock can utilize agricultural crop residues and farm by-products that are abundantly available. Cassava (*Manihot esculenta* Crantz) is an annual crop grown widely in the tropical and subtropical regions. It thrives well in sandy-loam soils with low organic matter, and in climates with low rainfall and high temperature. The crop often responds well to manure application. Cassava roots have high levels of energy and minimal levels of crude protein; they have been used as a source of readily-fermentable energy, while the top growth could be harvested at four months initially and at 2-3 month intervals subsequently. The leaves and green stems are chopped and sun-dried to reduce their moisture and hydrocyanic acid (HCN) content to produce "cassava hay", which has been used in ruminant feedings successfully (Wanapat, 2000; 2003). Furthermore, establishment and development of food-feed systems (FFS) under small-holder livestock farming systems have also been developed (Wanapat, 2003).

Cassava Hay

Cassava hay has been applied in ruminant nutrition as a high-quality protein supplement for dairy cattle, beef and buffalo production (Wanapat, 2003). Cassava hay consists of the whole above-ground part of the cassava plants harvested at 3-4 months of

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growth. The stems, petioles and leaves are chopped into 3-5 cm pieces and then sun-dried for approximately two days to attain a dry matter (DM) content of about 85%. Sun-drying also eliminates more than 90% of the hydrocyanic acid (HCN) and enhances the palatability and long-term storability. Feeding trials with cattle showed high levels of DM intake (3.2% of body weight) and high DM digestibility (71%). The hay contains about 4% condensed tannins and acts as rumen by-pass protein for further digestion in the small intestine. In comparison with soybean meal, cassava hay has a higher concentration of rumen undegradable protein (RUP) (Wanapat *et al.*, 2007) which is beneficial since it can supply more total amino acids for absorption in the lower-gut. The amino acid profiles of cassava hay were relatively comparable with those of soybean meal, while methionines in cassava hay were higher (Wanapat, 2003). Condensed tannins were generally found at higher levels in mature cassava leaves, but were lower in cassava hay from leaves harvested at a younger stage. Reed (1995) reported that if condensed tannins in the feeds exceeded 6% of DM, it would reduce feed intake and overall digestibility; however, if the concentration of condensed tannins is 2-4%, they would help to protect the protein from rumen degradation, thereby increasing by-pass protein. Therefore, supplementation with cassava hay at 1-2 kg/head/day to dairy cattle could markedly reduce concentrate requirements, and increase milk yield and composition.

Developed Products from Cassava Chips

Recent attempts have been made to develop new products using cassava chips as an energy source with urea as non-protein nitrogen (NPN). Two new cassava based products have been developed: ***Cassarea*** and ***Cassaya***. *Cassarea* was formulated to contain the following ingredients: 57.1% cassava chips + 9.9% urea and 3% tallow (*Cassarea I*, 30% crude protein); 83.6% cassava chips + 13.4% urea and 3% tallow (*Cassarea II*, 40% CP); 80.2% cassava chips + 16.8% urea and 3% tallow (*Cassarea* III, 50% CP). ***Cassareas*** were tested for rumen degradability using a nylon bag technique and were found to have 46.2-56.7% effective DM degradability. Further investigations with *Cassarea II* (40% CP) showed that it could be used to replace soybean meal in the rations of lactating cows, but supplementation with a rumen by-pass protein such as cottonseed meal would be recommended. ***Cassaya*** (30% CP) was a product formulated using chopped whole cassava crop hay (85%) + soybean meal (5%) + cassava chips (5%) + urea (2%) + tallow (2%) + sulfur (1%), mixed with water, pressed through a pelleting machine and sun-dried to at least 85% DM. The use of *Cassaya* in lactating dairy cows as a protein source proved to be efficient in promoting rumen fermentation, improved milk yield and composition, and in providing an increased economic return. Does "whole cassava crop hay" include dried leaves.

Food-Feed Systems (FFS) and Use of Cassava Hay

Planting cassava for hay is aimed at increasing the whole top digestible biomass, with the tuberous roots as a by-product. Earlier work by Wanapat *et al.* (1997) demonstrated that planting cassava at 60x40 cm and intercropping between rows with cowpea or leucaena could enrich soil fertility, while the legumes could be used as food and feed for humans and livestock, respectively.

Results of feeding trials with cattle, buffalo and dairy cows are shown in **Table 1**. The data revealed that cassava hay enhanced rumen fermentation and increased milk yield

and composition (Chanjula *et al.*, 2004; Hong *et al.*, 2003; Koakhunthod *et al.*, 2001; Wanapat *et al.*, 2000; Wanapat *et al.*, 2007; Wora-anu *et al.*, 2007). Furthermore, supplementation with cassava hay to dairy cows could markedly reduce concentrate requirements. In addition, cassava hay supplementation in dairy cattle could increase milk thiocyanate and thus, possibly, enhance milk quality and storage, especially in smallholder dairy farming. Condensed tannins contained in cassava hay have also been shown to have potential for reducing gastro-intestinal nematodes, and therefore act as an anthelmintic agent (**Table 1**) (Granum *et al.*, 2007; Netpana *et al.*, 2001).

Table 1. Summary of trials using cassava based-diets for ruminants production.

	Sources of data[1)]							
Items	A	B	C	D	E	F	G	H
Exp. animals	Dairy	Dairy	Dairy	Dairy	Dairy	B&B	B&B	Beef
Supplements	CH	HQFB-CH	CH	HHCC-CH	SBM-CH	CH	CH	CH
Level supplement, kg/day	1.7	Conc. use (-30%)[2)]	2	1	Conc. use (-20%)	1	1	*ad-lib*
Rumen ecology								
pH	6.8	5.69		6.9	6.7			6.9
NH_3-N, mg/dl	17.0	9.14		18.1	14.4			14.7
Total VFA, mmol/l					73.8			86.5
C_2, mol/100 mol					73			66.7
C_3, mol/100 mol					17.6			20.2
C_4, mol/100 mol					9.5			13.0
BUN, mg/dl					13.6			8.8
Milk production								
Milk yield, kg/day	15.4	9.4	8.0	7.4	8.1			
Milk fat, %	4.6	4.1	5.0	4.3	4.2			
Lactose, %	-	5.0		4.6	4.7			
Milk protein,%	5.3	3.3	3.9	3.0	3.1			
Solids not-fat, %	8.4	8.0	8.6	8..3	8.6			
Total solids, %	12.6	13.0	13.6	12.5	14.3			
Fecal parasitic egg count								
% Reduction	-					31.0	58/45	

[1)] A = Preston and Leng (1987); B = Elizalde *et al.* (1999); C = Chanthakhoun *et al.* (2008); D = Agboola and Fayami (1972); E = Kiyothong and Wanapat (2004); F = Granum *et al.* (2007); G = Chanjula *et al.* (2004) and H = Reed (1995).

[2)] Use 30% less concentrate.

Food-feed systems have been shown to produce both food for humans and feed for animals. Moreover, intercropping with legumes can enrich the soil with nitrogen and some interventions have produced some interesting results. The yield of cassava foliage, when intercropped with a cowpea resulted in an average 4.35 t DM/ha of cassava foliage to produce cassava hay by harvesting four times throughout the year (Wanapat *et al.*, 2007a). Cowpea planted as an intercropped grain legume produced 5.96 t/ha of green cowpea pods

and 1.51 t DM/ha in the plants' residues. Available local feed resources have been recommended for uses under smallholder farming (Wanapat, 2009).

When a forage legume, *Stylosanthes guyanensis*, was intercropped in the cassava plot, the Stylosanthes produced 3.51 t DM/ha. Development of cassava/legume intercropping systems could improve farm productivity, particularly for production of on-farm feed resources.

However, some farmers encountered problems with drying the hay in the rainy season. Therefore, an alternative strategy, such as constructing solar-drying houses using simple materials of plastic sheet and bamboo was recommended to farmers. As a result of these food-feed systems, green cowpea pods were used for household consumption, gifts for neighbors or sold for additional income, while cowpea residues or *Stylosanthes* fodder were also used as animal feeds (food-feed). Kiyothong and Wanapat (2004) reported that feeding cassava hay solely or in combination with Stylo 184 *(Stylosanthes guyanensis* CIAT 184*)* hay as a supplemental protein source could be a potentially valuable strategy in small-holder dairy farming systems in the tropics. This strategic supplementation significantly reduced concentrate use, which resulted in improved milk yields and milk quality for the supplemented cows. Moreover, it resulted in higher economic returns through increased productivity and lower ratios of concentrate to milk yield, from 1:2 to 1:3.

Legume crops are considered effective in enriching the soil nitrogen and for producing high protein foods and feeds for humans and animals. Particularly, *Phaseolus calcaratus* or Tua-mun was found to be a potentially useful crop to improve foliage biomass, condensed tannin and crude protein yields (Chanthakhoun *et al.*, 2008). *P. calcaratus* has a relatively high protein content (17-20.4% in DM), while the biomass yield was 1.9 t DM/ha and CP was 18.1% of DM, with neutral detergent fiber being 42.0% and acid detergent fiber 36.1% of DM. After two months, *P. calcaratus* can grow up to a height of about 60 cm (canopy), fully in bloom and produce pods at 3-4 months. The whole crop can be sun-dried to produce hay in about 2-3 days. Cultivation of *P. calcaratus* to produce hay is based on a first harvest of the foliage at three months after planting. Inter-cropping of leguminous fodder as food-feed between rows of cassava, such as with *P. calcaratus*, improves soil fertility and provides additional fodder. In addition, feeding and digestion trials with buffalo revealed high levels of DM intake (2.4% of body weight), high DM digestibility (71%), and apparent digestibility (75.2%). Condensed tannins (2-3%) were generally found in lower concentrations in mature *P. calcaratus* hay. As indicated before, condensed tannin levels between 2-4% of DM were found to protect protein from rumen digestion, thereby increasing by-pass protein.

In a recent trial, intercropping *P. calcaratus* in grass plots, it was found that the crude protein content of Ruzi grass, *P. calcaratus* and a mixture of the two were 10.7, 20.4, and 14.0%, respectively (Wanapat, 2008, unpublished data). Furthermore, *P. calcaratus* contained about 2.7% condensed tannins and this level is suitable for ruminant feeding. Leguminous species usually contain higher contents of crude protein in the DM and are effective in protein utilization (Elizalde *et al.*, 1999; Preston and Leng, 1987). The reason for the high proportion of by-pass protein in legumes could be due to the formation of condensed tannin-protein complexes, which will protect the protein from rumen degradation.

Agboola and Fayami (1972) reported an increase in maize grain yield over the control when corn was intercropped with *Phaseolus aureaus*. The transfer of N from the legume to corn was equivalent to 45 kg N/ha. While, apparent digestion coefficients of dry matter were 42% for wheat straw and 51% legume hay, respectively. Thus, if adequate amounts of legume hay could be produced and fed to ruminants, the nutrition of ruminants will be greatly improved. Therefore, by promoting the food-feed system, ruminant productivity can be improved and become more sustainable.

CONCLUSIONS AND RECOMMENDATIONS

Based on this review, it can be concluded that cassava chips, various cassava-based processed products and cassava hay are excellent sources of feeds for ruminants. Most importantly, whole cassava foliage can be formulated as a sole source of protein to support ruminant production. Food-feed systems (FFS) using cassava intercropped with various legumes were shown to have great potential under small-holder farming conditions to provide year-round feeding for livestock, and to provide protein for human consumption. Greater dissemination of the FFS is recommended as it would increase livestock productivity and ensure the sustainability of livestock production for small-holder farmers in developing countries.

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EVALUATION OF THE ECONOMIC EFFICIENCY OF USING CASSAVA LEAVES OF VARIETY KM 94 IN DIETS FOR PIGS IN CENTRAL VIETNAM

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is the third most important food crop in Vietnam (after rice and maize), and new high-yielding varieties, such as KM94, KM98-5 and KM140, as well as more sustainable production practices have increased the economic effectiveness of cassava production. The HCN content of fresh cassava leaves of KM94 was 1,745 mg/kg DM and this decreased by 51% after 24 hours of wilting by spreading on the floor. It was found that the inclusion of rice bran or cassava root meal as additives in the ensiling process at levels of 5 or 10% produced good quality leaf silage that could be stored for at least five months. The HCN content of ensiled leaves of KM94 decreased very quickly during the first 30 days, and at 90 days after ensiling the HCN content was only 10.4-13.2% of the initial level.

An experiment was conducted on-farm in Huong Van village, Huong Tra district, Thua Thien Hue province to determine the effect on performance of the use of different levels of ensiled leaves of KM94 in diets of growing pigs. There were four experimental diets, with inclusion of ensiled cassava (KM94) leaves in the diets at 0, 10, 15 and 20% of DM for the two growing phases of the pigs, 20-50 kg (phase 1) and 50-90 kg (phase 2). The daily weight gain to 75 kg were slightly decreased and the Feed Conversion Ratios (FCR) were slightly increased at the higher inclusion levels of ensiled leaves of KM94, but there were no statistically significant differences ($P>0.05$). Daily weight gains (DWG) were 576.9, 557.4, 534.3, 516.7 g/day, while the FCR were 2.73, 2.86, 2.99 and 3.06 kg DM/kg LWG ($P>0.05$) for the inclusion levels of 0, 10, 15 and 20%, respectively.

It was found that in the diet for growing pigs the inclusion of ensiled cassava leaves of KM94 at 10 to 20% of DM was not affecting the animals' health or overall performance and resulted in an 8-13.8% reduction in feed cost. Ensiled cassava leaves of the high-HCN variety KM94 can be used as a protein supplement for feeding pigs. Using ensiled cassava leaves of KM94 in the diets of pigs will bring economic benefits to farmers in Central Vietnam.

Key words: Ensiled cassava leaves (ECL); cassava KM94; dry matter (DM); crude protein (CP), hydrogen cyanide (HCN); cyanogenic glucosides; live weight gain (LWG), feed conversion ratio (FCR); feed cost (FC).

INTRODUCTION

In Vietnam, cassava has rapidly changed its role from a food crop to an industrial crop, with a high rate of growth during the eight first years of the 21st Century. Recently, the yield of cassava and the area planted has been increasing. New high-yielding cassava varieties, such as KM94, KM98-5 and KM140 were distributed to various provinces in the country (Nguyen van Bo *et al.*, 2010), and more sustainable production practices have increased the economic effectiveness of cassava production, especially in the Central region. The Vietnam Cassava Program, supported by the Ministry of Agriculture and Rural Development (MARD), and implemented in close cooperation with the Nippon Foundation-funded Cassava Project coordinated by CIAT (International Center for Tropical Agriculture), has promoted the rapid multiplication and widespread distribution of high-

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yielding and high-starch varieties, and the adoption of more sustainable cassava production practices. In 2007/08 556,000 ha of of cassava were planted, of which more than 350,000 ha were new varieties, mainly KM94 (Hoang Kim *et al.*, 2010); the total root production was about 9.40 million tonnes, resulting in an average root yield of 16.91 t/ha (FAOSTAT, 2010). At the time of root harvest, the yield of fresh foliage of KM94 is about 9 t/ha (Nguyen Huu Hy *et al.*, 2009) and leaf yield 5-7 t/ha (Nguyen Thi Hoa Ly, 2004 unpublished data).

Cassava leaves of variety KM94 have a high level of crude protein, from 25-34.7% in DM, and are a good source of protein for animal feeding (Phuc and Lindberg, 2001; Nguyen Thi Hoa Ly, 2006). The greatest limitation to the use of cassava leaves of KM94 as animal feed is the very high HCN content of the fresh leaves. Many researchers have reported that HCN in cassava can be reduced by processing; however, the most common procedures for reducing the cyanide content are sun-drying and ensiling (Nguyen Thi Loc *et al.*, 2000; Nguyen Thi Hoa Ly *et al.*, 1999; 2000; 2001; Wanapat, 2002; Man *et al.*, 2009; Man and Wiktordsson, 2001; 2009; Khieu Borin *et al.*, 2009; Buitrago, 2009; 2010; Montagnac *et al.*, 2009).

In the rainy season it is difficult to sun-dry, so under those conditions making silage is the most convenient method to preserve cassava roots and leaves and reduce the toxicity of HCN. Fresh cassava leaves of KM94 were found to have very high levels of HCN (1,745 mg/kg DM), so it is necessary to find appropriate methods to process and use KM94 for animal feeding.

The objective of these experiments was to identify appropriate preservation and processing methods for cassava leaves of KM94 variety, and to evaluate the economic efficiency of using ensiled KM94 cassava leaves for pig feeding under farm conditions in Central Vietnam.

Experiment 1. On-station evaluation of the effect of wilting time and additives on the quality of silage of cassava leaves of KM94.

Processing method of KM94 cassava leaves

Fresh leaves of the cassava variety KM94 were collected at the time of root harvest and spread out on the floor for wilting. The fresh leaves were analysed for DM, CP and HCN content at 0, 12 and 24 hours after wilting. After 24 hours of wilting the leaves were separated from the stems and petioles, chopped into small pieces (2-3 cm), mixed with 0.5% salt and additives (rice bran or cassava root meal at 5 or 10% levels), and the mixture was packed tightly in plastic bags and sealed. The treatment were:

5 CRM: Cassava leaves (KM94) + 0.5% NaCl + 5% Cassava root meal
10 CRM: Cassava leaves (KM94) + 0.5% NaCl + 10% Cassava root meal
5 RB: Cassava leaves (KM94) + 0.5% NaCl + 5% Rice bran
10 RB: Cassava leaves (KM94) + 0.5% NaCl + 10% Rice bran

Silage samples were taken after 0, 30, 60 and 90 days of ensiling and analyzed for pH, dry matter (DM), crude protein (CP) and HCN (AOAC, 1990). The analyses were done in the laboratories of Hue University in Hue city, Vietnam from December 2003 to April 2004.

RESULTS

The DM content of fresh cassava leaves of KM94 increased significantly after wilting for 12 or 24 hours (**Table 1**). The aim of wilting is to reduce the moisture and HCN contents of cassava leaves. Pre-wilting is a very important step to reduce the moisture content of the fermenting material, and several researchers have reported that a DM content of the material between 35 and 40% is suitable for ensiling (Liu Jian Ping and Zhuang Zhong Tang, 2000). After wilting for 24 hours, the DM % of cassava leaves was 37.82%, which is considered suitable for ensiling. Higher levels of moisture will cause the sugar and the colloidal matter in the plant liquid to be diluted, which will reduce the effectiveness of the lactic acid bacteria and cause the silage to become putrid.

The crude protein content of cassava leaves decreased slightly after wilting but these differences were not significant (P =0.16).

Table 1. Effect of wilting time on the DM, CP and HCN content of cassava leaves of KM94.

	DM (%)	CP (% DM)	HCN (mg/kg fresh)	HCN (mg/kg DM)
Fresh leaves of KM94	27.86[a]	28.26	486[a]	1,745[a]
-after 12 hours wilting	32. 56[b]	27.31	428[b]	1,313[b]
-after 24 hours wilting	37.82[c]	27.04	335[c]	885[c]
SE	0.274	0.403	6.294	19.5
P	0.001	0.16	0.001	0.001

[1)] Mean values within columns without common letters are different at P<0.05

The HCN content of the cassava leaves decreased after wilting (**Table 1**). The HCN content of the fresh cassava leaves was 1,745 mg/kg DM, and was reduced to 1,313 mg and 885 mg/kg DM after wilting for 12 and 24 hours, respectively. Thus, the HCN content was only about 75 and 51% of the initial level after 12 and 24 hours of wilting, respectively. Cassava leaves are often wilted at ambient temperature of 30^{0}C. Bala Nambisan (1994) reported that wilting for longer periods than 12 hours caused a further reduction in total cyanogen to 24% of the initial level. Padmaja (1989) also observed that wilting whole branches under shade, followed by drying the detached leaves at 60^{0}C was better than chopping the wilted leaves and drying at 60^{0}C. Drying of chopped leaves at 70^{0}C resulted in 70% retention of cyanogens. Wilting fresh leaves is effective in removing cyanogens; the longer the wilting time, the lower the retention of cyanogens.

Changes in the pH with time confirmed the visual observation that all treatments resulted in silage of acceptable quality. The pH of the silage fell within 30 days to 4.24-5.15 and fell further to 4.47-4.67 for all treatments after 90 days of ensiling (**Table 2**).

Both additives at 5 or 10% inclusion resulted in good quality silage (**Table 3**). The DM content of the silage decreased slightly from 0 to 90 days of ensiling. Significant losses of DM were the result of the activity of plant enzymes on the water-soluble carbohydrates, resulting in carbon dioxide and water. Most losses of nutrients occur as a

result of aerobic deterioration before the material is ensiled, or as a result of entrance of air during storage or after opening the plastic bags.

Table 2. Effect of adding two levels of cassava root meal (CRM) or rice bran (RB), and ensiling time on the pH of silage of cassava leaves of KM94 (ECL).

	Ensiling time, days			
	0	30	60	90
	pH			
ECL + 5% CRM	6.38	5.15	5.04	4.67
ECL + 10% CRM	6.42	4.24	5.21	4.49
ECL + 5% RB	6.25	5.32	5.17	4.47
ECL + 10% RB	6.23	4.87	4.86	4.47

Table 3. Effect of adding two levels of cassava root meal (CRM) or rice bran (RB), and ensiling time on the DM content of silage of cassava leaves of KM94 (ECL).

	Ensiling time, days					
	0	30	60	90	SE	P
	DM (%)					
ECL + 5% CRM	40.58	40.90	40.36	38.10	0.680	0.068
ECL + 10% CRM	43.04	43.10	41.86	42.21	0.586	0.404
ECL + 5% RB	40.26[a]	41.89[b]	40.25[a]	38.57[c]	0.285	0.001
ECL + 10% RB	42.67[a]	43.96[a]	41.19[b]	39.61[b]	0.638	0.007
Average	41.64[a]	42.46[b]	40.92[b]	39.62[b]	0.437	0.001

[1)] Mean values within rows not followed by common letters are different at $P<0.05$
SE = standard error of mean; P = probability

The crude protein content (**Table 4**) of all four additive treatments decreased significantly during the first 30 days of ensiling and then decreased slightly from 30 until 90 days of ensiling. The crude protein content of the silage fell for all treatments by 3-5%, probably as a result of bacterial degradation. Plant enzymes also bring about proteolysis and the production of amino-acids and peptides from the protein of the original material. The HCN content of the ensiled cassava leaves decreased very quickly between 0 (after leaf wilting 24 hours) and 30 days and then further decreased until 90 days after ensiling (**Table 5**). The HCN content of the fresh cassava leaves was 1,745 mg/kg DM, and was reduced to 885 mg/kg DM after 24 hours of wilting, when the HCN content was only about 51% of the initial level. Then, at 90 days after ensiling, the HCN content of the cassava leaves had fallen further to 181-231 mg/kg DM, corresponding to about 10.4-13.2% of the initial level.

Many previous studies concluded that ensiling is a convenient way of preserving the nutritional value and reducing the toxicity by cyanide precursors of fresh cassava leaves (Nguyen Thi Hoa Ly *et al.*, 2000; 2001a; 2005; Man and Wiktordsson, 2002; Man *et al.*, 2009; Khieu Borin *et al.*, 2009).

Table 4. Effect of adding two levels of cassava root meal (CRM) or rice bran (RB), and ensiling time on the CP content (% in DM) of silage of cassava leaves of KM94 (ECL).

	Time of ensiling, days				SE	P
	0	30	60	90		
	CP (% of DM)					
ECL + 5% CRM	24.39[a]	23.11[b]	22.58[b]	20.86[c]	0.176	0.001
ECL + 10% CRM	24.34[a]	21.95[b]	21.41[b]	19.04[c]	0.204	0.001
ECL + 5% R.bran	24.84[a]	23.26[b]	22.79[b]	21.88[c]	0.134	0.001
ECL + 10% R.bran	25.34[a]	23.81[b]	23.41[b]	22.56[c]	0.049	0.001
Average	24.73[a]	23.03[b]	22.55[b]	21.08[b]	0.265	0.001

[1)] Mean values within rows not followed by common letters are different at P<0.05

Table 5. Effect of adding two levels of cassava root meal (CRM) or rice bran (RB), and ensiling time on the HCN content of silage of cassava leaves of KM94 (ECL).

	Time of ensiling, days				SE	P
	0	30	60	90		
	HCN (mg/kg DM)					
ECL + 5% CRM	773.73[a]	649.70[b]	363.70[c]	231.84[d]	22.177	0.001
ECL + 10% CRM	706.87[a]	638.71[a]	311.87[b]	181.31[c]	17.226	0.001
ECL + 5% R.bran	767.66[a]	594.86[b]	324.82[c]	190.10[d]	19.166	0.001
ECL + 10% R.bran	705.34[a]	574.50[b]	293.79[c]	190.16[d]	18.427	0.001
Average	738.40	616.44	323.55	198.35	19.365	0.001

[1)] Mean values within rows not followed by common letters are different at P<0.05

Our previous research, on using various additives in the ensiling process, showed that the inclusion of rice bran or cassava root meal at levels of 5 or 10% or fresh cassava roots at levels of up to 50% (on fresh basis of cassava leaves of a local variety) produced good quality silage that could be stored for at least five months. The HCN content of the ensiled cassava leaves of the local variety decreased very quickly during the first 30 days, and the HCN content was only about 20-28% of the initial level at 90 days after ensiling.

Thus, cassava leaves of KM94 after wilting for 24 hours followed by ensiling, could be a suitable alternative way of preservation when the harvest of cassava coincides with the rainy season. The technique is simple, cheap and suitable for farm conditions in Central Vietnam.

Experiment 2. Effect of levels of ensiled cassava leaves of KM94 in the diets of growing pigs on their performance and on the economic efficiency as determined in on-farm experiments conducted in Central Vietnam

Animals, experimental design and feeding methods

The experiments were conducted in three pig-raising households in Huong Van village, Huong Tra district, Thua Thien Hue province from December 2004 to May 2005. Three households were selected to raise a total of 24 pigs (crossbreds of Mong Cai and Large White) with average initial live weights of about 23-24 kg. Each farmer was randomly allocated eight pigs which were distributed into four treatments, with 2 pigs in each pen. The trials used a completely randomized block design with four levels of ensiled cassava (KM94) leaves: 0, 10, 15 and 20% of ensiled cassava leaves (in DM) in the diets. The pigs were vaccinated against hog cholera and Pasteurellosis and were de-wormed two weeks before starting the experiment. The diets were formulated according to the two growing phases of the animals, i.e. 20-50 kg (phase 1) and 50-90 kg (phase 2). The diets were fed according to a restricted allowance recommended by the National Institute of Animal Husbandry of Vietnam (2001). The experiment lasted 90 days. The diets were distributed equally into three meals per day. Refusals were collected and weighed the following morning before the first meal. Drinking water was available *ad libitum*.

The diets for the four treatments were:

1. Control diet: Basic diet containing rice bran, yellow maize, ensiled cassava roots (ECR), fishmeal and sweetpotato vines
2. 10% KM94 diet: 90% of DM as basic diet + 10% as DM of ensiled cassava leaves (ECL) of KM 94
3. 15% KM94 diet: 85% of DM as basic diet + 15% of DM as ECL of KM94
4. 20% KM94 diet: 80% of DM as basic diet + 20% of DM as ECL of KM94

The chemical composition of the feed ingredients is shown in **Table 6**.

The four diets were compounded to have (as DM) around 3000 kcal ME/kg, and 14% CP, 0.65% lysine and 0.25% methionine in phase 1; and 3000 kcal ME/kg and 12% CP, 0.55% lysine and 0.23% methionine in phase 2. The protein supplement in the experimental diets consisted of fishmeal and ensiled cassava KM 94 leaves, in which ensiled cassava KM 94 leaves was included at levels of 0, 10, 15 and 20% (as DM) for the two stages of growing pigs (**Tables 7** and **8**).

A vitamin and mineral premix was added (0.5% of DM) according to requirements given by NRC (1998). The composition of the Premix per kg: 2400 mg retinol; 4.32 cholecalciferol; 15,000 mg -tocopherol; 5000 mg phytylmenaquirone; 2000 mg thiamin; 15,000 mg riboflavin; 25,000 mg calcium pantothenate; 30,000 mg niacin; 30 mg cyanocobalamin; 2000 mg folic acid; 100 mg choline; 100 mg Fe; 115 mg Zn; 40 mg Cu; 0.15 mg Co; 0.6 mg I; 0.3 mg Se.

Chemical analyses

The feed stuffs in the experimental diets were analyzed for dry mater (DM), crude protein (CP), crude fibre (CF) and HCN (AOAC, 1990) in the Hue University laboratories. Amino acids were analyzed according to Spackman *et al.* (1958) on an ion-exchange column using an HPLC. Amino acids were analyzed in the laboratories of the National Institute of Animal Husbandry (NIAH) in Hanoi.

Table 6. Chemical composition of the feed ingredients (as DM) used to formulate the four diets.

Ingredients	DM (%)	ME[1)2)] (kcal/kg)	CP[1)] (%)	CF[1)] (%)	Lysine (g/kg)	Methionine (g/kg)	HCN (mg/kg)
Rice bran		2890	11.46	15.61	4.86	2.31	
Maize		3596	9.56	2.74	3.13	1.94	
ECR		2963	3.09	3.98	1.11	0.42	55.06
Fish meal		3161	58.47	0.00	33.33	10.45	
Sweetpotato vines		2247	17.75	17.98	7.12	2.25	
ECL KM94		2462	21.04	11.66	9.17	3.24	195.34

[1)] ME = metabolic energy; CP = crude protein; CF = crude fiber; ECR = ensiled cassava roots; ECL = ensiled cassava leaves

[2)] Calculated; ensiled cassava roots and leaves analized at 60 days after ensiling

Table 7. Ingredient content and chemical composition (on DM basis) of the four experimental diets in phase 1 (pigs of 20-50 kg).

	Control diet	10% ECL (KM94)	15% ECL (KM94)	20% ECL (KM94)
Ingredients				
Rice bran	32	32	30	30
Maize	18	18	21	24
ECR	30	30	26	20
Fish meal	10	10	8	6
Sweetpotato vines	10	-	-	-
ECL KM94	-	10	15	20
Chemical composition (%, kg of DM)				
ME (kcal/kg)	3002	3023	3015	3005
CP (%)	13.94	14.26	14.08	14.06
CF (%)	8.48	7.85	8.04	8.45
Lys (g/kg)	6.50	6.60	6.45	6.27
Met (g/kg)	2.50	2.58	2.53	2.52
HCN (mg/kg)	16.52	36.05	43.62	50.08

[1)] All diets also contained Vitamin and mineral premix at 0.5% (as DM).

Table 8. Ingredient content and chemical composition (on DM basis) of the experimental diets in phase 2 (pigs of 50-90 kg).

	Control diet	10% ECL KM94	15% ECL KM94	20% ECL KM94
Ingredients				
Rice bran	38	36	35	28
Maize	16	18	19	24
ECR	30	30	27	25
Fish meal	6	6	4	3
Sweetpotato vines	10	-	-	-
Chemical composition (%, kg of DM)				
ME (kcal/kg)	2977	3013	3000	3000
CP (%)	12.10	12.18	12.15	12.24
CF (%)	8.85	8.47	9.20	8.35
Lys (g/kg)	5.66	5.56	5.30	5.30
Met (g/kg)	2.32	2.30	2.20	2.20
HCN (mg/kg)	16.52	36.05	44.20	52.83

[1)] All diets also had Vitamin and mineral premix mixture 0.5 % (as DM).

Data collection

Feed consumption was determined by weighing the amount of feed given and subtracting any feed remaining the following morning. The pigs were individually weighed initially, monthly and at time of slaughter, and the daily weight gains, daily feed intake, feed conversion ratio and feed cost/kg live weight gain were calculated for each treatment.

The data collected were analyzed by the ANOVA using the General Linear Model (GLM) of Minitab Statistical Software Version 13 (2000). Tukey pair-wise comparisons were used to determine the significance of differences between treatment means at $P< 0.05$.

RESULTS

Final live weight, daily weight gain and feed conversion ratio

The data in **Table 9** shows that the final live weight and the daily weight gain tended to decrease as the levels of ensiled cassava leaves increased; however, there were no significant differences in the final live weight and daily weight gains among the experimental diets ($P>0.05$). The daily weight gains were 576.9, 557.4, 534.3 and 516.7 g/day for the control diet, and the diets with 10, 15 and 20% ECL diets (**Figure 1**), respectively ($P= 0.287$). Similarly, there were no significant differences in DM intake among the experimental diets ($P = 1.000$).

The data in **Table 9** also show that the feed conversion ratios (FCR) slightly increased at the higher levels of ensiled cassava leaves in the diets, but there were no significant differences among the treatments ($P= 0.632$). Fresh cassava leaves of KM 94

leaves had high HCN contents, but this was greatly reduced by the wilting and ensiling process; therefore, when 10, 15 or 20% DM in the basic diet was replaced by ECL this had no effect on the performance of the growing pigs.

Table 9. Effect of using ensiled cassava leaves of KM94 in the diets of growing pigs on their performance and on the economic efficiency.

	Control diet	10% ECL KM94	15% ECL KM94	20% ECL KM94	SE	P
Initial LW (kg)	23.17	23.25	23.92	23.75	0.523	0.688
Final LW (kg)	75.08	73.50	72.00	71.08	2.368	0.655
Daily weight gain (g/day)	576.9	557.4	534.3	516.7	22.70	0.287
DM intake (kg/pig/day)	1.57	1.57	1.56	1.57	0.043	1.000
FCR (kg DM/kg LWG)	2.73	2.86	2.99	3.06	0.189	0.632
Feed cost (VND[1])/kg LWG)	7,852	7,225	7,121	6,767	483.7	0.472
Relative to control (%)	100	92.01	90.69	86.18		

[1] VND = Vietnam Dong; 1 US$ = 15,800 VND

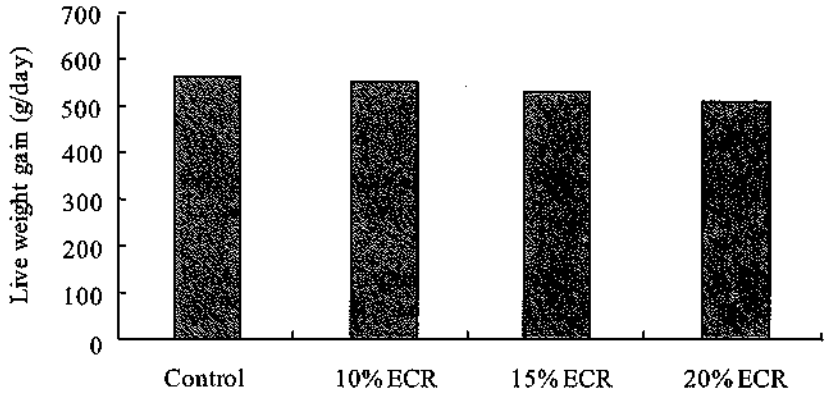

Figure 1. Effect of using KM94 ensiled cassava leaves in the diet of growing pigs on daily live weight gain.

Feed cost

There were no significant differences in feed cost/kg weight gain among treatments (P = 0.472). However, **Table 9** shows that the feed cost tended to decrease as the level of ensiled cassava leaves increased in the diets (**Figure 2**). Using 10, 15 and 20% ensiled cassava leaves reduced the feed cost by 8, 9.3 and 13.8%, respectively. This indicates that ensiled cassava leaves of KM94 variety can be used as a protein source for feeding pigs under farm conditions in Central Vietnam.

Several of our experiments using ensiled cassava leaves of the local variety Ba Trang for growing pigs indicated that using 13-15% (as DM) of ensiled cassava leaves in

the diets improved the daily live weight gain and the feed conversion ratio, and reduced the feed cost by 25.0-26.8% under village conditions (Nguyen Thi Hoa Ly *et al.*, 2001); using 16% ensiled cassava leaves (ECL) or dry cassava leaf meal (CLM) in the diets had no statistically significant effect on live weight gain or feed conversion ratio, but reduced the feed cost by 12-16% as compared to pigs fed a diet containing 16% ensiled sweetpotato vine (Nguyen Thi Hoa Ly *et al.*, 2002). Hang (1998) also reported that there were no significant differences in daily weight gain and feed conversion ratio between pigs fed the control diet and the ECL diet, but using 9% ECL (as DM) reduced the feed cost by 16%.

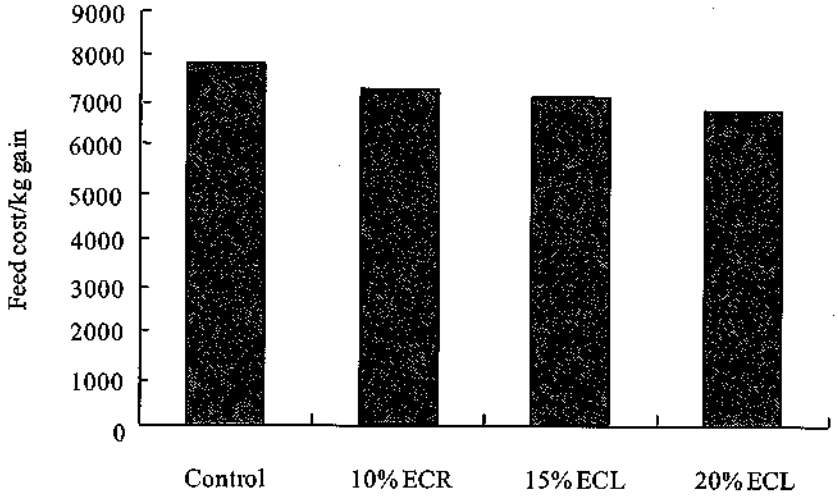

Figure 2. Effect of using KM94 ensiled cassava leaves in the diets of growing pigs on feed cost per kg live weight gain.

In another study conducted in South Vietnam, Bui Huy Nhu Phuc and Ogle (2005) found that using up to 12% cassava leaf meal (CLM) in the diet of growing-finishing pigs, or 30% of CLM in the diet of pregnant sows had no detrimental effects on the pigs' performance. Our results are in agreement with those of Bui Huy Nhu Phuc (2000), who concluded that cassava leaves can be used as a protein supplement in the diets of growing pig and that ensiled or dried cassava leaves are potentially useful feed resources in developing countries.

SUMMARY AND CONCLUSIONS

Wilting fresh cassava leaves of variety KM94 was effective in reducing the concentration of cyanogens; the longer the wilting time the lower the level of cyanogens in the leaves.

The inclusion of rice bran or cassava root meal at levels of 5 or 10% produced good quality silage that could be stored for at least five months. The HCN content of ensiled cassava leaves (KM94) decreased very quickly during the first 30 days, and the HCN content was only 10.4-13.2% of the initial level at 90 days of ensiling.

The inclusion of 10, 15 and 20% (as DM) ensiled cassava leaves of KM94 in diets for growing pigs did not affect the animals' health or overall performance, and resulted in a 8-13.8% reduction in feed costs.

Ensiled cassava leaves of KM94 can be used as a protein supplement for feeding pigs and this will result in higher economic benefits for farmers in Central Vietnam.

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ENSILED CASSAVA LEAVES AND FRESH WATER SPINACH AS PROTEIN SOURCES FOR FATTENING PIGS ON FARMS IN CAMBODIA

Chhay Ty[1] , *Khieu Borin*[1] *and Reinhardt Howeler*[2]

ABSTRACT

Twenty crossbred pigs (local x exotic) with about 12-17 kg initial weight were allocated to ten households in two villages (five households per village) to compare the effect of supplementing a basal diet of rice bran and broken rice with ensiled cassava leaves alone or together with water spinach, on the growth of pigs. Each farmer received two piglets (male and female), cassava stems for planting, the cost of cassava leaves, materials for making silage, rice bran for making silage and for feeding the pigs for 16 weeks, a scale with capacity of 5 kg, a book, pen and salt, but farmers had to contribute their own broken rice and water spinach. Cassava leaf silage was made by mixing 100 kg of fresh leaves (without petioles or stems) with 10 kg of rice bran and 0.5 kg of salt, packing this mixture tightly in plastic bags and storing these for one month before feeding.

There were no symptoms of toxicity caused by the cassava leaf silage, or diarrhea caused by fresh water spinach, but contrary to expectation, the pigs grew very well. Pigs fed the mixed feed (ECL+WS) had a high total feed intake but low crude protein intake compared with those fed only ensiled cassava leaves (ECL). The growth rates of pigs in individual households were not significantly different with or without water spinach, but the growth rates and feed conversion ratios were improved in treatments with water spinach.

There appears to be an advantage in terms of pig growth and feed conversion ratio from feeding the mixture of cassava leaf silage and fresh water spinach as compared to feeding cassava leaf silage alone.

Key words: pigs, fattening, on-farm, cassava, leaf silage, water spinach, rice bran, broken rice

INTRODUCTION

Pig production plays an important role in the farming activities in Cambodia, especially for smallholder farmers. The pigs provide manure, meat and income. In recent years, the income from pig raising has been very low and in some cases is negative because the pigs grow slowly. The main cause is the lack of protein in the diet, in spite of having sufficient energy sources such as rice bran and other by-products. Those feeds have a low protein content, which does not meet the requirements for growing pigs. In general, farmers do not use the conventional protein sources, such as fishmeal and soybean meal, because these are too expensive, and the farmers do not have enough money to buy them. Therefore, there is a need to identify and promote other protein sources, especially those that can be produced on the farm, such as cassava and water spinach

Cassava plants can withstand defoliation for several years if they receive adequate fertilization and irrigation, and under such management have the potential to produce up to four tones of protein per hectare annually (Montaldo, 1977). Ensiling of cassava leaves is an appropriate way to conserve them (Limon, 1992; Bui Van Chinh *et al.*, 1992; Du Thanh

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Hang, 1998; Chhay Ty *et al.*, 2001). It has been shown that the ensiled cassava leaves can provide all the protein in a diet based on sugarcane juice for native Mong Cai pigs (Du Thanh Hang *et al.*, 1997), and up to 50% of the protein in diets based on ensiled cassava roots (Du Thanh Hang, 1998).

Water spinach has been used in Cambodia in pig feed for many years as a supplemental feed. In a recently study Chhay Ty and Preston (2005A; 2005B) showed that water spinach can be used as a supplementary source of protein in a diet based on broken rice or rice bran, mixed with cassava root meal for growing pigs. The results show that water spinach can improve the feed intake, growth rate, feed conversion ratio, digestibility of DM, OM and N, as well as the crude fiber and N retention. Moreover, other researchers have reported similar results when pigs were fed water spinach as a supplementary source of protein in diets for growing pigs fed a basal diet of broken rice (Ly *et al.*, 2002).

Cassava is rich in lysine but lacks methionine (Eggum, 1970), while in water spinach methionine is also limiting. Mixing two sources of leaves as sources of protein may be beneficial in view of possible complementary effects of the two types of amino acids.

OBJECTIVE

The objective of this study was:

To evaluate ensiled cassava leaves and water spinach as protein supplements in diets for growing-fattening pigs fed a basal diet of rice bran and broken rice at the village level in Cambodia.

To demonstrate to farmers the use of cassava leaf silage and water spinach as pig feed.

To encourage farmers to use local feed resources.

MATERIALS AND METHODS

Location and Duration

The study was carried out in two villages, Srah Takoun and Lok villages of Sanlong commune, Trang district in Takeo province, around 110 km south of Phnom Penh, from Dec 20, 2005 to April 11, 2006.

Selection of Farmers

The farm families were selected based on:

The farmers' willingness to participate in the trials

Their willingness to share the knowledge with other farmers

Having pig pens with cement floors of adequate size, equipped with water nipples

Having enough labor to take care of pigs and feeding

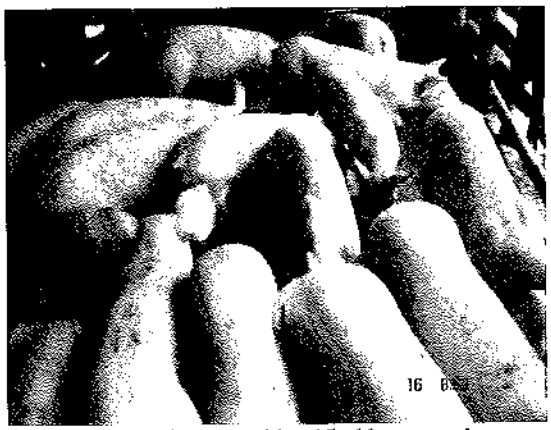
Having enough land for planting cassava and water spinach

Treatments and Design

The experiment was conducted by five farmers in each of two villages. Each farmer received from the project were two piglets, cassava stems for planting, the cost of cassava

leaves, materials for making cassava silage, rice bran for feeding the pigs during a 16-week period, a scale with capacity of 5 kg, a book, pen and salt, but the farmers had to contribute their own broken rice and water spinach. There were two treatments (cassava leaf silage with or without water spinach) with five replicates per treatment. The design was a completely randomized design (CRD).

Picture 1: The farmer receives a pig from CelAgrid's staff.



Picture 2: All pigs were identified by a number on the back and were selected by voting.

The two treatments were as follows
1. ECL: A basal diet of rice bran and broken rice supplemented with ensiled cassava leaves
2. ECL+WS: A basal diet of rice bran and broken rice supplemented with ensiled cassava leaves plus water spinach

Table 1 shows the chemical characteristics of the feed ingredients used, and **Table 2** the feed composition of the two treatments.

Table 1. Chemical characteristics of the ingredients of the diets

	Dry matter (%)	Crude protein (%)
Cassava leaf silage	30.0	21.0
Water spinach	7.65	23.0
Rice bran	89.34	9.0
Broken rice	88.55	7.2
Salt	-	-

Animals, Feed and Feeding

Twenty crossbred pigs (local x exotic) with and initial weight of about 12-17 kg were allocated to ten farmers in two villages. Each treatment consisted of five replicates with two pigs per pen (male and female) with a concrete floor and provided with feeders and water nipples. Pigs were vaccinated against Samodelosis, Pasteurella, pest and dewormed before the start of the experiment. The adoption period was seven days before starting to collect the data; the experiment continued for 16 weeks.

Table 2. Feed composition on dry matter basis (%).

	ECL	ECL+WS
Cassava silage	49	29
Water spinach	0	20
Rice bran	37.5	37.5
Broken rice	12.5	12.5
Salt	1	1

Cassava was planted by farmers and the foliage harvested at around 3-3½ months of age; additional foliage was purchased from farmers who had planted cassava for root production. The foliage was used for this experiment. Cassava leaf blades were mixed with 10 kg of rice bran and 0.5 kg of salt for every 100 kg of cassava leaves. The mixture was packed in large plastic bags, which were then closed tightly to allow for anaerobic fermentation during one month before feeding. Water spinach was planted by farmers and fertilized with effluent from a biodigestor. Rice bran and broken rice were purchased from a local rice mill in the village.

Picture 3: cassava plantation in the village.

Picture 4: Water spinach grown in the pond.

Rice bran, broken rice and salt were mixed together and fed first before the feeding of other ingredients. Cassava leaf silage and water spinach were chopped into small pieces and fed when rice bran and broken rice had all been consumed. The feeding was done 3-4 times per day depending on observation of the feed trough. Pens were cleaned every morning after collecting of the feed residue left from the previous day, and before the first feeding of the day.

Procedure

All participants in the project were trained on how to record the data and the feeding system before starting the experiment. Staff of CelAgrid calculated the feed's formula and wrote this down in the farmers' book. The pigs were weighed every 14 days until 16 weeks using a 100 kg capacity scale. Feed on offer and the residue that was left over was recorded daily by farmers using a 5 kg capacity scale. Feed samples were

analyzed for DM and N. The DM content was determined using the microwave method of Undersander *et al.* (1993). N was analyzed following procedures of AOAC (1990).

Statistical analysis

Data for weight gain, DM feed intake, crude protein intake and feed conversion ratio were analyzed using the general linear model (GLM) option of the ANOVA software of Minitab (14.200). The sources of variation were treatment and error.

RESULTS

General Observations

During the 16 weeks of the trial, farmers in Srah Takoun and Lok villages of Sanlong commune did not observe any symptoms of toxicity caused by feeding the cassava leaf silage, or diarrhea caused by the water spinach; in fact, the pigs had positive growth rates during the whole experiment. The farmers now know more about how to use local resources to feed their animals.

Daily Feed Intake

The energy sources from rice bran and broken rice were completely consumed. The feed intake of rice bran, broken rice and total intake was significantly higher ($P<0.001$) in pigs fed with a mixture of cassava leaf silage and water spinach (ECL+WS) as compared with those fed cassava leaf silage (ECL) alone (**Figure 1**). In contrast, feed intake of foliage and percent of total intake were significantly higher ($P<0.001$) in pigs fed cassava leaf silage alone. Total crude protein intake was not significantly different ($P>0.05$) between the two treatments (**Tables 3** and **4**; **Figure 2**).

Table 3. Average feed intake of two pigs fed the two treatments of basal diet of rice bran and broken rice, supplemented with cassava leaf silage alone (ECL) or together with fresh water spinach (ECL+WS).

	Treatments			
Feed intake (g/day)	ECL	ECL+WS	SEM	Prob
Rice bran	645.4	785.8	12.16	0.001
Broken rice	212.8	260.3	4.02	0.001
Foliages	807.4	730.0	12.78	0.001
Total	1665.7	1776.1	26.63	0.003
Foliage (as % of total intake.)	48.0	41.8	0.33	0.001

Growth Rates

1. First 8-week period

Table 5 and **Figure 3** show the live weight gains of pigs of individual farmer participants during the first period (0-8 weeks). In this period the live weight gains of pigs supplemented with ensiled cassava leaves alone or together with water spinach were not significantly ($P>0.05$) different.

Table 4. Average protein intake of two pigs fed the two treatments of basal diet of rice bran and broken rice, supplemented with cassava leaf silage alone or together with fresh water spinach.

	Treatments			
Protein intake (g/day)	ECL	ECL+WS	SEM	Prob
Rice bran	58.08	70.72	2.85	0.001
Broken rice	15.32	18.74	0.74	0.001
Foliages	180.50	168.70	2.67	0.002
Total	253.90	258.16	3.86	0.44

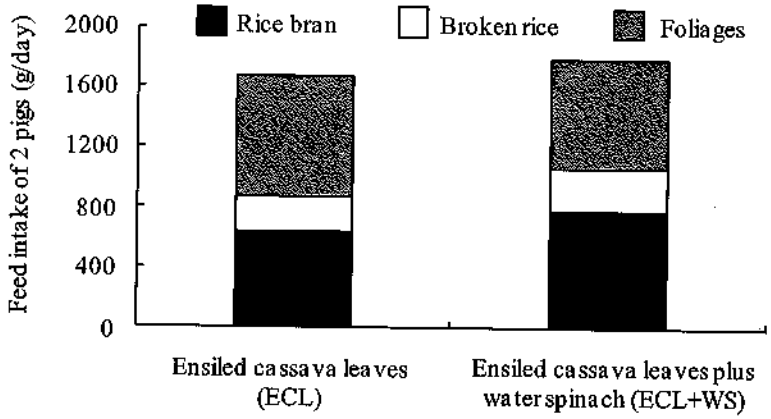


Figure 1. Average feed intake of two pigs fed a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with fresh water spinach.

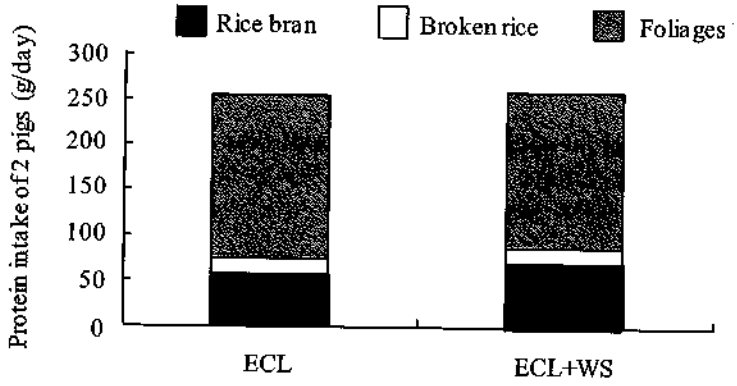


Figure 2. Average protein intake of two pigs fed a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with water spinach.

Table 5. Live weight gain of pigs of individual participants fed with a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with water spinach, from 0-8 weeks.

	ECL+WS					ECL alone						
	Rany	Sarum	Sokha	That	Touk	Brus	Mom	Sarong	Toul	Chanthy	SEM	Prob
Live weight, kg												
- initial	14.0	13.5	13.5	15.3	17.3	13.5	13.5	12.5	13.5	17.0	2.53	0.786
-final	21.5	23.5	27.0	23.0	27.0	17.5	21.0	17.0	20.5	27.0	4.88	0.13
LW gain, g/day	130.0	180.0	246.5	128.5	180.0	77.0	139.5	75.0	118.0	180.0	44.80	0.315

However, **Table 6** shows that the average live weight gain during this period was higher in the treatment using a mixture of ensiled cassava leaves and water spinach (ECL+WS) compared with feeding only ensiled cassava leaves (ECL), but it was not statistically significant (P=0.072).

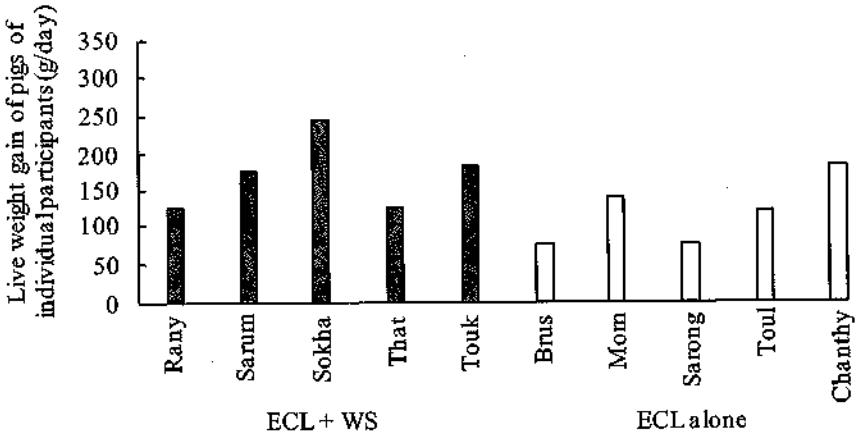


Figure 3. Daily live weight gain of pigs of individual participants fed a basal diet supplemented with ensiled cassava leaves alone or together with water spinach, in the first period (0-8 weeks).

Table 6. Average live weight gain of pigs fed a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with water spinach, from 0-8 weeks.

	Treatments			
	ECL	ECL+WS	SEM	Prob
Live weight, kg				
-initial	14.0	14.7	0.97	0.619
-final	20.6	24.4	1.90	0.175
LW gain, g/day	117.9	173.0	20.35	0.072

Table 7 and **Figure 4** show the live weight gain of pigs of individual participants in the second period (8-16 weeks); in this period the live weight gains were again highest using the mixed feed of ensiled cassava leaves with water spinach, but the differences were not statistically significant (P>0.05).

Table 7. Live weight gain of pigs of individual participants fed a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with water spinach, from 8-16 weeks.

	ECL+WS					ECL alone						
	Rany	Sarum	Sokha	That	Touk	Brus	Mom	Sarong	Toul	Chanthy	SEM	Prob
Live weight, kg												
- initial	21.5	23.5	27.0	23.0	27.0	17.5	21.0	17.0	20.5	27.0	4.88	0.13
-final	39.5	39.5	40.5	40.0	44.5	29.0	30.0	22.5	36.0	42.5	7.39	??
LW gain, g/day	321.0	304.0	243.0	314.0	325.0	205.0	157.5	112.5	275.0	278.5	50.9	0.34

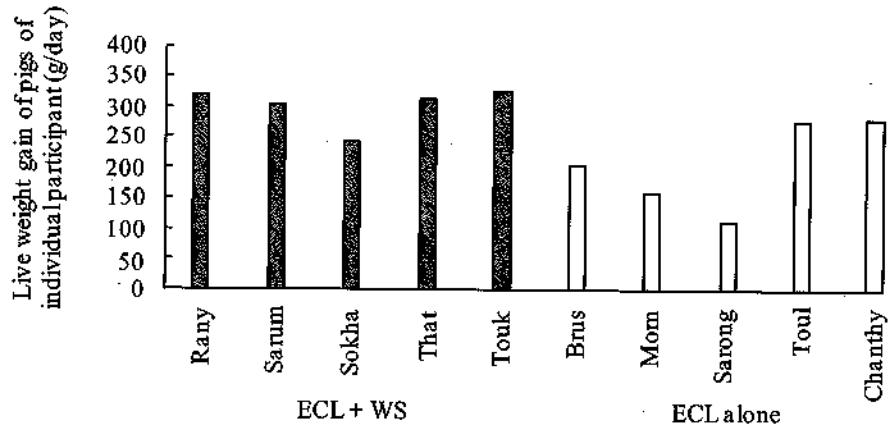


Figure 4. Live weight gain of pigs of individual participants fed a basal diet supplemented with ensiled cassava leaves alone or together with water spinach, in the second period (8-16 weeks).

Table 8 shows that the average live weight gain in this period (8-16 weeks) was significantly higher (P<0.05) in the treatment of the mixture of ensiled cassava leaves and water spinach (ECL+WS) as compared to that of ECL alone.

Table 9 and **Figure 5** show that in the total period of 0-16 weeks the effect of the two treatments on the live weight gain was similar to that in the second period, as the weight gain was higher using the mixture of ECL and WS compared with feeding ECL alone, but the differences were not statistically significant.

Table 8. Average live weight gain of pigs fed a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with water spinach, from 8-16 weeks.

	Treatments		SEM	Prob
	ECL	ECL+WS		
Live weight, kg				
-initial	20.6	24.4	1.90	0.175
-final	32.0	40.8	2.96	0.05
LW gain, g/day	205.7	301.5	23.9	0.011

Table 9. Live weight gain of pigs of individual participants fed a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with water spinach, from 0-16 weeks.

	ECL + WS					ECL alone						
	Rany	Sarum	Sokha	That	Touk	Brus	Mom	Sarong	Toul	Chanthy	SEM	Prob
Live weight, kg												
-initial	14.0	13.5	13.5	15.3	17.3	13.5	13.5	12.5	13.5	17.0	2.53	0.90
-final	39.5	39.5	40.5	40.0	44.5	29.0	30.0	22.5	36.0	42.5	7.39	0.55
LW gain (g/day)	232.5	234	249	227	249	141.5	152	90.0	192.5	225.0	46.9	0.33

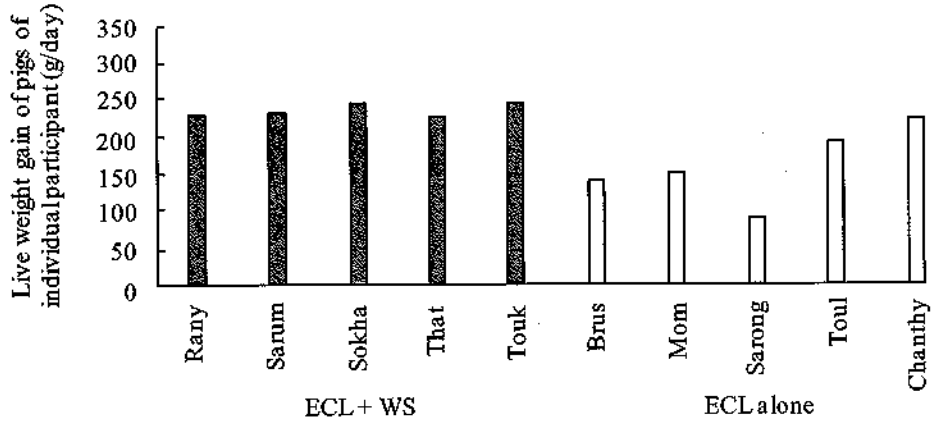


Figure 5. Live weight gain of pigs of individual participants fed a basal diet supplemented with ensiled cassava leaves alone or together with water spinach, in the overall period (0-16 weeks).

Table 10 and **Figure 6** show that the average live weight gain in the overall period (0-16 weeks) of the pigs fed with the mixed feed (ECL+WS) was significantly higher than those fed ECL alone ($P<0.05$).

Table 10. Average live weight gain of pigs fed with a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with water spinach, from 0-16 weeks.

	Treatments			
	ECL	ECL+WS	SEM	Prob
Live weight, kg				
-initial	14.0	14.7	0.97	0.619
-final	32.0	40.8	2.96	0.05
Live weight gain, g/day	160.3	238.4	19.16	0.01

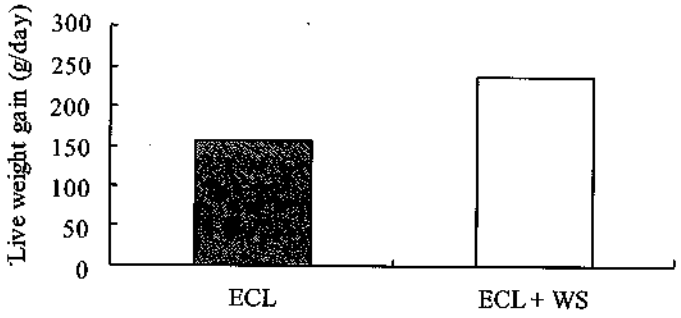


Figure 6. Average live weight gain of pigs fed a basal diet supplemented with ensiled cassava leaves alone or together with water spinach, in the overall period (0-16 weeks).

Feed Conversion Ratio

Table 11 and **Figure 7** show that the feed conversion ratio (FCR) was better ($P<0.05$) in the treatment without the water spinach during the first period (0-8 weeks), but that the FCR improved in the second period ($P<0.05$) when pigs were fed the mixture of ensiled cassava leaves and water spinach. For the total 16-week period the difference between the two treatments was not statistically significant.

Table 11. Mean values of DM feed conversion (per head) of pigs fed a basal diet of rice bran and broken rice supplemented with ensiled cassava leaves alone or together with water spinach.

	Treatments			
Weeks	ECL	ECL+WS	SEM	Prob
0-8	3.63	3.80	0.05	0.03
8-16	3.75	3.48	0.06	0.002
0-16	3.56	3.60	0.05	0.61

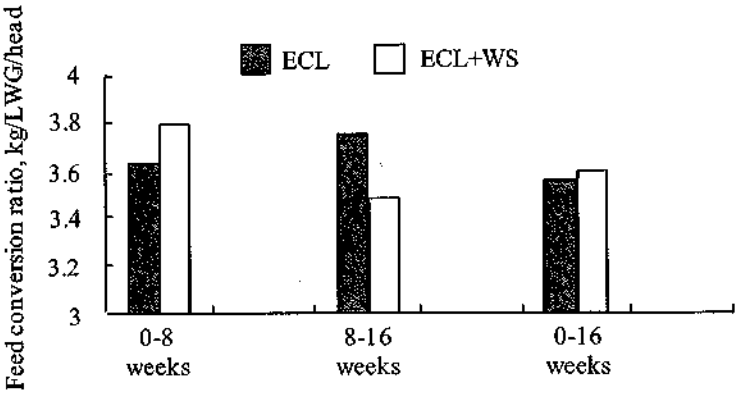


Figure 7. Feed conversion ratio of the pigs during the first, second and the total 16-week period when fed a basal diet supplemented with ensiled cassava leaves alone or together with water spinach.

Table 12 shows the fresh yields of cassava foliage in the two villages where cassava was planted by farmers who participated in the project. The farmers did not add any fertilizers. The data are only for the first harvest at 75 days after planting.

Table 12. Yield of fresh cassava foliage in Srah Takoun and Lok villages at 75 days after planting.

Area (m^2)	Total foliage production (kg)	Total foliage yield (kg/ha)	Proportion on fresh basis (%)		
			Leaves	Petioles	Stems
108	96.9	8,972	33.33	22.22	44.45
144	198.7	13,798	36.36	18.18	45.45
112	74.9	6,687	30.00	13.33	56.66
110	136.4	12,400	42.42	24.24	33.33
38.43	65.7	17,096	34.88	30.23	34.88
48.1	62.8	13,056	36.66	16.66	46.66

DISCUSSION

The feed intake of the mixed feed of ensiled cassava leaves and water spinach was better than ensiled cassava leaves alone, because the pigs consumed more rice bran and broken rice and less foliages, which could have been due to the bulkiness of the cassava leaf silage and water spinach. In the present study, the feed intake of the water spinach and cassava leaf silage was slightly lower than in the studies reported by Chhay Ty and Preston (2005a; 2005b; 2006) in which fresh cassava leaves and water spinach were fed together with a basal diet of broken rice. However, the intake of foliage as percent of total intake and the crude protein intake were both higher in the present study.

The growth rate of pigs was not significantly different for individual participants, but averaged over all participants the growth rate was higher for the mixed feed compared with the ensiled cassava leaves alone, both in the first and second period, and in the overall period. This may be because of a better digestion of the feed, and by providing the required nutrients that growing pigs need. The growth rates during the second 8-week period of this study were similar to those reported by Chhay Ty and Preston (2006), but were lower than those in the overall period (0-120days). The FCR was better in this study compared with that in Chhay Ty and Preston (2006). The growth rate and FCR using the mixed feed was higher in Chhay Ty and Preston (2005) compared with this study using the same diets; in the overall period these were 382.5 and 2.56 *vs* 238.4 and 3.60, respectively. In another study by Sorn Suheang and Preston (2005) using different levels of dry fish from 50-200 g/day with sugarcane juice or stalks with *ad libitum* feeding of water spinach, the growth rates were similar but the FCR was poorer than in this study, which used foliage and by-products only.

Growth rates and FCR of pigs fed cassava leaf silage alone was better in the study reported by Chhay Ty *et al.* (2003c) (312 g/day and 3.20) as compared to this study (238.4 g/day and 3.60), in the total 16-week period.

CONCLUSIONS

From this experiment conducted in two villages during 16 weeks we can conclude that:

Total feed intake and crude protein intake, live weight gain and feed conversion ratio were better in pigs fed ensiled cassava leaves plus water spinach as compared to ensiled cassava leaves alone.

As a result of this experiment farmers now know how to use some local feed resources, such as cassava leaves and water spinach, to feed their pigs.

ACKNOWLEDGMENTS

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THE USE OF CASSAVA STARCH FACTORY WASTE (PULP) AS FEED FOR DAIRY CATTLE BY SMALLHOLDER FARMERS IN EAST JAVA, INDONESIA

Marjuki[1]

ABSTRACT

A field survey on the use of cassava pulp as feed for dairy cattle was conducted in three dairy cattle production centers of East Java. A total of 32 small-scale dairy farmers with not more than 15 heads of cattle, and four large-scale ones with more than 100 heads of cattle were surveyed. The survey aimed to study the importance of cassava pulp as feed for dairy cattle by smallholder farmers.

Out of the total number of dairy farmers surveyed, 28 small-scale dairy farmers and three large-scale dairy farmers always used cassava pulp as additional feed for all stages of dairy cattle, except calves. The other four smallholder farmers surveyed used the pulp only sometimes during the dry season when there was a large supply of the pulp available.

Cassava pulp was periodically supplied to the farmers by cassava starch factories and in smaller quantity by traditional home-scale cassava starch industries. In addition to forages, the pulp was fed to dairy cattle in wet form and mixed with concentrate by smallholder farmers or with concentrate and tofu waste by bigger dairy cattle farmers, either with or without water added.

Most of the farmers experienced that feeding cassava pulp to dairy cattle gave some advantages in improving palatability of concentrate feed, making cattle looked more satisfied than fed concentrate without cassava pulp, and increasing the milk yield, although this feeding method slightly decreased the milk fat content. Those advantages were more important during the dry season when the availability of forages was limited. The farmers used the pulp regardless of either the HCN content or the physical condition of the pulp after having been stored for weeks in their farm, as they had never experienced any negative impact of feeding cassava pulp on cattle, including poisoning due to the HCN content of the pulp.

It was concluded that cassava pulp was potentially important as feedstuff for dairy cattle feeding by farmers. However, lack of its availability in relation to the dairy cattle population had limited the use of the pulp as feed by farmers. Increasing cassava production would be expected to improve the availability and the potential of cassava pulp being used as dairy cattle feed.

Key words: cassava, cattle, feed, pulp, starch factory waste

INTRODUCTION

Forages are naturally the main feed for wild ruminants, from which the animals get nutrients to support their live and production. This also happens in the case of intensively managed ruminant production systems, although in such systems forages are generally supplemented with concentrate feeds to improve the nutrient concentrations in the rations supplied to the animals. However, forages availability has become a major constraint in the ruminant production systems, especially for smallholder farmers due to certain conditions. The contrasting seasonal availability of forages in the wet and dry seasons is one of those conditions. During the wet season, forage is available in excess of the animals' requirements, but these same forages become scarce during the dry season. In addition, average land ownership by farmers in Indonesia, mainly in Java island, which is the most densely populated island of Indonesia, is very small, not more than 0.5 ha per farmer. The

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first priority of use of the land is for crops rather than for forage production. Almost no land is specifically used for growing fodder. Some farmers are even landless. The dairy cattle population in Indonesia is mostly concentrated in hilly upland areas around forests which is primarily for two important reasons, i.e. for utilizing the forest as a forage resource for dairy cattle, and for the lower environmental temperature, which is required for dairy cattle. However, these two reasons do no longer support the system, as the forests have been degraded in the last ten years due to illegal logging and utilization of opened forest land for crop plantations by farmers.

Consequently, the demand for non-conventional feedstuffs for use in animal diets has increased as a result of the increase in livestock production in the last few years and the decrease of the availability of feed/forage resources. Cassava pulp is one of the non-conventional feedstuffs which can be potentially used in the livestock diets. This product is produced after extraction of starch from cassava roots in the starch factories. Cassava roots produce approximately an equal amount of starch and pulp (Grace, 1977). Marjuki reported that when fresh cassava roots were completely sun-dried, they produced a dry weight of 37-45% of the fresh weight (unpublished data). Obalua (2007) also reported that dry pulp constitutes about 20% of the original weight of fresh cassava roots. Cassava pulp still contains quite high levels of starch and fiber (cellulose and hemi-cellulose), but is low in protein. It contains about 56.0% starch, 35.9% crude fiber, 5.3% crude protein (CP), 0.1% fat, and 2.7% ash on a dry matter basis (Grace, 1977). With these nutrient contents, cassava pulp has potential as an energy source feed, especially for ruminant animals. Thus, this research aimed to study the potential use of cassava pulp as feed for dairy cattle by smallholder farmers in East Java province of Indonesia.

MATERIALS AND METHODS

The research was conducted in dairy cattle production centers in Malang, Kediri, and Blitar regencies of East Java province, Indonesia, in June-August 2008. A Rapid Rural Appraisal (RRA), followed by a survey, were conducted. The RRA was aimed to get general information about dairy cattle production in the area of study. During the RRA, interviews and discussions were held with key persons including people from local livestock service offices and representatives of dairy cattle farmers (the head of farmers group). Based on the RRA data, 10 to 11 dairy cattle farmers from two villages in each regency, each rearing 5 to 15 heads of dairy cattle, and having worked for more than five years as dairy cattle farmers, were purposely randomized and sampled as respondents in the survey. The survey included direct observations, interviews and discussions with a total of 32 selected respondents with an emphasis on dairy cattle feeding practices and the use of cassava pulp as feed for dairy cattle.

A semi-structured questionnaire was prepared and used for interviewing the respondents. The main points listed in the questionnaire for the survey were dairy cattle production by farmers and their feeding practices; whether they know or not about cassava pulp as feed for dairy cattle; if they know about it, whether they use it as feed for their dairy cattle or not, and what are their reasons; if they use it, how is the feeding practice of the pulp including frequency, method and amount of feeding. According to the farmers, what is the effect of feeding such pulp on cattle performance; from where and how do they get the pulp; what is the price; and how is the supply to the farmers? The collected data were analyzed using descriptive statistics.

Attempts were also made to survey feeding practices of dairy cattle in four larger-scale dairy cattle farms, each with more than 100 heads of dairy cattle to compare with those practiced by the smaller-scale dairy cattle farmers, especially on the aspect of the use of cassava pulp as feed for their dairy cattle. In addition, a survey was also conducted among cassava starch factories in East Java.

RESULTS AND DISCUSSION

Dairy Cattle Production and its Importance for Smallholder Farmers

As in other areas or in other tropical developing countries reported by Devendra (1999), smallholder farmers in the area of study in East Java are mostly involved in mixed farming systems with crop production (mainly food and horticulture crops) and livestock production (mainly dairy cattle) as the two major agricultural enterprises. Both these enterprises are operated together and get more or less the same attention by the farmers with respect to the allocation of resources, especially labor and capital, but not in terms of land. The farmers utilize as much as possible their own family labor in the enterprices. Land owned by the farmers is mainly used for growing crops, but not for fodder plants. Food crops, mainly rice, maize and on a minor scale cassava, are grown especially to provide food for their own family consumption, while horticulture crops, including vegetables, potatoes, garlic, and onion are grown mainly for sale to provide cash income.

Dairy cattle production, especially milk, is the most important source of daily income for most farm households in the area of study. Lactating dairy cows are milked twice a day, in the morning and afternoon. Milk is then delivered to the local dairy cooperatives after every milking, through a milk collecting unit in each village. The milk is in turn delivered to milk industries by the cooperatives. The farmers get payment for milk from the cooperative every fifteen days after subtracting several costs such as for their regular saving, payment for concentrate feed, artificial insemination and health services for their cattle, and repayment of their credit in case they have credit from the cooperative. Dairy cattle also have a main function as savings, especially in the form of calves, and as a source of fertilizer in the form of manure. Recently, some farmers in Malang have established biogas plants from cattle manure supported by the local government forestry department. The biogas plants are used to supply gas for daily cooking, and are also intended to reduce the collecting of fire wood from forests by farmers, while the sludge produced by the biogas plants can be used as fertilizer.

In contrast to the small-scale dairy cattle farmers, dairy cattle production for the larger-dairy cattle farmers is the dominant enterprise with respect to resource utilization and source of income. Labor is mostly recruited with monthly payment. Some large dairy cattle farmers also function as nucleus farms who coordinate other small dairy cattle farmers.

Feeding Practices of Dairy Cattle by Smallholder Farmers

Feeds given to dairy cattle by all farmers in the area of study are in the form of concentrate feeds and forages. The concentrate feeds are bought by farmers from the local dairy cooperatives under a credit system. The forages are collected mainly from forest and agricultural fields. Some farmers grow elephant grass and leguminous shrubs/trees on their own non-arable land, especially on steep land along fences, on field banks or along boundaries. Some farmers have also a chance to rent forest land from local forestry

departments for IDR. 150,000 per ha per year (1 USD = IDR. 9,300) for growing food crops and fodder plants, especially elephant grass under forest trees, while the farmers have the responsibility to manage the land and the trees. During the wet season the fodder plants grow well and the forages are available in abundance. During this season, much of the elephant grass is too mature to be cut, and much of it is left in the fields under-utilized; when this feed is given to cattle, most parts, especially the stem parts, are refused by the cows as the stem to leaf ratio is too high. In contrast, the same forages are scarce during the dry season; hence, crop residues, such as rice straw and maize residues are collected from other areas and together with a small amounts of grass are used as feed for dairy cattle. Sometimes during the dry season, farmers also use banana stems as dairy cattle feed. However, the dry season during this year was much less intense than those in previous years, as the rains came earlier in August than in the previous years, when it started to rain in December or January. Thus, the availability of forages this year was much better than in previous years.

Cut-and-carry systems are used by all farmers in this area. Farmers never store or conserve the excess of forages available in the wet season for dry season feeding, nor do they graze their cattle as there is no rangeland available for grazing. These systems require less cash inputs by the farmers, which is suitable for smallholder farmers which generally have limited cash flow. However, the system has some disadvantages, i.e. the farmers must be pushed to collect forages every morning regardless of the weather conditions, and the systems is very sensitive to the fluctuation of feed availability. Farmers must also limit the number of cattle that can be maximally reared during the dry season.

The amount of forages given to lactating dairy cows is in the range of 30 to 40 kg/head/day, mostly in the form of elephant grass, rice straw, maize stover, sugarcane tops, and to a lesser extent, the leaves of legume trees/shrubs, and concentrate at a rate of 5 to 7 kg/head/day. The average milk yield is 8 to 9 liters/head/day.

Feeding Cassava Pulp to Dairy Cattle

In addition to the concentrate and forages, most dairy cattle farmers also used cassava pulp as additional feed for their dairy cattle. Out of the 32 smallholder and four larger dairy cattle farmers surveyed, 28 and three of the respective types of dairy cattle farmers, always used cassava pulp as additional feed all through the year, for all growth stages of dairy cattle except for calves. These farmers received a continuous supply of the pulp from suppliers, or directly from producers, as they bought the pulp under contract systems. The other four smallholder farmers did not use the pulp as feed for their dairy cattle at the time of the survey; these latter farmers used the pulp only sometimes when they received a supply of the pulp from a supplier.

Cassava pulp was periodically supplied to the smallholder farmers mostly by suppliers; however, for larger farmers they had direct access to the cassava starch factories to get cassava pulp. The farmers bought the pulp directly or via suppliers under contract systems. By this buying system, the supplier or the larger farmers got priority from the cassava starch factory to get cassava pulp, especially when cassava pulp production was less. This happened especially during the wet season when there wass less cassava root production.

As reported by many authors (Howeler *et al.*, 2001; IITA, 2005) cassava pulp is also commonly used as feed by farmers in Indonesia, especially for ruminant animals. The

pulp is fed to dairy cattle by smallholder farmers in wet form at 9.2 $\pm$ 3.6 kg fresh cassava pulp per head per day. The pulp is fed as a mixture with concentrate and some water, twice a day just before milking. Larger dairy cattle farmers feed the pulp mixed with concentrate and tofu waste, either without or with some water added. Dried cassava pulp powder is also commonly used as a component of concentrate for ruminants up to 5 to 10%.

Most of the farmers experienced that feeding cassava pulp to dairy cattle had some advantages in improving the palatability of concentrate feed, making cattle look more satisfied than when fed concentrate without cassava pulp added, and increasing the milk yield, even though this feeding method slightly decreased the milk fat content. Those advantages were more important during the dry season when the availability of forages was limited; hence, cassava pulp played a role in partially substituting for forages. The farmers used the pulp regardless of either the HCN content or the physical condition of the pulp, as they had never experienced any negative impact of feeding cassava pulp on the cattle's conditions, including poisoning due to the HCN content of the pulp. Except, some dairy cattle farmers in a certain village of Malang regency stated that feeding too much cassava pulp, more than 20 kg wet pulp per head per day, could cause hoof lessions. For this reason, farmers in this area did not feed cassava pulp to their dairy cattle.

Cassava Starch Factories as Producers of Cassava Pulp in East Java

Based on their scale of production, cassava starch factories can be placed into three categories, i.e. industrial (large) scale cassava starch factories, medium-home-scale, and small-home-scale cassava starch factories. In industrial-scale cassava starch factories the processing of the roots into starch is completely mechanized, starting from washing and rasping/grating whole cassava roots, as well as extracting and drying the starch, except for the sorting and cutting the stem part of some roots, which is done by hand. Cassava starch is the main product and pulp is a by-product. Each factory in this category can process 100-500 tonnes of cassava roots per day. In certain periods, July to September or October when cassava production is at its peak, some factories operate 24 hours per day with more or less double the amount of cassava roots being processed. However, during times of lower cassava root production, especially during the rainy season, some factories stop processing. There are at least 11 cassava starch factories of this scale in East Java i.e. in Lumajang (2 factories), Pasuruan (1), Malang (4), Kediri (2), Jombang (1), and Ponorogo (1). Two of the cassava starch factories belong to PT. Sorini Agro Asia Corporindo, Tbk., the regional industry which produces sorbitol using cassava starch as the raw material.

In the home-scale cassava starch factories the processing of cassava roots into starch involves the sorting, peeling, washing and grating of cassava roots, followed by sieving, settling and drying the starch. Medium-home-scale cassava starch factories partly use machinery including for grating of cassava roots and sieving the starch. The other processes, including sorting, peeling, and washing cassava roots are done by hand and the drying of starch is done through sun-drying. Medium-home-scale cassava starch factories process 3-5 tonnes cassava roots per day. Small-home-scale cassava starch factories use mostly manpower in the processing of cassava roots to produce starch and pulp. The only equipment used in this process is a machine for grating the cassava roots. Home-scale cassava starch production is mostly done by families in groups with 5-10 members per group. Each group is coordinated by a family. Mostly, the members work for the coordinator in processing cassava roots to produce starch. The coordinator provides cassava

roots as raw material and a communal machine for grating cassava roots, while the members have the responsibility to process the cassava roots to produce starch, starting from peeling and grating the cassava roots, extracting and drying the starch. The members have to submit dried cassava starch back to the coordinator and they receive as payment 5 kg of dry starch for every 20 kg of dry starch which they have submitted to the coordinator. In addition, the members can also take home the peelings, culled small-size cassava roots, and the pulp, which are all produced from the cassava roots they have processed. The latter products are used to feed their livestock, as almost all the members rear sheep, goats or cattle; if not, they will sell these products to other farmers.

These home-scale cassava starch producers can be found especially in Blitar and Kediri regencies. In Jugo village, Kesamben district, Blitar, these home-scale cassava starch producing units were started in the 1960s. In the 1970-80s almost all families in this village were operating these cassava starch factories, but now only 19 families still remain, including three families as coordinators. Each family processes 200 to 300 kg cassava roots every day, almost throughout the year. Cutting the stem part and the end tip of roots, culling small roots and peeling are done by hand in the evening using a special knife made from a bicycle wheel steel (**Figure 1**) to remove the whole peeling including a small part of the root flesh. Then, early in the morning they start rasping/grating the roots using a communal rasping/grating machine provided by the coordinator; this is followed by sieving of the starch, which is completely done by hand. A part of the rasped root mass is put in batches on a screening cloth fastened on four poles and hung like a bag above the drain leading directly to the sedimentation tanks. Sometimes a bamboo basket is used to support the screening cloth. The rasped roots are then vigorously stirred and pressed using both hands. Some water is periodically added to the rasped roots, and then stirring and pressing are continued. This step is repeated several times and is finished when the water draining from the screening cloth is clear. Once finished, the pulp is collected from the batch and put in another bag. The batch is used again for the same process of another part of the rasped cassava roots. After screening out the starch water from all rasped cassava roots, the starch water is left in the sedimentation tank for a few hours to sediment out the starch. When the starch has sedimented, the supernatant water is carefully removed from the tank and the sedimented wet starch is collected for sun drying. This processes is very similar to that reported by Grace (1977).

The cassava pulp produced by the starch factories is commonly marketed directly to dairy cattle farmers or via distributors, either in the fresh (wet) form with 75-80% moisture content, or as dry pulp with 12-15% moisture content. Fresh cassava pulp costs IDR. 250,000 per tonne, equal to US$ 26.3, while the dry pulp costs IDR. 900,000 per tonne, equal to US$ 94.7. Fresh cassava pulp is only locally marketed due to the problem of high transport cost as this fresh product contains a lot of water. Dry cassava pulp, on the other hand is regionally marketed. Some distributors of cassava pulp put their promotion on the internet.

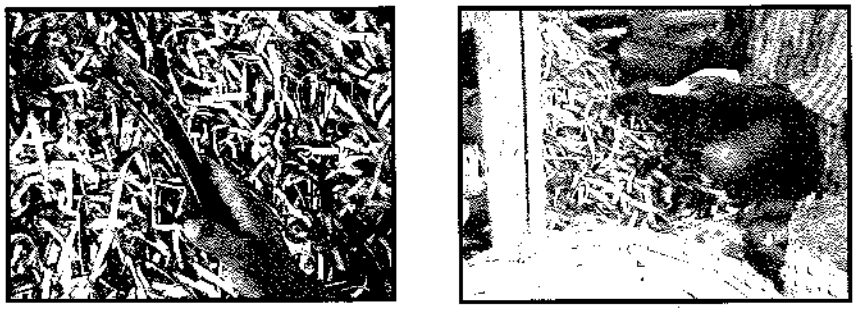

Figure 1. A special knife made from bicycle wheel steel used for peeling cassava roots in home-scale cassava starch factories

CONCLUSIONS

Cassava pulp is potentially important as a feedstuff for dairy cattle. However, lack of its availability in relation to the dairy cattle population has limited the use of the pulp as feed by farmers. Increasing cassava production would be expected to improve the availability and the potential of cassava pulp being used as dairy cattle feed.

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NEW PROGRESS IN PROCESSING CASSAVA INTO STARCH AND BIOPLASTICS

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ABSTRACT

Cassava has been well-recognized as an important staple food crop and industrial crop worldwide, and has continuously developed to serve the various markets' needs. In this paper, ongoing research on the utilization of cassava for different commercial requirements is summarized.

With the collaboration of the private sector, the production technology for low-cyanide cassava flour through a mechanized process has been developed in cassava starch factories. Low-cyanide flour (<10 mg HCN equivalent/kg dry weight) can now be produced commercially from high cyanide varieties.

In addition, through a collaborative agreement with CIAT, amylose-free cassava starch, developed through conventional breeding at CIAT, has been characterized in terms of some physico-chemical properties in comparison with other commercial amylose-free starches and normal cassava starch. This information is very useful for future development of modifying and utilizing amylose-free cassava starch to serve various industrial needs.

Moreover, under the collaborative program with the National Institute of Advanced Industrial Science and Technology (AIST) in Japan, the production of optically pure lactic acid (stereospecific D or L type), a feedstock for producing polylactic acid – an eco-friendly biodegradable plastic made from cassava starch and chips – has been investigated. The productivities of different fermentation processes (batch *vs* fed-batch; sequential *vs* simultaneous saccharification and fermentation) have been evaluated. Currently, an energy-saving process for lactic acid production from cassava starch is being developed.

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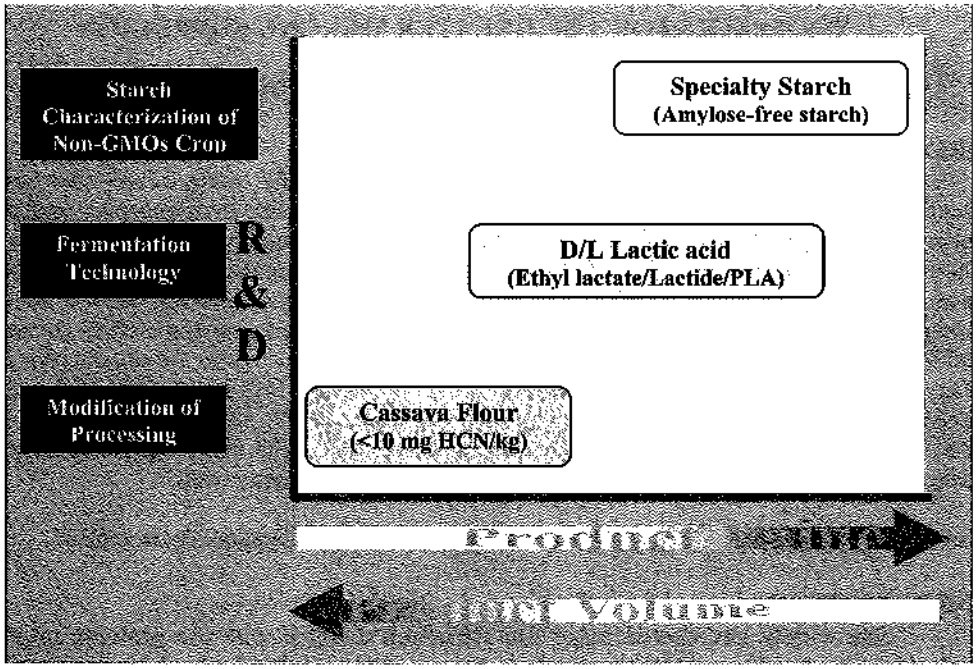
Starch Characterization of Non-GMOs Crop
Fermentation Technology
R & D
Modification of Processing
Specialty Starch
(Amylose-free starch)
D/L Lactic acid
(Ethyl lactate/Lactide/PLA)
Cassava Flour
(<10 mg HCN/kg)
Product with
Volume

CASSAVA-BASED BIO-ETHANOL AND BIO-CHEMICALS: FUTURE PROSPECTS FOR THE GREATER MEKONG SUBREGION

Samai Jai-In[1], *Sittha Sukkasi*[2], *Boonyawan Yoosuk*[2)], *Ukrit Sahapatsombut*[2)] *and Piyarath Saosee*[2)]

ABSTRACT

Bio-ethanol is an alternative and environmentally friendly energy source that has many promising prospects. Its potential benefits in the economic, social, environmental, and national energy-security aspects make bio-ethanol an attractive developmental pathway for many countries. The countries in the Greater Mekong Subregion (GMS) are no exception. Most countries in the GMS have competitive production capacities of cassava, which is a major feedstock crop for bio-ethanol production. Even though the national biofuels policies and legislation in some GMS countries are still far from comprehensive, many bio-ethanol production-related activities are already taking place. Many of the projects are on a large scale and involve foreign investment. Besides bio-ethanol, cassava-based biochemicals also have high potential in the GMS, although there are still many challenges to the implementation of biochemical's production. With many supporting factors, the future prospects of bio-ethanol and bio-chemicals in the GMS look promising.

Keywords: cassava, bioethanol, biochemicals, Greater Mekong Subregion, development.

INTRODUCTION

The widely anticipated fossil fuel depletion coupled with the growing urgency to curb greenhouse gas emissions has led to a sharpened focus on alternative and environmentally friendly energy sources such as biofuels. Bio-ethanol is one of the leading biofuel candidates. It can be used to replace gasoline, its fossil-based counterpart, in engines. Unlike gasoline, however, bio-ethanol is renewable, since it can be produced from plants, such as cassava and sugarcane. This prospect is attractive to many countries, since domestically produced bio-ethanol can help reduce their reliance on foreign oil, and consequently increase their national energy security. Moreover, their reduction in oil imports can translate to a significant cut in the national trade deficits.

Concerning the environmental aspects, bio-ethanol has a potential to be "greener" than gasoline. Bio-ethanol is produced from plant feedstock, and these plants capture carbon dioxide when they grow. The captured carbon dioxide can offset the carbon dioxide emitted from engines in which bio-ethanol is used. Thus, the total carbon emissions of bio-ethanol over its life cycle can be neutral, or even negative. Nevertheless, the carbon balance of bio-ethanol also depends on the intermediary stages of its life cycle, including the production, storage, and distribution stages.

Production of bio-ethanol and the planting of feedstock crops can also provide job opportunities and additional income revenues, especially in the agriculture sector. These socio-economic benefits are particularly valuable to poor farmers in rural communities of developing countries. The additional option to grow crops for bio-ethanol feedstock also

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helps diversify market opportunities for the farmers. Furthermore, they may be able to produce bio-ethanol themselves and use it for their own fuel needs.

The Greater Mekong Subregion, or GMS, is an example of a group of developing countries that can benefit from the above-mentioned prospects of bio-ethanol. The GMS consists of six countries sharing the Mekong river: Cambodia, Lao People's Democratic Republic, Myanmar, Thailand, Vietnam, and Yunnan province and Guangxi Zhuang Autonomous Region of the People's Republic of China. The GMS is home to about 325 million people and has vast natural resources, including timber, minerals, coal, petroleum, and water from the many rivers (ADB, 2009).

This paper focuses on future prospects of bio-ethanol and bio-chemicals in the GMS. In particular, cassava-based bio-ethanol and bio-chemicals are discussed. The current production of cassava is reviewed to show the potential capacities for producing bio-ethanol and bio-chemicals. The biofuel policies of each GMS country, which may help indicate the opportunities and future development directions, are also summarized. Also, existing industrial-scale bio-ethanol activities are surveyed. Finally, beyond the prospects of bio-ethanol, those of the lesser-known bio-chemicals are discussed as well.

Cassava Production in the GMS

Every country in the GMS is active in cassava production. According to the Ministry of Agriculture, Forestry and Fisheries of Cambodia, the country currently harvests more than two million tonnes of cassava a year, but exports much of it to Thailand and Vietnam. The yield can range from 40 tonnes per hectare in Battambang and Kampong Cham to 10 tonnes per hectare in Kampong Speu (Sovan, 2008).

In China, the province of Guangxi produces 5.2 million tonnes of cassava a year, accounting for 65% of China's total production (China knowledge, 2008).

The amount of cassava production in Lao PDR is unclear. Nonetheless, there was a report that a cassava-based ethanol plant of Hainan Yedao in Hainan, China, would utilize 4,498 hectares in Laos to provide feedstock for the plant (Biofuels Digest, 2008a).

Thailand is the world's number one exporter of cassava. The current yield is 23 tonnes of cassava roots per hectare per year, with an expected total production of 27 million tonnes of fresh roots (FAOSTAT, 2010).

In 2007, Vietnam ranked 13th in terms of cassava production in the world. In Vietnam, cassava is used both for domestic consumption and for export. In South Vietnam, cassava is used as raw material for cassava processing factories, which have a total capacity of one million tonnes of fresh roots per year. Fluctuating prices and marketing problems, as well as rather slow adoption of new varieties and improved technologies are the main constraints in cassava production in Vietnam (Bien *et al.*, 2007).

Biofuels Policies in the GMS

The levels of comprehensiveness of national policies and legislation on renewable energy and biofuels in the GMS vary significantly from country to country. In many countries, foreign private investments can help accelerate the development of biofuels, but, nevertheless, can also have adverse effects, for example on the local environment and population, if proper regulations and policies are not in place.

The Cambodian government considers renewable energy as a means to reduce poverty by providing electricity to the poor in rural areas (ECFA, 2007). It has conducted

several renewable energy development studies, many of which in cooperation with international assistantship, such as that from JICA (Japan International Cooperation Agency) (ECFA, 2007). Wind, micro-hydro, biogas and biomass are the types of renewable energy that the government considers most seriously, for rural electrification purposes, while biofuels are not as much highlighted (OCM, 2002). Nonetheless, a plan aimed directly at development of biofuels for transportation is being drafted. This plan incorporates the inputs from the private sector, NGOs, and international organizations (ECFA, 2007). Due to lack of funds, the government's plans for biofuels development might take a long time to be fully realized.

Biofuels have quickly become significant in China's energy policy. In 2006, the National Development and Reform Commission (NDRC) set a target of meeting 15% of transport energy needs by 2020, which translates to a requirement of 39-44 million tonnes of biofuels, or about 40 times the amount of China's 2005 biofuel production (USDA, 2006; Wang, 2006). Like many other governments, the Chinese government is concerned by the debate on the conflicts between food and energy. In June 2007, the central government banned the use of grain crops to produce ethanol, limiting biofuel production to non-grain energy crops. In April 2008, five provinces were identified as the most suitable locations for non-grain ethanol projects, based on yam, cassava and sweetpotatoes (Schwartz, 2008). Fuel ethanol is now used in ten Chinese provinces, including Jilin, Liaoning, Heilongjiang, Henan, Hebei, Anhui, Shandong, Jiangsu, Hubei, and Guangxi (China Knowledge, 2008).

Lao PDR lacks a comprehensive, institutionally supported, approach to the planning and implementation of a biofuels program. The Laotian government's energy policy focuses primarily on the development of low-cost indigenous fuel, such as coal, development of hydropower, pricing policies, and institutional capacity (UN ESCAP, 2007). Even though a formal national level policy on biofuels has yet to be developed, the Laotian government is pushing to support the commercial production of appropriate oil crops as a substitute for expensive oil imports. For example, the *Resolution of the VIIIth General Congress of the Lao Revolutionary Party, 2006 -Section 5.1. : Development Plan for Industrial Sectors* encourages industry sectors and government agencies to invest in biodiesel and bio-ethanol production. The Ministry of Energy and Mines has a policy on fuel saving and promotion of biofuel production, which sets a target for biofuels to account for 5% of total fossil fuel consumption by 2015.

Thailand's biofuel programs started over 30 years ago, following the successful example of the Royal Projects under His Majesty the King's patronage. Bio-ethanol and biodiesel were promoted through Cabinet resolutions in 2000 and 2001, respectively, as part of seven strategies for sufficiency development set forth by the Ministry of Energy (Secretariat of the Cabinet, 2000). A range of biofuels-related measures was also issued, including investment promotion, biofuel standardization legislation, fuel tax incentives, vehicle specifications, and tax incentives, research and development programs, and logistics and transportation of biofuels. Targets are set to increase the share of renewable energy from 0.5% in 2003 to 8% by 2011. About 2% is to be sourced from biofuels, which translates into 2.4 million liters/day of bio-ethanol and 3.0 million liters/day of biodiesel in the transportation sector. In April 2008, the Ministry of Energy launched a long-term strategic plan targeting the transportation sector for the next 15 years and set a target of 1.9% from combined bio-ethanol and biodiesel usage in 2011, and 14% by the year 2022.

The Vietnamese government has recently shown a new commitment to biofuel development. In November 2007, a Biofuel Master Plan was issued, outlining development of biofuel projects to 2015, with an outlook to 2025, with the following quantitative goals. By 2010, 100,000 tonnes of E5 and 50,000 tonnes of B5 will be produced, in order to meet 0.4% of domestic fuel demand. By 2015, 250,000 tonnes of bio-ethanol and biodiesel will be produced, which will be sufficient to produce 5 million tonnes of E5 and B5 combined, in order to satisfy 1% of domestic fuel demand. By 2025, 1.8 million tonnes of bio-ethanol and biodiesel will be produced, in order to satisfy 5% of domestic fuel demand. The planned total budget over nine years (2007-2015) is US$ 15.3 billion (259.2 billion VND). In addition, the Master Plan also promotes international cooperation and technology transfer, with a goal to launch 20 international cooperation projects in biofuels. Following the announcement of the Master Plan, many organizations, including government offices, educational institutes, private companies, and NGOs, have launched their own initiatives related to their respective areas of expertise and responsibility.

Existing Bioethanol Activities in the GMS

In Cambodia, the MH Bio-Energy Group, a South Korean company, has invested $30 million in what is claimed to be Cambodia's first bio-ethanol plant that will start operating in Oct 2008. Located in Kandal province, the plant has a planned capacity of 130-300 tonnes of ethanol per day. It will require up to 50,000 hectares of cassava. The company buys dry cassava chips from Kampong Cham and Battambang provinces, at the prices between $130 and $180 a tonne. To ensure adequate supplies, the company plans to grow cassava on 8,000 hectares of land it owns in Kampong Speu province, employing about 10,000 people (Sovan, 2008).

Guangxi is the first province in China to use cassava instead of grain to produce ethanol. The first project was the Guangxi Beihai (Northern Sea) project, a development of the Guangxi Zhongliang Bio-energy Co., Ltd., planned to produce 200,000 tonnes of fuel ethanol per year (Schwartz, 2008). Starting April 1, 2008, fourteen cities in Guangxi began selling and using ethanol for vehicles, but the supplying of ethanol to vehicles had to stop on April 15, 2008, because the rapid increase in the cost of the feedstock has made the project unprofitable (Schwartz, 2008).

In Laos, Mitr Phol Group, as of February 2010, has 8,000 hectares of sugarcane plantation (Bangkok Post, 2010). Meanwhile, in July 2008, Hainan Yedao of China announced the construction of a 30 Mgy (million gallons per year) cassava-based ethanol plant in Hainan province (Biofuels Digest, 2008a). The $51 million project would utilize 4,498 hectares in Laos to provide feedstock for the plant.

In Thailand, as of 2008, there were a total of nine commercial ethanol plants (mostly from molasses and one from cassava) with a total capacity of 1.575 million liters per day. In addition, eleven additional ethanol plants (from both molasses and cassava equally) were being constructed with an additional capacity of 2.4 million liters per day (Jai-In, 2007). In the future, cassava will play an important role in ethanol production. As several investors are planning to expand production, it is expected that by the end of 2010, Thailand's ethanol production capacity may reach 6-8 million liters/day, and the production capacity is expected to rise further if the market response in the next few years are positive. Bio-ethanol is currently available as transport fuels in various blends, including E10 91 RON, E10 95 RON, and E20 blends. In response to the high price of petroleum, the

government also approved a plan to introduce E85 (85% blend of ethanol with gasoline) for flexible fuel vehicles.

In Vietnam, as of June 2008, Biotekhnologia Corp., a Russian company, was planning to team up with PetroVietnam and Metropol to produce bio-ethanol in Vietnam. The plant's capacity may reach 100,000 tonnes of biofuel per year, using cassava, byproducts from rice processing, and sugarcane as feedstock (Kommersant, 2008).

Prospects of Cassava-based Bio-chemicals

The world's biochemical industry is set for rapid growth, at least in the next two decades. Products derived from bio-chemicals exhibit many distinct advantages over those from petrochemicals. The current world scenario is the abundance of raw materials. While the major portion of raw materials will be used in food applications, a significant amount will be used in the production of bio-chemicals and their derivatives.

The cost factor is working in favor of bio-chemicals. Given high petroleum prices, it will be more expensive to make the same products from petroleum. This makes it very attractive to use bio-chemicals in many applications from the economic point of view. Furthermore, petroleum, being a nonrenewable resource, cannot compete with the renewable bio-chemicals in term of dependability of supply of raw materials.

Environmental issues are also major factors. Products derived from bio-chemicals are more readily biodegradable and this works very much in the favor of bio-chemicals.

The Asian countries are poised to play a greater role in the world's biochemical industry. It is logical that the production of the basic bio-chemicals should be close to the raw materials. The Asian countries have entered a critical phase in the development of the biochemical industry. However, the next phase of development would be in the further downstream processing of the basic bio-chemicals into value-added derivatives and consumer products (Soon, 2000). Innovation is the lifeblood that enables all companies to participate in this industry where consumer needs are evolving. Niche solutions are required to suit the diverse lifestyles and attitudes of Asian consumers. The Asian market itself is a huge one. With expanding economies in many Asian countries and a better standard of living, the demand for bio-chemical-based products is set to increase significantly in the foreseeable future (Dale, 2003; Bachmann, 2005).

In Thailand, for example, the products made from bio-based raw materials currently represent only a minor fraction of the output of the chemical industry. The efforts to shift the prime resource base of the industry from non-renewable to renewable feed stocks have recently gained momentum, primarily because of the rapid rise in the costs of crude oil and an increasing concern about the depletion of these resources in the near future. In the chemical industry, the use of fossil-based raw materials is often exempted from environmental taxes, leading to much weaker incentives for increasing the use of renewable feedstock. A crucial issue to be addressed would be the expansion of the existing policy instruments that favor the increased use of renewable carbon dioxide neutral feedstock in the chemical sector. The production of plant biomass in Thailand is vast and is more than enough to match the demand for the co-production of chemicals, materials and fuels with the demand of foods and feeds. Currently, non-used land should enable the further expansion of the biochemical industry, provided the technological and economic limitations are overcome.

Thailand has a variety of agricultural products with an annual export value of at least 200 billion baht. However, most are exported as primary products, which are of low value. If these products enter a processing process enhanced by innovations in technology, the new products could be of higher value. This will also provide substantially higher value-added economic activities, besides promoting production in agriculture and forestry.

While the export value is increasing, Thailand has witnessed a growing value of imports of raw materials and semi-finished goods for industrial use, even in categories in which Thailand has the capacity to produce on its own. This is particularly true in extracting or synthesizing chemicals from the cassava starch and sugar sectors. Molasses and cassava have been mostly processed into animal feed of low value. With a systematic development process, these products could spearhead the adding of value to Thailand's agricultural goods. However, development of innovative and sustainable process technologies will be needed for realizing the shift to bio-based production of chemicals. **Figure 1** shows some of many possible biochemicals from glucose.

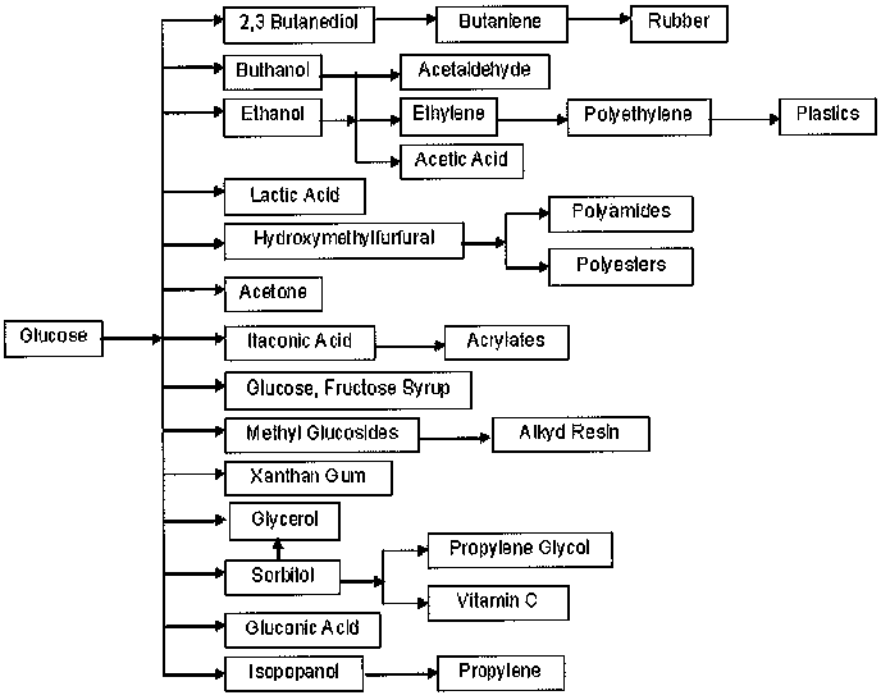

Figure 1. Some of many possible biochemicals from glucose
***Source:** Salazar, 1980.*

Besides the feedstock issue, there are some other challenges. For instance, there is a need to adopt costly imported advanced technology; thus, it is not suitable for small and medium businesses. Also, there is high competition in raw-material supply. The structure of the biochemical industry is similar to that of the petrochemical industry, so the biochemical business should be promoted in the same way as the petrochemical one in terms of investment and tax cuts. The government should establish a federal agency that is

in charge of monitoring demand and supply of agricultural products, such that the demand of the products is in equilibrium with supply, and there are adequate raw materials for all domestic uses. Finally, current governmental inspection procedures for some types of biochemical substances do not facilitate production sectors. It is clear that governmental assistance is needed to promote the biochemical industry.

CONCLUSIONS

The prospects of cassava-based bio-ethanol and bio-chemicals in the Greater Mekong Subregion are promising. Every country in the GMS is currently active in cassava production. Some are even among the top world exporters. Although a significant portion of the current capacities is dedicated to export, cassava production dedicated solely to bio-ethanol production also exists.

In the policy context, even though many GMS countries still lack comprehensive national biofuels policies and legislation, the governments are very receptive to biofuels and other forms of renewable energy. Evidence shows that bio-ethanol production activities are already taking place on a commercial scale in many countries. With the current trend, the cassava-based bio-ethanol production in the GMS will likely expand in the near future. Bio-chemicals production from cassava faces many challenges now, but the future prospects still look promising, given the factors that are supporting bio-ethanol production.

With proper planning and management, bio-ethanol and bio-chemicals can contribute toward the sustainable development of the GMS in many ways, economically, socially, politically, and environmentally.

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PROCESSING OF CASSAVA INTO BIOETHANOL

Klanarong Sriroth[1,2] and Kuakoon Piyachomkwan[3]

ABSTRACT

Cassava (*Manihot esculenta* Crantz) is a very promising feedstock for production of ethanol, the renewable biofuel for the foreseeable future. This excellent drought-tolerant crop provides great benefits in terms of crop cultivation, including being able to grow in infertile soils and under dry conditions, while having low input requirements. Fresh roots with very high starch contents can be readily transformed into dried chips for prolonged shelf-life. Various forms of cassava, including fresh roots, dried chips and extracted starch can be used industrially for bioethanol production. When cassava is used, the starch has to be converted to sugar by liquefying enzymes (i.e. α-amylase) and then by saccharifying enzymes (i.e. gluco-amylase) to glucose prior to yeast fermentation to ethanol. In this paper, the production technology of ethanol from cassava chips is summarized; also the production data of ethanol from dried chips using the Simultaneous Saccharification and Fermentation, (SSF) process is reported.

Keywords: Thailand, cassava, feedstock, ethanol production.

INTRODUCTION

The energy crisis is one of the most concerning issues of every country. Among various types of energy resources, the fossil oil is the most important one being used mainly as liquid fuel for transportation. With the depletion of fossil fuel reserves, high oil prices and the threat of global warming, biofuels, including bio-ethanol and biodiesel, have been introduced as an alternative source of energy in many countries, including Thailand, where the main energy source is imported crude oil. Ethanol is recognized as more environmentally friendly and is a renewable energy source, which can be obtained from biomass feedstock. It can be a partial or complete substitute for gasoline, depending on automobile designs. Bioethanol can be produced by yeast fermentation of sugars derived directly from sugar-rich feedstock or from the acid and/or enzyme hydrolysis of starch and lignocellulosic feedstock. In Thailand, two feedstocks, i.e. molasses and cassava chips, are commonly employed for bioethanol production. Since molasses consists mainly of sucrose, glucose and fructose, it can be fermented directly by yeast. In contrast, the production of bioethanol from cassava includes more steps including feedstock preparation and enzyme hydrolysis of starch to glucose prior to fermentation of glucose to ethanol by yeast. The purification by distillation and dehydration to obtain anhydrous ethanol is then applied after fermentation is completed. This paper provides a brief summary of the existing technology of bioethanol production from cassava, which is presently practiced in Thailand, as well as some potential improved technologies.

RAW MATERIAL PREPARATION

Various forms of cassava, including fresh roots, dried chips and extracted starch, can be used industrially as the feedstock for bioethanol production. The most important

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one is dried chips. Commercial starches can be used, but are not cost-effective, while fresh roots are available mainly at certain times of the year, but are very cheap during the harvest season. The decision of feedstock types depends on their availability and the price, as well as the plant design and processing equipment. When cassava is used to produce bioethanol, it must be processed to sugar syrup. Initially, starch is hydrolyzed by liquefying enzymes (i.e. α-amylase), and then by saccharifying enzymes (i.e. gluco-amylase) to glucose. Glucose is readily fermented to ethanol by yeast. To improve the efficiency of enzyme hydrolysis, the material should be milled to small pieces and the starch is cooked to gelatinization, i.e. a process that disrupts the ordered structure of starch granules. The process of raw material preparation is feedstock type-dependent.

1. Chips

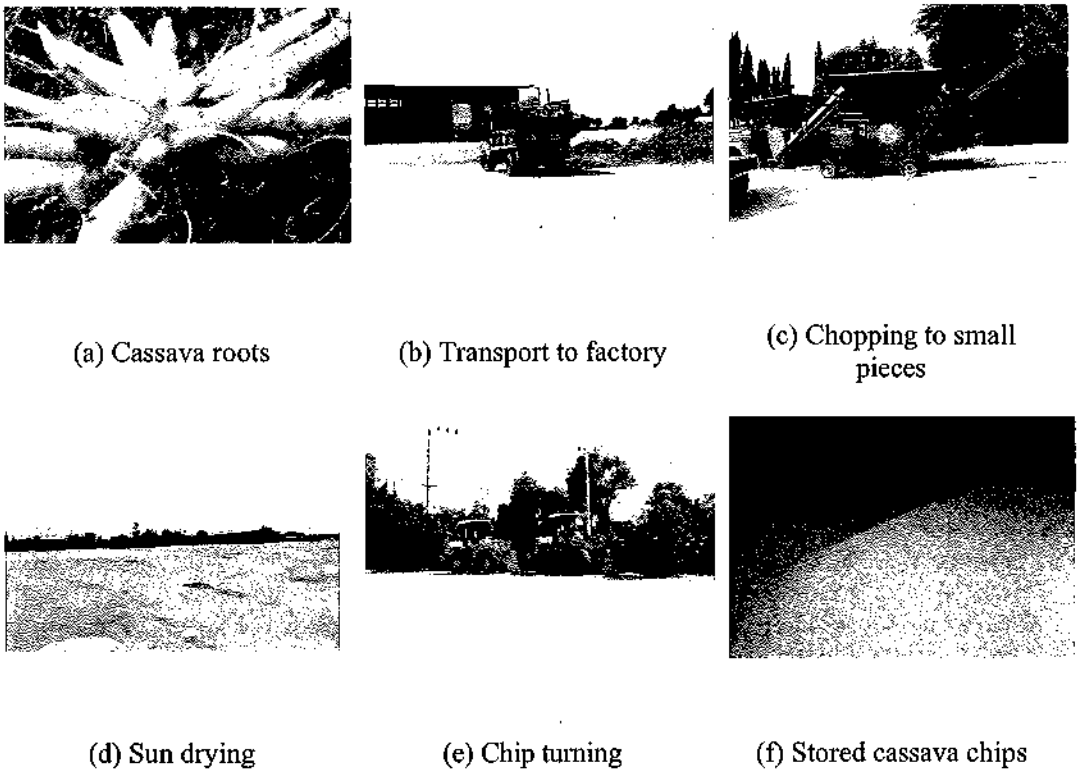
a) Production of cassava chips

Fresh roots are very perishable due to their high moisture content (60-70%). After being harvested, roots are readily converted to dried chips using only a simple chopping machine, as shown in **Figure 1c**. After chopping into small pieces, the chips are sun-dried on a cement floor. Dried chips are easy to transport and can be stored for a year in the silo (**Figure 1f**). The chips should be dried properly, having a moisture content not greater than 14%, to prevent mold contamination. Furthermore, care must be taken when storing the dried chips as heat can be generated and may accumulate inside the heap. Therefore, the warehouse should have a good air circulation system to prevent overheating and burning of chips. When used, the chips have to be transferred, using the method of first-in and first-out, to the process line. Dust is produced, resulting in starch loss as well as severe air pollution. In addition to starch and moisture content, the sand and soil contamination in dried chips is another important issue concerning the quality of chips. Sand and soil contaminants need to be removed before the bioethanol production process.

b) Preparation of cassava chips for the bio-ethanol production process

There are two processes for preparing cassava chips for bio-ethanol production, namely the "Dry Milling" and "Wet Milling" process. In the Dry Milling process (**Figure 2**), the chips are transferred to the hopper and a metal and stone detector. The chips are then milled and sieved to obtain a fine powder. Coarse powders are remilled. The fine powder is mixed with water and the slurry with some fibrous materials then proceeds to the enzyme hydrolysis stage, i.e. liquefaction. Most of the currently existing factories in China and some factories being installed in Thailand apply this dry milling process as it uses less equipment and investment. The dry milling process is suitable for batch fermentation.

In the Wet Milling process (**Figure 3**), the starch slurry is prepared from dried chips by modifying a typical cassava starch production process. Chips are milled and mixed with water. The starch is then extracted from chips by a series of extractors. After depulping, the starch slurry is then concentrated by a separator and subjected to a jet cooker for liquefaction. Currently, only a few plants are using this process, because this process requires a high investment and also generates high starch losses in the solid waste. However, the wet milling process is more controllable and can be practically applied to a continuous fermentation process.



(a) Cassava roots (b) Transport to factory (c) Chopping to small pieces

(d) Sun drying (e) Chip turning (f) Stored cassava chips

Figure 1. Process of making dry cassava chips from fresh roots.

2. Fresh roots

During the cassava harvest season (Nov-March), fresh roots are amply available and cheap. These are a very good raw material for bio-ethanol production. Similar to dried chips, there are two processes for preparing cassava fresh roots for bio-ethanol production, namely the "With fiber" and "De-fiber" process.

In the "With Fiber" process (**Figure 4**), the roots are transferred to the root hopper, in which soil and sand are removed by root peelers. The roots are then washed and subjected to the chopper and rasper. The puree of milled roots is then slurried without fiber removal and used for liquefaction. This process requires less equipment and investment cost and is recommended for batch-type fermentation.

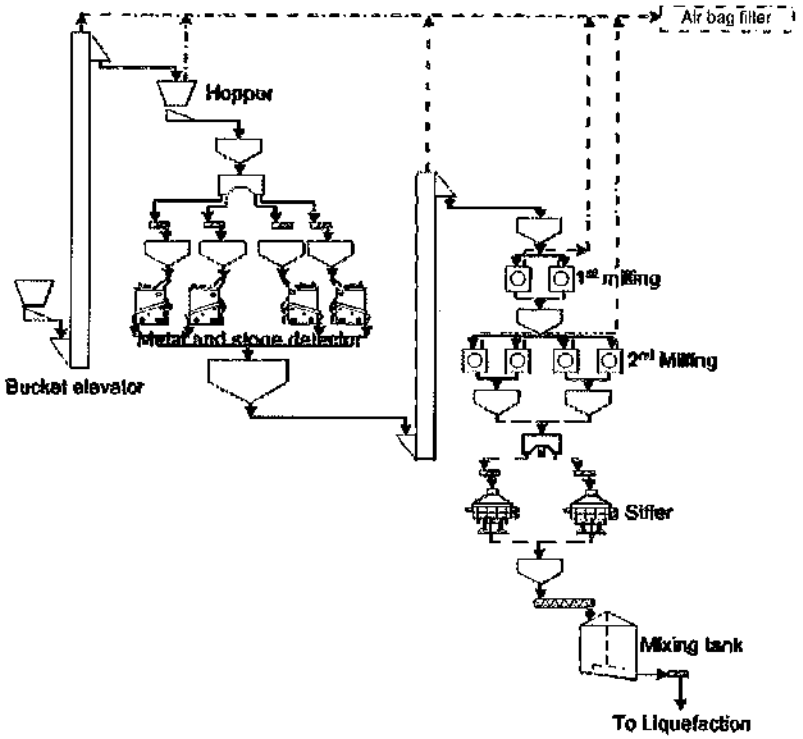


Figure 2. Chip grinding and slurry preparation in the dry milling process

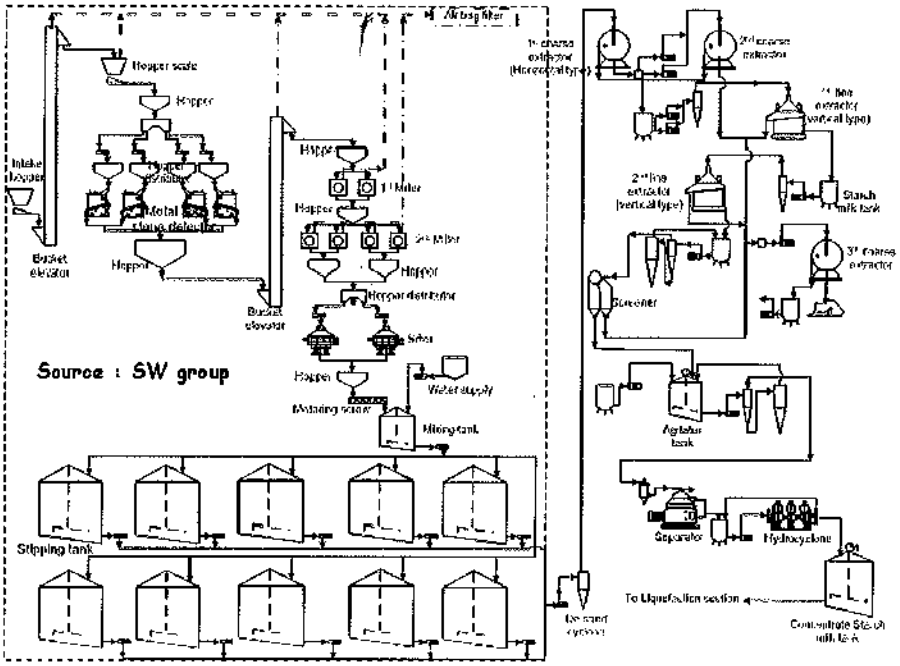


Figure 3. Chip grinding and slurry preparation in the wet milling process.

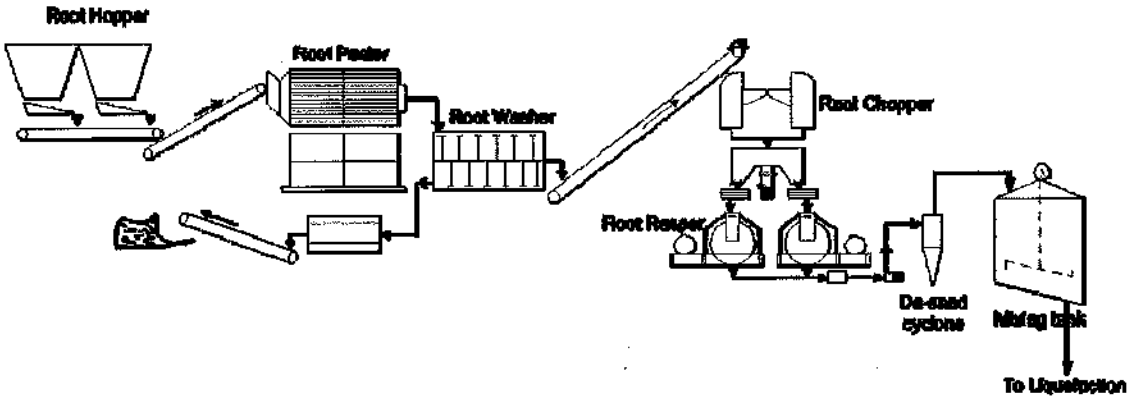


Figure 4. "With fiber" process - starch slurry preparation from fresh cassava roots.

In the "De-fiber" process (**Figure 5**), the starch slurry is prepared from fresh roots by modifying a typical cassava starch production process. After desanding and washing, roots are subjected to the chopper and rasper. The pulp is removed and starch is extracted by a series of extractors. After depulping, the starch slurry is then concentrated by a separator and subjected to a jet cooker for liquefaction. This process requires a higher investment cost and also generates high starch losses in the pulp. However, the wet milling process is more controllable and can be readily applied to current well-established technology of ethanol production from other materials. It is also practical for use in the continuous fermentation process.

THE BIO-ETHANOL PRODUCTION PROCESS

The ethanol production from starch-containing feedstock such as corn in the USA has long been a questionable issue with regards to the negative value of the net energy (Pimentel, 1991). In the conventional process (**Figure 6**), a lot of energy must be used to cook the starch (gelatinization) at a temperature greater than 90°C prior to liquefaction (**Figure 7**) and to maintain the liquefied mash at 55-60°C for further saccharification by industrial enzymes (mainly α-amylase and gluco-amylase). This enzyme process is required to hydrolyze starch into fermentable sugars which is much more effective when the starch is cooked. The production process used nowadays can reduce processing time and energy consumption significantly by accomplishing the saccharification and fermentation simultaneously; this process is called "Simultaneous Saccharification Fermentation", or SSF process.

The process of ethanol production from cassava, either in the form of dried chips or fresh roots can be analogous to that of corn grains (moisture content ~13%). The chips and roots after being prepared to slurry with water (with or without fiber separation) can be cooked to gelatinize the starch for facilitating enzymatic hydrolysis. The high viscosity of the mash induced by starch gelatinization and swelling of small particles is prevented by cooking in the presence of liquefying enzymes, i.e. α-amylase. Other viscosity reducing enzymes can also be applied to improve the mixing and cooking efficiency. The process design of fermentation and distillation can be similar to that of corn with only a slight modification in processing parameters. After fermentation, the ethanol of the mash is

concentrated by steam distillation and the further dehydration of concentrated ethanol (95%) to anhydrous ethanol can be achieved by a molecular sieve.

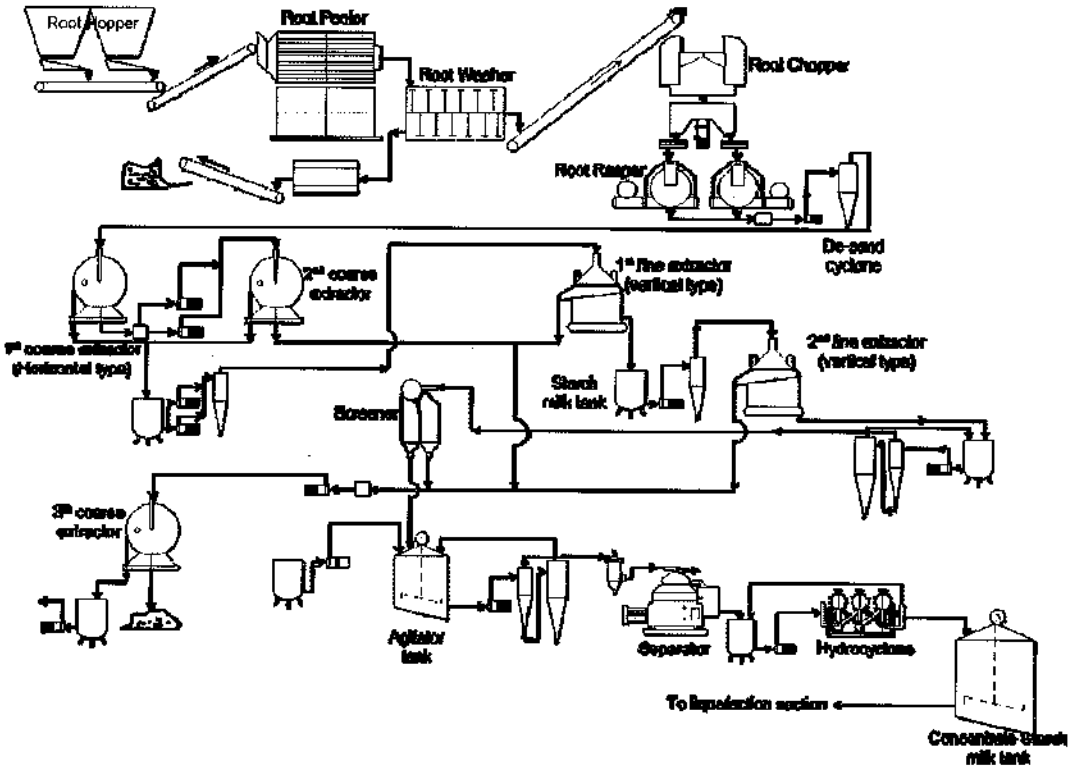


Figure 5. "De-fiber" process - starch slurry preparation from fresh cassava roots.

The material balance during ethanol production (150,000 liters/day) from dried cassava chips is estimated as shown in **Table 1**. The conversion ratio of feedstock to ethanol is about 2.5:1 for dried chips, and 6:1 for fresh roots, i.e. 2.5 kg dry chips or 6 kg fresh roots to produce 1 liter of ethanol. These conversion factors are starch-quantity dependent. The Thai government has targeted that by the implementation of the ethanol policy, the root price of cassava should stabilize at 1.70 baht/kg which will benefit both farmers and the industrial sector. With this aim, the raw material cost for 1liter of ethanol from cassava is estimated to be 10.20 baht/liter (1 USD = 34 baht). Other production costs of ethanol from cassava are shown in **Table 2**. Combining both raw material and processing costs, the total production cost of ethanol from cassava is estimated to be 19.00 baht/liter. A comparison concerning the production cost and energy balance of ethanol from cassava with other feedstock is shown in **Tables 3** and **4**, respectively.

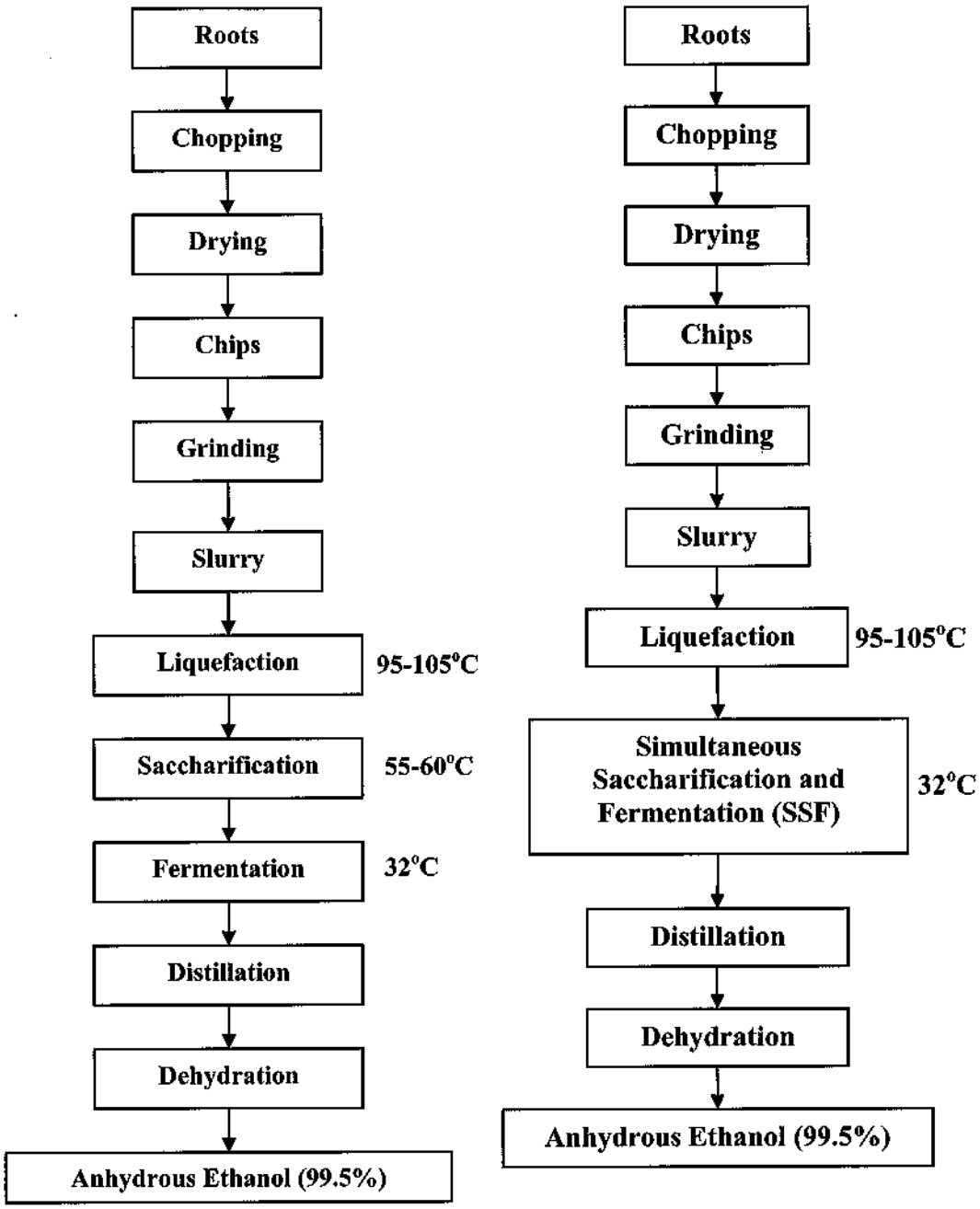


Figure 6. Conventional (left) and SSF (right) process of ethanol production from fresh roots of cassava.
Note: The temperatures used depend on the enzyme and yeast types.

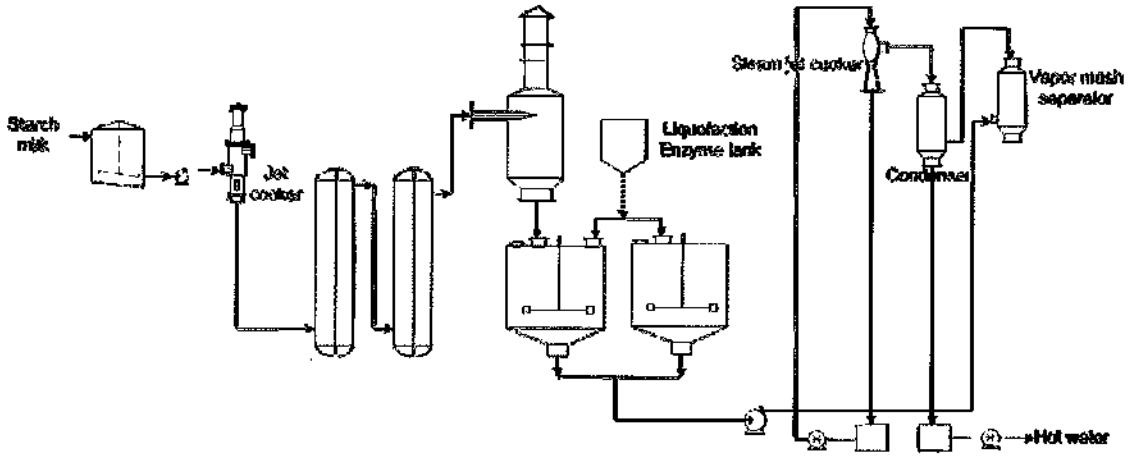


Figure 7. Liquefaction of cassava slurry (less fiber).

Table 1. Material balance of ethanol production from dried cassava chips.

INPUT / OUTPUT	Quantity and Quality	
	Quantity	Quality
INPUT		
1. Raw material (tonnes/day)	350-370	- moisture content 12-16% - starch content 64%
2. Water (m^3/day)	1,200-1,500	-
3. Reagents		
- Yeast powder (kg/day)	20-80	-
- Enzymes (kg/day)	20-800	-
- Other reagents (kg/day)	1,000-5,000	-
4. Energy		
- Electricity (kW-h/day)	25,000-47,000	-380 V 50 Hz
- Stream (tonnes/day)	300-500	-pressure 3-10 bar
OUTPUT		
1. Ethanol (liters/day)	150,000	- TISI Standard (640-2533)
2. Carbon dioxide (tonnes/day)	100-120	-
3. Fusel oil (liters/day)	300-600	-
4. Stillage (m^3/day)	1,400-1,600	- total solids 5-7% - COD 40,000-60,000 mg/l - BOD 15,000-35,000 mg/l
4.1 Wet cake (tonnes/day)	100-200	20-30% Total solids
4.2 Waste water (m^3/day)	1,200-1,400	- 2-4% total solids - COD 20,000-40,000 mg/l - BOD 10,000-30,000 mg/l

***Source**: Sriroth et al., 2006.*

Table 2. Production costs of ethanol from cassava in China and Thailand.

Description	China (US$/kl)[a]	Thailand (US$/kl)[b]
Materials and chemicals	200.5	31.8
Energy	13.2	108.8
Wage and addition	5.3	14.4
Depreciation	15.8	35.9
Maintenance	10.5	1.8
Miscellaneous	2.6	7.1
Fiscal charges	13.2	28.5
Land rent expense	0.3	-
Selling expense	2.6	14.4
Waste treatment	-	14.4
Insurance	-	1.8
Water	-	-
Total cost (US$/kl)	264.0	258.9

Sources: *[a] adapted from Zhang et al., 2003 with the conversion 460 l ethanol/tonne of cassava chips*
[b] Sriroth et al., 2006 with the conversion 400 l ethanol/tonne of cassava chips and excluding the raw material cost; 1US$ = 34 baht

Table 3 Production costs (excluding the raw material costs) of ethanol from various crops used in different countries.

Countries	Production costs (US$/liter)
United State [a]	0.25 from corn
Brazil [a]	0.20 from sugar cane juice and molasses
Australia [a]	0.30 from C molasses
EU [a]	0.48 from sugar beet
	0.43 from wheat
Thailand [a]	0.24 from cassava
Thailand [b]	0.259 from cassava

Sources: *[a] Licht, 2006; [b] Sriroth et al., 2006.*

Table 4. Energy balances of biomass fuels produced from different crops.

Crop	Biomass fuels	Energy input (GJ/ha)			Output (GJ/ha)	Output: Input
		Agricultural production	Conversion to ethanol	Total		
Sugar beet	Ethanol	22	34-67	56-89	118	2.1-1.3
Maize	Ethanol	26	18-36	44-62	62	1.4-1.0
Winter wheat						
a)without straw	Ethanol	22	16-33	38-55	57	1.5-1.0
b)with straw	Ethanol+straw	26	22-39	48-65	147	3.1-2.3
c)whole plant	Whole plant	26	7	33	195	5.9
Rapeseed						
a)without straw	Oil+meal	17	4	21	72	3.5
b)with straw	As a)+straw	24	8	32	147	4.6
Sweet sorghum	Ethanol	20	Bagasse	20	104	5.2
Sugar cane	Ethanol	13-14	27-34	40-48	179	3.7-4.5
Cassava	Ethanol	11	37	48	56	1.2

Source: *Licht, 2006.*

PROCESSING WASTES

1. Solid waste

Though the solid waste from cassava chips is not as valuable as DDGS (Dry Distillers Grains With Solubles) from corn, it can be utilized in many ways:

- To produce biogas: this waste treatment has been practiced in China. The solid waste in the thick slop is sent to the Biomethylation process. The results were successfully reported by Dai *et al.* (2006).
- To feed the burner: Another alternative design for the Thai factories is that the solid waste from the thick slop is separated by a decanter so that the moisture content is around 50% of total solids (50% H_2O). This semi-dry solid is then used as the feedstock for fuel production by direct burning.
- To supplement in animal feed: By our experience in a pilot plant, the separation of the solid waste can be simply accomplished prior to distillation, resulting in a high yield (40%). The solid cake still contains some ethanol; therefore, the loss of ethanol must be considered. This solid can be used as animal feed fillers.

2. Liquid waste (stillage)

The most important characteristic of the liquid waste from ethanol plants using cassava as feedstock is the color. Whilst the slop from molasses is very dark in color, cassava liquid waste has a light yellowish color with a lower COD (40,000-60,000) and BOD (15,000-35,000) values. The characteristics of waste water from the ethanol factories using cassava and molasses as feedstock are shown in **Table 5**. In consideration of this, the waste water from the cassava-based process is much easier to handle than the waste obtained from the processing of molasses. This implies less investment and operational costs. In China, cogeneration of biogas obtained from waste water treatment in the ethanol

factory operating with cassava is reported to be able to cover all electricity needs in the ethanol production process and still have some excess to supply to the grid (Dai *et al.*, 2006).

Table 5. Characteristics of stillage obtained from ethanol factories in Thailand.

	Factory using cassava chips	Factory using molasses
1. Chemical Oxygen Demand (COD, mg/l)	40,000-60,000	100,000-150,000
2. Biological Oxygen Demand (BOD, mg/l)	15,000-30,000	40,000-70,000
3. Total Kjedahl Nitrogen (TKN, mg/l)	350-400	1,500-2,000
4. Total Solids (mg/l)	60,000-65,000	100,000-120,000
5. Total Suspended Solid (TSS, mg/l)	3,000-20,000	14,000-18,000
6. Total Volatile Solids (mg/l)	20,000-40,000	N.A.
7. Total Dissolved Solids (mg/l)	50,000	105,000-300,000
8. pH	3.5-4.3	4.1-4.6

***Source**: Sriroth et al., 2006; N.A = not applicable*

CONCLUSIONS

Cassava is a very effective photosynthesizing plant that can absorb solar energy and convert it, with use of inexpensive resources, i.e. carbon dioxide (CO_2) and water from the environment, to an invaluable substance of carbohydrate, i.e. starch. Starch has long been known as a good energy source of plant, animal and mankind. Nowadays, starch can economically be converted to another form of energy, i.e. ethanol as liquid fuel. Furthermore, the ethanol industry from cassava will induce an enormous demand for fresh roots which will help stabilize the root price and make farmers more confident to invest in the crop. This is also synergistic to the ethanol plants as the productivity of cassava roots will increase and be sufficiently supplied to both existing and new-coming producers. Moreover, the high starch-containing roots are easy to handle as feedstock for ethanol production by being readily converted to dried chips. The processing cost of ethanol from cassava feedstock is also competitive, with a great advantage of cost-savings in the treatment of wastes.

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FUEL-ETHANOL MARKET ASSESSMENT AND THE POTENTIAL ROLE OF CASSAVA IN BIOFUEL PRODUCTION IN THAILAND

Surapong Charoenrath[1]

ABSTRACT

In Thailand, there are two main crops used in producing ethanol, i.e. sugarcane and cassava. These are available in large quantities and in the past have mostly been exported. Other crops can also be converted to ethanol, but this is not economically viable. Cassava is a natural alternative to sugarcane, because it has an ample supply and prices were low. It could be grown even in low-fertility soils. Many ethanol plants now under construction plan to use cassava as their feedstock. The reason that this has not yet happened is that cassava has currently a strong export demand. The range of uses of cassava is very wide, as an ingredient for production of animal feed in the form of pellets and chips, to flour, starch and degradable plastics. This has resulted in marked increases in the price of cassava products in early 2008.

The Thai government has decided to increase cassava production mainly by increasing yields while maintaining the acreage planted with cassava. Currently, about one million hectares of land are being used for cassava. The total production should reach 26-27 million tonnes a year. The yield in 2004 was 20.28 t/ha and reached 22.92 t/ha in 2007. The total production costs per hectare has increased steadily because of rising tractor plowing costs and labor wages in harvesting. The fresh root price in 2007 was very high at 2,400 baht (US$ 75.97) per tonne for roots having 30% starch. The reason for the high cassava price is the recent high demand for cassava roots and cassava-based products, both within the country and overseas, particularly in China. High prices of other feed crops, such as maize and barley, in the rest of the world have made cassava particularly attractive. Cassava has been used as feedstock in some ethanol plants in Thailand but because of strong demand from other processing industries, the increasing root price has become a serious problem for the ethanol industry.

A comparison of the economic returns using cassava or sugarcane in 2007 indicate that the net profit per hectare for cassava was lower than that for sugarcane. However, the price of cassava received by farmers, was only two-thirds of the price set by the government under the loan scheme. Under these circumstances, sugarcane production is likely to persist and molasses will be available for ethanol production. However, with these high cassava prices the ethanol industry will find it unattractive to use cassava as feedstock. The Siam Ethanol Company has already indicated that it cannot operate economically at a cassava root price of more than 2.00 baht (US$ 0.06) per kilogram. In all, sugarcane seems to be a more logical choice than cassava under present conditions in Thailand.

Thailand has come a long way toward a biofuel development program in which energy crops are produced and converted into a source of energy for transportation. The biofuel policy was formulated and revised several times. Looking at biofuel crops, priority should be placed on sugarcane and oil palm in the production of ethanol and biodiesel. Cassava is also a viable alternative, except that it has multiple other uses and for that reason the price this year reached an all-time high. There is a need for greater research and development efforts in energy crops, especially cassava and oil palm. Areas of interest are varietal improvements, effects of irrigation and good farm management practices. Strong government support is also needed to encourage farmers to grow these crops and obtain higher yields at lower costs in order to satisfy the increasing demand, which in turn will reduce prices. This will make cassava more competitive as a feedstock for the bio-ethanol industry.

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INTRODUCTION

For half a century, Thailand has been involved in the adoption of crops as a renewable energy source to replace fossil fuel, in order that the country would be less dependent on imported oil for survival. The efforts were, however, less than continuous, since the price of imported fuels has fluctuated greatly, and has not been on a continuous upward path. Lately, when the oil price continued their upward trend, due to a number of factors, political or otherwise, the country realized that the time of cheap oil had already passed, and that there was a need to develop a national program to deal with an era of expensive oil imports. Since Thailand has a strong agricultural base, and oil and starchy crops are the natural alternative source of energy, a biofuel program was formulated and its implementation started to take shape.

The national biofuel policy is rather straight forward, as is its program for implementation. Only when it was going into full swing, it was realized that there were several loopholes and shortcomings, both on the production side and on the side of the end-users, particularly the automobile industry. Crop production did not increase to any appreciable extent; because of this, conflicts arouse about the allocation of feedstock resources to satisfy the multiple demands for food, feed and fuel. Government authorities were unaware of such conflicts and very much indulged in the responsibilities entrusted to them. The national biofuel development program did not truly recognize that it needed a common integrated approach from all stakeholders in order to achieve any degree of success. Besides, the automobile industry was not receptive to the government's call for early adoption of biodiesel and gasohol to partially replace fossil fuels. The automobile manufacturers felt that, while they had to avoid the destabilizing oil price spiral as manifested in 2007-2008, they did not like to be compelled to adjust their engine specifications to accommodate new energy sources. Major physical alterations were also required for petrol stations to offer new lines of bio-energy sources, such as biodiesel and gasohol of different octane contents.

This paper will assess what has been achieved and analyze the bottlenecks which must be overcome if the biofuel policy is to be effective, and responsive to the country's wide-ranging needs. The basic question is whether we can sacrifice food security for our need for bioenergy. Somehow, a delicate balance must be stricken in terms of policy, and in the course of program implementation.

MARKET OUTLOOK

Energy Consumption and Demand

In Thailand, the primary sources of energy are derived from fossil fuels such as crude oil, natural gas, and coal, as well as hydro-power and others. The contribution from each energy source can be seen in **Figure 1**, with oil being the largest source of supply at 47%. Natural gas has gained its prominence of late and accounts for 33%. Coal is heavily used in generating electricity and in heavy industries, and accounts for about 14% of the total supply. The energy supply must satisfy the demands in various economic sectors. The two largest sources of demand can be found, like in many other countries, in the industry and transportation sectors, which account for 38% and 36% of the total demand, respectively. **Figure 2** shows the percentage of energy demand by industry, transportation, households and business, and agriculture.

The final forms of energy demand are in petroleum products, electricity, coal and natural gas. Sixty percent is in the form of petroleum products, simply because they are widely used in the industry and transportation sectors. Another 21% is in the form of electricity, which is mainly consumed by the household and business sectors and to a lesser extent by industry. The country was still dependent to a large extent on oil imports, taking into account that the proportion between imports and total consumption in oil equivalent was over 60% in 2002-2006. The value of crude oil imports went up from 287 billion baht or US$ 6.67 billion in 2002 to 750 billion baht or US$ 19.77 billion in 2006.

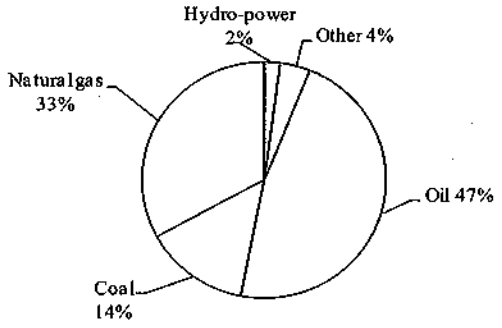

Figure 1. Contribution from primary energy sources to meet the total energy demand in Thailand, 2007.

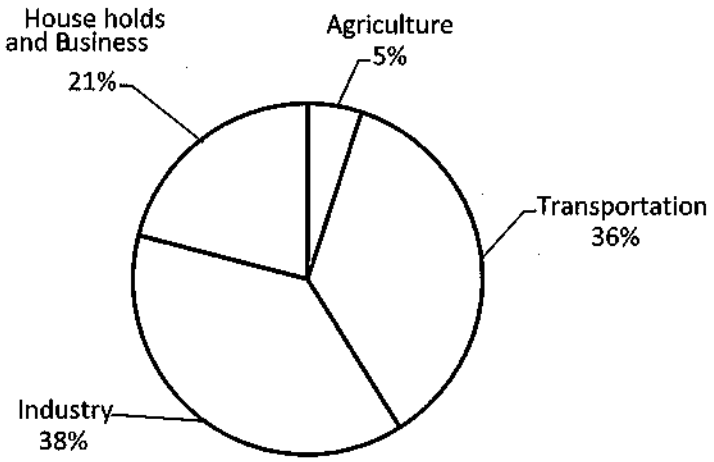

Figure 2. Percentage of energy demand by economic sectors in Thailand, 2007.

In 2003, renewable energy was only 0.5% of total energy consumption. With government efforts, coupled with the participation of the private sector and the public as a whole, it has risen to 4% in 2006. Currently, the target is set at 8% for 2011, which comprises 1% in power generation, 4% in heat process and 3% in the transport sector, basically through biofuels. Power generation draws renewable energy from biomass, biogas, wind and solar sources, which in 2006 provided 2,061 MW and will increase to 3,251 MW in 2011. In biofuels, the government aims to increase the use of ethanol from the existing 0.4 million liters a day to 3.0 million liters a day by 2011.

Ethanol Production and Demand

Since transportation consumes more than a third of total energy requirements, the government has taken the initiative to introduce alternatives to fossil fuels. There are other sources of power such as electricity and hydrogen to run automobile engines, but these hybrid cars are still in an experimental stage and their costs are much higher than conventional ones. With the introduction of gasohol 91 and gasohol 95, the octane booster MTBE will be replaced with 10% of ethanol, and the demand for gasoline in the forms of benzene 91 and benzene 95 in the period of 2008-2011 is expected to decrease sharply. This is due partly to the government regulations on the blending of gasoline, and partly to the government's decision on pricing differentials between gasoline and gasohol, which has recently widened from 1.50 baht or US$ 0.05 to 4.00 baht or US$ 0.13 per liter, making gasohol considerably cheaper than benzene of the same octane number. Gasohol 95 is even cheaper than benzene 91. Thus in 2011, we can expect a diminishing demand for benzene 91 and benzene 95, as shown in **Table 1**. The level of consumption of benzene 95 is expected to fall from 0.99 million liters a day to 0.72 million liters a day between 2008 and 2011. As for benzene 91, it will probably disappear entirely by 2011 Consumption of gasohol 95 will increase from 8.89 million liters a day to 9.50 million liters a day during the same period while consumption of gasohol 91 is expected to grow nearly four times in four years to the level of 12.02 million liters a day.

Initially, raw materials used in producing ethanol are mainly drawn from molasses, a by-product of sugar mills. In the past, alcohol in the beverage industry has been produced from molasses and its production has always been tightly controlled under government monopoly. Sugar production has remained stagnant over time and hence molasses. Since four-fifth of cassava produced is exported, the government has projected a steady increase in domestic cassava consumption for conversion into ethanol over the 2008-2011 period. **Table 1** indicates that in 2008 only 20% of ethanol will be produced from cassava, but by 2011 the proportion will rise to 50%, which will increase the requirement of cassava as raw material for ethanol to 2.57 million tonnes at the end of the period.

The production of ethanol in Thailand is dependent on two major kinds of raw materials, i.e. molasses and cassava. At present, most ethanol plants use molasses to produce ethanol, with an exception of the Thai Nguan factory, located in Khon Kaen, which has a capacity to produce 130,000 liters of ethanol a day from cassava fresh roots, as shown in **Table 2**. There are a total of nine fuel-ethanol plants in operation, with a combined capacity of 1.26 million liters a day. The actual production is about 0.98 million liters a day, which is in line with the current demand for gasohol.

Table 1. Expected demand for benzene and gasohol, from 2008 to 2011, in Thailand and the raw materials used for production of the needed ethanol.

		Quantity Demand			
Item	Unit	2008	2009	2010	2011
Benzene 95	mil.l/day	0.99	0.89	0.80	0.72
Gasohol 95	mil.l/day	8.89	9.05	9.21	9.50
Gasohol 95 (E20)	mil.l/day	0.25	0.58	0.90	1.23
Benzene 91	mil.l/day	7.63	5.69	3.57	0.00
Gasohol 91	mil.l/day	3.27	5.69	8.32	12.02
Total ethanol	mil.l/day	1.27	1.59	1.93	2.40
Raw material use					
-molasses	%	80	70	60	50
-cassava	%	20	30	40	50
Raw materials					
-molasses	mil.t/year	1.48	1.62	1.69	1.75
-cassava	mil.t/year	0.54	1.02	1.66	2.57

[1)] Conversion rates for molasses and cassava are 250 and 170 liters ethanol/tonne, respectively.
Source: *Pongphiroldom, 2007.*

Table 2. Ethanol factories in operation in 2007.

		Capacity (liters/day)	
Name of plants	Feed stock	Registered	Actual production
Porn Wilai	Molasses	25,000	-
Thai Alcohol	Molasses	200,000	114,488
Thai Agro Energy	Molasses	150,000	120,964
Thai Nguan	Cassava	130,000	-
Khon Kaen Alcohol	Sugarcane/Molasses	150,000	140,630
Petro Green (Chiyapum)	Sugarcane/Molasses	200,000	153,726
Thai Ethanol	Sugarcane/Molasses	100,000	86,572
K.I. Ethanol	Sugarcane/Molasses	100,000	101,434
Petro Green (Kalasin)	Sugarcane/Molasses	200,000	260,710
Total		**1,255,000**	**978,824**

Source: *Pongphiroldom, 2007.*

Nevertheless, there is a glut of ethanol in storage, both at the production site and at the oil refineries. By the end of 2008, more ethanol plants will start to operate, this time using mostly cassava as the feed stock. This stems from the situation Thailand faced in the past few years, when sugar prices in the export market were low and domestic prices of cassava were so low that they needed government intervention in the form of a loan support scheme. **Table 3** indicates that eight of the ten plants currently under construction will use cassava or cassava/molasses as the feedstock; this corresponds to 80% of the total capacity of these new plants. The situation on feed stock began to change and already the industry felt the pinch in January 2008, when cassava root prices had nearly doubled as compared to a year ago.

Table 3. List of ethanol plants under construction in 2008.

Name of plants	Feed stock	Registered capacity (liters/day)	Expected date of operation
I.E.C. Business Partner	Cassava	150,000	-
Fah Khuan Tip	Cassava	60,000	-
Ekarat Pattana	Molasses	200,000	Mar 08
Rachaburi Ethanol	Cassava/Molasses	150,000	Mar 08
Thai Rung Ruang	Sugarcane/Molasses	120,000	Apr 08
E.S. Power	Cassava/Molasses	150,000	Apr 08
Sima Inter Products	Cassava	150,000	Q2/08
Sup Tip	Cassava	200,000	Q1/08
P.S.C. Starch Products	Cassava	150,000	Q1/08
T.P.K. Ethanol	Cassava	340,000	Q3/08
Total		**1,670,000**	

Source: Pongphiroldom, 2007.

Characterization of the Resource Base and Its Productive Potentials

Thailand is rich in agricultural resources. It is true to say that in the past agriculture has expanded through deforestation. Much of these natural resources, along with their biodiversity, have been sacrificed for the spectacular growth in agriculture and in the farm sector. The forest in much of the cassava growing areas has been destroyed nearly completely, and the potential for further development must be found in utilizing more effectively the present existing farmland. Fortunately, Thailand's resource base extends across various farming activities, from staple foods like rice and fish, to tropical fruits and vegetables. The major factor underlying the success of the farm sector is probably due to human resources, both at the technical level and at the farm household level. Skilled manpower training in secondary and tertiary education has produced an excellent human resource base with strong specialization in research and development activities. The drive to lift themselves out of poverty, coupled with government support, has compelled many farmers to readily adopt new improved technologies, such as higher yielding crop varieties, use of fertilizers and irrigation, and better farm management practices.

In Thailand, there are three main biofuel crops. For production of ethanol, sugarcane/molasses and cassava are the two leading crops. They are available in large quantities and in the past these crops have been mainly used for export. Other crops can also be converted into ethanol, but they are not economically viable, as other alternative uses for these crops offer higher returns. Maize, for example, at present commands a very high price, due to the huge demand for conversion into ethanol in the USA, leaving less for export to the rest of the world. It is also a major ingredient of animal feed in the Thai livestock industry and cannot be easily substituted. Sweet sorghum had a dismal record in Thailand as a feed crop, and its re-entry as a bio-energy crop is doubtful.

As a bio-ethanol feedstock cassava was a natural alternative to sugarcane, because there was an ample supply and prices were low. It can easily be grown even in low fertility soils. Many of the ethanol plants now under construction will draw their feed stock from

cassava. But a fact that has been ignored is that cassava is in great demand abroad. The crop has multiple end-uses, ranging from simple animal feed in the form of pellets and chips to starch and degradable plastics. Thus, the demand for cassava extends far beyond ethanol. This has resulted in marked price increases for cassava in early 2008. The government found it challenging to increase yield and production by controlling the acreage planted with cassava, for fear of economic inefficiency. We would expect total production of cassava to increase through the expansion of acreage and greater use of inputs, when the price of roots is attractive enough. The cassava industry will likely be faced with a situation in which either the traditional overseas markets are to be retained or a new domestic market propelled by ethanol producers is to be created.

The Fact Sheet of Sugarcane

There were about 200,000 farm households growing sugarcane in the country. The planted area was around one million hectares, producing 60 million tonnes a year. The yield fluctuated over time and did not display an appreciable increase. **Table 4** shows important statistics about sugarcane production from 2004 to 2007. The cost of production per hectare rose from 22,888 bath or US$ 568.36 in 2004 to 36,450 baht or US$ 1,054.69 in 2007.

Table 4. Basic fact sheet for sugarcane.

	Unit	2004	2005	2006	2007
Farm households	number	223,213	223,213	223,213	223,213
Planted area	mil.ha	1.12	1.07	0.97	1.01
Production	mil.tonnes	65.0	49.6	47.7	64.4
Yield	t/ha	57.9	46.4	49.4	63.7
Production costs	US$/ha	568.36	600.17	743.47	1,054.69
Exchange rate	baht/US$	39.37	40.26	37.93	34.94
Sugar production	mil.tonnes	6.99	5.17	4.84	6.72
Domestic consumption	mil.tonnes	2.18	2.48	2.28	2.07
Exports (sugar)	mil.tonnes	4.6	3.04	2.24	4.42
Farm price	US$/tonne	9.14	12.91	17.61	19.76

Source: OAE, 2008.

About a quarter of the sugar produced was consumed domestically and the rest was exported. The price of sugarcane was 683 baht or US$ 19.76 per tonne in 2007 and it is not likely to increase much in the next few years. The National Sugarcane and Sugar Board operate under the law on sugarcane and sugar. It supervises and regulates production and marketing via two other committees, the Sugarcane Committee and the Sugar Committee. The Board is monitoring molasses as the feed stock for ethanol production, but has not interfered. When sugarcane is directly used as feed stock, the Board may probably decide to intervene in the supply side, because it can adversely affect sugar production. It should be noted that in the ethanol industry, four-fifth of feed stock today is molasses, while the rest is from cassava. Owing to the low prices of cassava in the past, the government had pushed for greater use of it in producing ethanol and earmarked the proportion of feed stock to be 50:50 for sugarcane and cassava by 2011.

The Fact Sheet of Cassava

About one million hectares of land is currently being cultivated with cassava. The total production is about 26-27 million tonnes of fresh roots a year, as shown in **Table 5**. The yield in 2004 was 20.28 t/ha and reached 22.93 t/ha in 2007. The cost of production per hectare increased steadily because of rising tractor plowing cost and labor costs in harvesting. The cassava fresh root price at this moment is exceptionally high at 2,400 baht or US$ 75.97 per tonne. In the coming years, more cassava will be grown, probably at the expense of sugarcane and the second-season rice crop. The current very high cassava prices are due to increasing demand for cassava products, both within the country and overseas, particularly in China. Rising prices of feed crops and cereals in the rest of the world have also made cassava exceptionally attractive as an ingredient in commercial animal feeds.

Table 5. Basic fact sheet for cassava.

	Unit	2004	2005	2006	2007
Farm households	number	507,770	464,956	476,352	474,823
Planted area	mil.ha	1.06	0.99	1.07	1.17
Production[1)]	mil.tonnes	21.44	16.94	22.58	26.92
Yield[1)]	t/ha	20.28	17.18	21.09	22.93
Production costs	US$/ha	367.37	401.04	468.97	546.70
Exchange rate	baht/US$	39.37	40.26	37.93	34.94
Domestic consumption[2)]	mil.tonnes	3.40	3.65	4.26	7.82
Exports[2)]	mil.tonnes	6.653	4.664	6.560	6.536
Farm price[1)]	US$/tonne	23.59	34.02	31.90	52.66
For ethanol production	mil.tonnes	-	-	0.21	0.26

[1)] Fresh roots;
[2)] Dry products
[3)] 1 tonne fresh roots will produce 0.425 t dry chips, 0.408 t cassava pellets, 0.215 t of starch or 167 liters of ethanol
***Source:** OAE, 2008.*

According to the Cassava Strategic Development Plan, the government wants cassava production to increase using the existing level of land resources. Expansion of land is regarded now as unfeasible and the cost of production for cassava can no longer be lowered by planting a larger area. The only alternative is to develop and disseminate higher-yielding varieties, to choose proper varieties for each soil type and to foster more efficient farm management practices. Cassava farmers now use fertilizers regularly, in contrast with the past when land was newly opened for production and its fertility was still sufficiently high. In their attempt to reap the benefits from high cassava prices, many farmers harvested their cassava roots early and sold them to the drying yards. Some of the cassava roots were still young, being harvested at six months, instead of leaving them in the ground to reach their optimal yields at about eleven months. The effect was that the yields were rather low and so was the starch content. Nonetheless, the cassava farmers were happy.

Prioritization of Fuel-Ethanol Crops

Taking into consideration the production potentials, we consider only the two potential ethanol crops, sugarcane and cassava. Emphasis was placed on cassava, with

molasses becoming less important in the future. However, with high cassava prices, this was thrown into doubt, and sugarcane could very well become as important as before. Sugarcane may actually take precedent over cassava. Considering the issue of food security, both sugarcane and cassava products are traditionally exported, the supplies are ample and at difficult times exports can be restricted to ensure their availability for domestic consumers. With regard to economic risks, the demand for cassava as an ingredient of many food products in the form of starch and for production of animal feed is quite high.

When comparing the economic returns from using cassava or sugarcane, we can see from **Table 6** that in 2007, the amount of net profit for cassava was only 5,701 baht or US$ 180 per hectare, which was lower than that from sugarcane, at 7,170 baht or US$ 227 per hectare. However, the price of cassava received by the farmers was only two-thirds of the price set by the government under the loan scheme. If we look only at the government price, growing cassava would have brought much higher returns than sugarcane. On the other hand, when cassava prices were high the ethanol industry found it unattractive to use cassava as feed stock. The Siam Ethanol Company has already said that it becomes uneconomic to use cassava when its price is above 2.00 baht or US$ 0.06 per kilogram of fresh roots, although its factory was still under construction. In all, sugarcane seems to be a more logical choice than cassava.

Table 6. Economic comparison between cassava and sugarcane, 2007.

Item	Cassava	Sugarcane
Yield (t/ha)	22.9	63.7
Farm price (baht/t)	1,050.0	600.0
Total income (baht/ha)	24,045.0	38,220.0
Total cost (baht/ha)	18,344.0	31,050.0
Net profit (baht/ha)	5,701.0	7,170.0

Source: *OAE, 2008.*

Government Measures

Feed stock production: The price of cassava went up from 1.20 baht or US$ 0.03 per kg in January 2007 to 1.90 baht or US$ 0.05 per kg in December 2007. Consequently, many cassava farmers harvested and sold the roots when plants were only seven months old. This resulted in a fall in production by 20-25% from the level estimated earlier. In order to raise production up to the level where it meets the domestic and export demand and maintain price stability, the Ministry of Agriculture and Cooperatives (MOAC) formulated the following strategic plan of cassava production for 2008-2010: the cassava planting area should be kept at 1.15 million hectares but the yield should be raised from 23.2 t/ha in 2007 to 29.4 t/ha in 2010. To achieve this, the following measures will be adopted:

Productivity increase: Land for cassava is to be selected from areas where the average cassava yield is above 23.2 t/ha. The type of activities introduced includes the use of high-quality cuttings for planting, breaking of the hard pan in the subsoil, soil and land improvement, weeding and harvesting at proper times. For the other areas, the government will encourage the use of high quality cuttings and participatory transfer of technologies.

Value addition: Additional value can be added to the harvested roots by producing clean cassava chips and starch without impurities, and by conversion to ethanol.

Research and development: Research and field experiments will be carried out to select better cassava varieties for production of ethanol and with high starch content. More research will be conducted on production technologies, agricultural machinery to improve planting and harvesting and product development. Several research institutions are involved in identifying ways in which cassava yields can be increased. These include Kasetsart University, Suranaree University of Technology, and the Field Crops Research Institute of the Department of the Agriculture of the Ministry of Agriculture and Cooperatives.

Marketing potentials: Domestic consumption and uses will be expanded. Efforts will be made to maintain existing export markets and to search for new markets. Product quality and branding will be raised.

Bio-energy production measures: The Ministry of Energy has issued quality control measures on ethanol, gasoline and gasohol so as to build confidence among consumers. It has also formulated the pricing of biodiesel and ethanol, to which stakeholders have agreed. This provides an assurance to consumers of fair prices. The biodiesel price is dependent largely on the world (Malaysian) price of crude palm oil, whereas the price of ethanol uses the import price parity principle, in which the world (Brazilian) price of ethanol is the major determinant. These prices are intended to enable domestic producers to be competitive.

Bio-energy use measures: The government has made a regulation requiring all government vehicles throughout the country to use gasohol. The price of gasohol should be lower than that of gasoline of similar octane number, and the price of B5 should be lower than diesel, through various changes to the Oil Fund in order to maintain price differences at retail outlets. At the request of the Ministry of Energy, the motor industry and oil companies must assure the public that vehicles, particularly recent models, can use gasohol without causing any damage to the engines. This helps to increase consumers' confidence toward bio-energy uses.

Pricing of ethanol:

The price of ethanol at the factory gate is set using the following formula:
Price of ethanol = Brazilian price + logistics + insurance + loss + survey

Basically, it is based on the world price of ethanol, which is dictated by Brazil, the second largest ethanol producer in the world. The other factors are basically transport costs which would make the price of ethanol in Thailand equal to the price of Brazilian ethanol if it were to be imported by Thailand. In this sense, it is competitive with imported ethanol, as long as the local producers can realize some profit at this price. In order to encourage the use of biofuels, the government issued a number of regulations regarding gasohol and biodiesel. Gasohol 95 and gasohol 91 are now available throughout the country. The retail gasoline prices in Bangkok on February 2, 2008 was 32.79 baht per liter for gasoline 95 and

28.79 baht per liter for gasohol 95. This four baht difference per liter has a major impact on the motorists' preference for fuels. The consumption of gasohol 95 and gasohol 91 both increased markedly in the past few months.

The pricing of ethanol was thought to be reasonable, as it reflects the world prices, and the domestic industry would be in better shape to compete against foreign imports. However, it did not take into account the domestic price level, particularly, the high prices of feedstock. Fortunately, most ethanol producers can switch from cassava to molasses as their feedstock. However, the level of gasohol consumption has unexpectedly been lower than targeted and, as a result, there is currently a glut of ethanol on the local market. The government finally allowed ethanol to be exported, thus dampening the main purpose of introducing ethanol into the gasoline industry with the aim of reducing oil import bills.

CONCLUSIONS

Thailand has come a long way toward a biofuel development program in which energy crops are produced and converted into a source of energy for the transportation sector. The biofuel policy was formulated and revised several times. As can be expected, biofuel development depends on a number of factors across the board, from farmers to urban dwellers and automobile manufacturers. It involves public-private partnerships, where the government provides incentives and makes the policies and the private sector has to follow suit after a series of consultations. Looking at biofuel crops, priority should be placed on sugarcane and oil palm in the production of ethanol and biodiesel. Cassava is also a viable alternative, but this crop has multiple other uses of the produce, resulting in competition for the raw material and major price increases of the fresh roots. There is a need for more research and development efforts in energy crops, especially cassava and oil palm. Areas of special interest are varietal improvements, effects of irrigation and improved farm management practices. Detailed planning as well as strong government support is needed to encourage farmers to grow these crops in sufficient quantities.

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CONSTRUCTION PROPOSAL OF A CASSAVA INDUSTRIAL COMPLEX

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ABSTRACT

The industrial processing of cassava roots into value-added products, such as starch, sweeteners and ethanol, as well as their by-products, such as animal feed, CO_2 and biogas, is often the first step on the road to rural development and the creation of rural employment. It allows small-scale farmers to sell their roots and to move from a subsistence to a market economy. Many developing countries in the tropics have been on this road and their populations have benefited from rapid economic development. Other countries would like to follow in their footsteps but require expert advice in the planning of the cassava supply chain, the design and installation of the processing facilities as well as the financing of the project.

Our team is able to assist in all these areas, including cassava planting, harvesting, processing and marketing, supported by the Chinese government and the Ministry of Finance through "Buyer Credit" loans from foreign banks such as the China Exim Bank. Currently we have specialists teams working in Nigeria, Kenya, Indonesia, Vietnam and Thailand. In the design of the projects, a series of new technologies will be applied to ensure that the project is feasible, sustainable, innovative and cost-effective.

This paper is to introduce a cassava project package that is easy to be implemented in tropical countries.

PROJECT PLANNING

1. Brief description

The project will start from the cassava plantation, followed by the first stage of investment in cassava processing such as starch/flour, ethanol and other by-products (CO_2, feedstuff etc.). The proposed economic capacity is to process 1500-2000 tonnes of fresh cassava roots per day. The total size of the investment in Asia is around 50-70 million US dollars, while the investment in African countries will be at least 40% higher than in Asia. The next stage will be able to produce modified starch and sweeteners.

2. The project components

The complete project will consist of the following sub-projects:

Cassava plantation: Establish a sample cassava planting base, plant 5000 ha of high-quality cassava, annually harvest about 150,000 tonnes fresh cassava roots, and provide high-quality cassava planting material for a potential 15,000 ha of cassava in the following year.

A cassava starch and flour factory, processing fresh cassava roots at a capacity of 400 tonnes per day, to produce at least 100 tonnes of cassava starch or flour per day. The factory will be operating at least 300 days per year, the production capacity will be not less than 30,000 tonnes starch/flour per year.

A cassava ethanol plant, producing cassava ethanol from fresh cassava and cassava chips with a capacity of at least 200,000 liters per day. The annual production

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capacity of finished products includes: 50 million liters of fuel-ethanol, and 10 million liters of drinking ethanol.

A CO_2 plant for reclaiming CO_2, with a daily capacity of 50 t CO_2/day and an annual capacity of food-class liquid CO_2 of 15,000 tonnes.

An electric power plant, which utilizes steam from the 35 t boiler of the ethanol factory and install a 3000 kw steam generator.

A waste water treatment system with a capacity to treat 5000 m^3 of waste water from the starch and ethanol factories per day, using the UASB reacting system to produce bio-gas. The bio-gas can be utilized as fuel for the steam boiler, which will probably save at least 15% of fuel.

Polymer technology will be applied to separate the solids from the effluent.

A feed mill to process the wet pulp from the cassava starch plant and the solid waste from the ethanol plant, with an annual capacity of 50,000 tonnes of feedstuff.

Polymer technology will be applied for dewatering the wet residues.

Civil building and associated auxiliary project.

All the above sub-projects will be integrated into one cassava industrial complex (**Figure 1**).

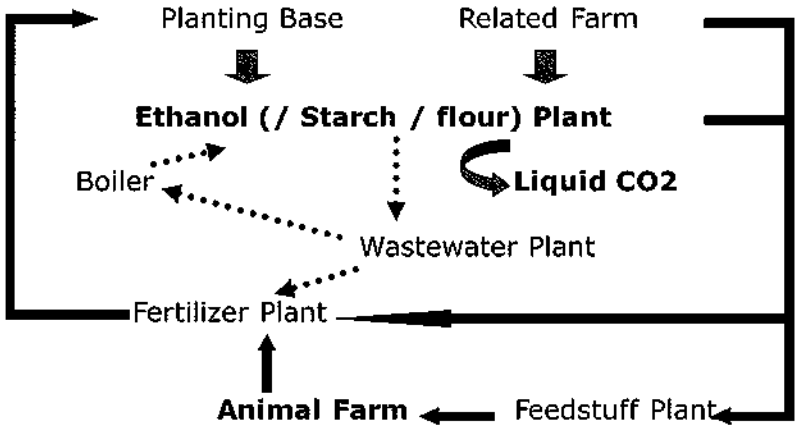

Figure 1. Ecosystem of cassava industrial complex.

3. Technology level of the project

The plants will be specially designed in accordance to advanced technology standards:

- *For the cassava planting base:*
  Cassava yield: 25-35 tonnes fresh roots/ha
- *For the 100 t/day cassava starch line:*

Extraction efficiency	≥92%
Water consumption	≤15 m^3 water/tonne starch
Power consumption	≤180 kwh/tonne starch
Oil consumption	≤40 kg/tonne starch

- *For the 200,000 liters per day cassava ethanol line:*
  "Double Enzyme" high-efficiency saccharification technology,
  "Self flocculated stabilized yeast cell particles" for continuous fermentation
  Variable pressure distillation and molecular screening for dehydration
  based on Chinese standards, which have reached international standards
- *For the waste water treatment system:*
  Solids are separated from the effluent and the dehydrated residue can be sold to the feed mill as a feed resource
  For the treatment of waste water anaerobic and aerobic technology will be utilized for high-efficiency bio-gas output and low energy consumption. It is possible to replace 15% of fuel for the boiler by biogas.
- *For CO_2 production:*
  The traditional wash and refining technology will be used to produce food-class liquid CO_2, but industrial class CO_2 can also be produced depending on the requirements
- *Standard of mechanical and electrical equipment:*
  All equipment is designed, made and/or assembled according to the latest standards and technologies. All pumps, electrical motors, P & ID and other peripheral items within this project are of first-class quality and in conformity with the international industrial norms and standards.

4. Marketing of the various products

The market situation of cassava products is very positive as production of these products in the world cannot keep up with increasing demand. This is clearly indicated by the rapid increase in investment in various cassava processing industries:

The cassava starch market is still a "seller's market", e.g. China had to import 450,000 tonnes of cassava starch during 2006/07, but there was still a shortage of 500,000 tonnes, corresponding to nearly 30% of requirements.

Ethanol is in high demand as a renewable fuel for the partial replacement of petroleum-based fuels according to the Chinese government's energy policy. Ethanol is also becoming a hot issue in international markets.

Liquid CO_2 is widely used in the food industry (especially in beverage) and in light industry.

Feedstuff from by-products of industry is a new resource for producing commercial animal feed.

5. Project financing

- Project developing funds
- Private investment
- "Buyer's Credit" loan from foreign banks (e.g. China Exim Bank)

CONDITIONS OF THE INVESTMENT

1. Raw material supply

A steady and permanent supply of roots from the cassava plantation is the first condition for the success of this project. We will need a large enough cassava supply as follows:

The cassava growth period should not be more than 200 days/year. The quantity of fresh cassava roots produced within this growth period should not be less than 2000 tonnes/day, or a total amount of 450,000 tonnes per year. The sample cassava planting base of 5000 ha is enough to plant the initial cassava.

2. Factory construction area

An area of at least 20 ha is used for factory construction, which should be as close as possible to the cassava plantation

3. Water and electricity supply

Clean water requirement: 5000 m^3/day

Power requirement: 3000 Kw, to be supplied by the installed power plant

4. Road and transportation conditions

Road conditions should be adequate to insure that fresh cassava roots can be supplied year-round to the factory and finished products can be delivered in time to the appointed destination. The inland transportation costs and the time required from the factory to the nearest seaport are also important factors

5. Political, economic and legal issues

The most important conditions include a stable government, an enlightened and facilitating political environment, favorable revenue and legal policies, foreign exchange mechanisms at international standards, etc.

6. Human resources

It is of great importance to employ the necessary capable professional persons with knowledge and experience in local businesses, and who can assume technical and commercial responsibilities in the factories.

INVESTMENT BUDGET AND SIMPLE BENEFIT ANALYSIS

1. Estimated initial investment: 55,800,000 USD

Annex 1: General Investment Budget

2. Benefit/Cost analysis

a) General costs:

- Material consumption and operational costs: 34,230,000 USD/year

Including the cost of:	
100 t/day cassava starch and flour line	6,828,000 USD/year
200 kl/day cassava ethanol line	21,260,000 USD/year
5000 m^3/day waste water treatment system	142,000 USD/year
200 t/day feedstuff plant	2,000,000 USD/year
50 t/day CO_2 plant	1,000,000 USD/year
5000 ha cassava planting base	3,000,000 USD/year
Total	34,230,000 USD/year

- Other cost: 13,080,000 USD/year including:

  Labor cost: 300 persons at 2,500 USD/person/year on average, or a total of 750,000 USD/year

  Cost of sales promotion (including advertising), taxes, new products development fund and maintenance (total amount 18% of sales income): 12,330,000 USD

b) Estimated sale income of products: 68,500,000 USD/year

Item	Contents	Unit	Quantity	Unit price	Total(US$)
1	Fresh cassava from planting base	MT	150,000	50.00	7,500,000.00
2	Native starch	MT	30,000	300.00	9,000,000.00
3	Ethanol (fuel class)	KL	50,000	600.00	30,000,000.00
4	Ethanol (potable class)	KL	10,000	800.00	8,000,000.00
5	Liquid CO_2	MT	15,000	100.00	1,500,000.00
6	Feedstuff	MT	50,000	250.00	12,500,000.00
	Total Amount				**68,500,000.00**

Note: Unit price will be adjusted according to market conditions.
The fresh cassava from the planting base is accounted in the sales income.

c) Anticipated financial returns

Annual expected profits = 68,500,000 - 34,230,000 -13,080,000 = 21,190,000 USD.
Duration for recuperating the investment (plus 2 years construction period): 5 years

PROJECT IMPLEMENTATION

The project will be organized and implemented by local investors. Help can be provided to the investor by our global specialist team, such as:

- Cassava breeding, mechanized planting and harvesting specialist.
- Bio-chemists, experienced engineers specialized in cassava processing and management.
- Global marketing experts.

The professional technical suppliers will be fully responsible for providing all facilities and services. The construction and technical support group should be organized as follows:

- Standard and quality control team
- Designing team
- Manufacturing team
- Installation and testing team
- Training, service and management team
- Research and development supporting team

It is possible to construct the project within 16 months under a normal implementation plan.

CONCLUSIONS

The proposed medium-scale cassava industrial complex is suitable for investment in developing or under-developed countries with basic conditions and financial support from the government or private sectors. This is the most effective way to develop and improve the standard of living in poor cassava growing areas.

Annex 1. General Investment Budget.

Item	Content	Evaluation (US$ X 1000)				Unit Index of Buildings			Account for	Note
		Civil work	Equipments	Others	Total	Unit	Quant.	Index (US$)	%	
I	**Section One: Engineering cost**	**7015.20**	**40333.75**	**4031.50**	**51380.45**				**92.23**	
1	100t/d cassava starch line	400.00	1800.00	180.00	2380.00	m^2	2000	200.00	**4.27**	
2	200KLPD Cassava ethanol line	3000.00	26000.00	2600.00	31600.00	m^2	15000	200.00	**56.73**	
3	200t/d feed stuff plant	200.00	1500.00	150.00	1850.00	m^2	1000	200.00	**3.32**	
4	50t/d CO2 plant	200.00	3000.00	300.00	3500.00	m^2	1000	200.00	**6.28**	
5	3000kw power plant	240.00	3000.00	300.00	3540.00	m^2	1200	200.00	**6.35**	
6	Waste water treatment plant	600.00	5000.00	500.00	6100.00	m^2	3000	200.00	**10.95**	
7	Warehouse	800.00			800.00	m^2	4000	200.00	**1.44**	
8	Cassava deposition ground	400.00			400.00	m^2	5000	80.00	**0.72**	
9	Office and Lab	400.00	15.00	1.50	416.50	m^2	1000	400.00	**0.75**	
10	Road	120.00			120.00	m^2	6000	20.00	**0.22**	
11	Bridge scale station	5.20	18.75		23.95	m^2	40	130.00	**0.04**	
12	Oxidation pond	600.00			600.00	m^2	60000	10.000	**1.08**	
13	Virescence	50.00			50.00				**0.09**	
II	**Section Two: Other costs**			**1673.71**	**1673.71**				**3.00**	
1	Reconnaissance engineering			1.25	1.25					
2	General designing (including civil work)			1027.61	1027.61					
3	Insurance of the engineering			21.05	21.05					0.30%
4	Cost of office furniture and commodities			50.00	50.00					
5	Preparation cost of testing and running			60.00	60.00					
6	Cost of combining testing and running			513.80	513.80					1.00%
III	**Section Three: Fund of preparation**			**2652.71**	**2745.84**				**4.76**	
1	Basic fund of preparation			2652.71	2745.84					5.00%
2	Price difference fund of preparation			0.00	0.00					
IV	**Total fixed assets (Section one ~three)**	**7015.20**	**40333.75**	**8357.92**	**55800.00**				**100.00**	

Note: 1. The unit price in "Unit Index" of I 1-12 will be adjusted according to local standards.

2. The "Others" of Item I 1-9 refers to the cost of freight in the destination country, installation and testing

3. Note: this budget was based on the INP of Indonesia in 2007.

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APPENDIX

Results of Soil Analyses in Asia 2006-2009

Reinhardt H. Howeler

The following tables present the analysis results of soil samples taken in various countries in Asia, mainly in soil fertility maintenance experiments and in FPR trials in farmers fields. To facilitate interpretaion of the results, **Table 1** indicates the approximate classification of soil chemical characteristic according to the nutritional requirements of cassava.

Table 1. Aproximate classification of soil chemical characteristics according to the nutritional requirements of cassava.

Soil parameter[1)]	Very low	Low	Medium	High	Very high
pH	<3.5	3.5-4.5	4.5-7	7-8	>8
Org. matter (%)	<1.0	1.0-2.0	2.0-4.0	4.0-8.0	>8.0
P (µg/g)	<2	2-5	5-20	20-50	>50
Ca (me/100 g)	<0.25	0.25-1.0	1.0-5.0	>5.0	
Mg (me/100 g)	<0.2	0.2-0.4	0.4-1.0	>1.0	
K (me/100 g)	<0.10	0.10-0.15	0.15-0.25	>0.25	
Al-saturation (%)			<75	75-85	>85
Na-saturation (%)			<2	2-10	>10
Salinity (mmhos/cm)			<2	2-10	>10
S (µg/g)	<20	20-40	40-70	>70	
B (µg/g)	<0.2	0.2-0.3	0.3-1.0	1-2	>2
Zn (µg/g)	<0.5	0.5-1.0	1.0-5.0	5-50	>50
Mn (µg/g)	<5	5-10	10-100	100-250	>250
Cu (µg/g)	<0.1	0.1-0.2	0.2-1.0	1-5	>5
Fe (µg/g)	<1	1-10	10-100	>100	

[1)]pH in H_2O: OM by ethod of Walkley and Black;
Al saturation = 100 x Al (Al + Ca + Mg + K) in me/100g;
P in Bray II; K, Ca, Mg and Na in 1$\underline{N}$ NH_4-acetate; S in Ca-phosphate;
B in hot water; and Cu, Mn, Fe and Zn in 0.05 $\underline{N}$ HCl + 0.025 $\underline{N}$ H_2SO_4
Source: *modified from Howeler, 1996.*

REFERENCE

Howeler, 1996. Diagnosis of nutritional disorders and soil fertility maintenance of cassava. *In*: G.T. Kurup *et al.* (Eds.). Tropical Tuber Crops. Problems, Prospects and Future Strategies. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi, India. pp. 181-193.

[1)]CIAT Cassava Office for Asia, Dept. of Agric., Chatuchak, 10900 Thailand.

Table 2. Soil samples taken in Cambodia from 2006 to 2009.

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Phnom Penh	-1	CARDI; cassava variety trials, yellow silt loam	Oct 06	11°28'38"	104°48'30"	17
	-2	CARDI; soil brought in for cassava field in back of buildings	Sep 07	11°28'38"	104°48'26"	8
Kampong Cham	-1	Tbong Kmom, village 10-5 in NPK check plot	Oct 06	11°58'03"	105°38'26"	49
	-2	Tbong Kmom, Nong Reav, Chroy Chang Ha village: FPR trial Mr Kong Thoun; dark brown clay	Sep 07	11°53'10"	105°34'51"	31
	-3	Tbong Mhmom district, Chrouy Kor village; NPK fertilizer trial; red sticky clay, 8 years cassava without fertilizers	Nov 08	11° 59' 23"	105° 34' 14"	68
	-4	Tbong Khmom district, Vihear Lourg, Kean Roung village; Mr. Bun Nara; FPR fertilizer check plot; sticky red-brown clay; K deficiency symptoms after 9 years cropping	Nov 08	11° 55' 23"	105° 41' 23"	24
	-5	Kampong Siem, Srok village, FPR trials Mr. Mol Heng; rather fertile dark red clay	Sep 07	12°09'53"	105°28'13"	63
	-6	Kampong Siem, Ro Hang, Romoul village; FPR trials of Mr. Chhor Chheung; red clay with plinthite	Sep 07	12°01'56"	105°26'48"	60
	-7	Chamcar Leu Seed Farm; potential field for cassava experiments; red soil after maize harvest	Feb 08			
	-8	Chamcar Leu Seed Farm; long-term NPK trial, check plot; vigorous cassava growth	Nov 08	12° 12' 12"	105° 19' 09"	116
	-9	Chamcar Leu Seed Farm; long-term NPK trial; check plot Reps I, II and III	Mar 09	12° 12' 12"	105° 19' 05"	113
	-10	Dambe district; cassava field being harvested, gravelly soil	Nov 08	11° 53' 50"	105° 48' 13"	27
Kampong Speu	-1	Trapaeng Saray village; Lim Sokhom, in NPK check plot	Oct 06	11°12'30"	104°12'29"	80
	-2	Trapaeng Saray village; Lim Sokhom, vertical planting on termite hill	Oct 06	11°12'30"	104°12'29"	80
	-3	Trapaeng Saray village; Lim Sokhom, in NPK check plot	Mar 07	11°12'30"	104°12'29"	80
	-4	Trapaeng Saray village; Lim Sokhom, vertical platning on termite hill	Mar 07	11°12'30"	104°12'29"	80
	-5	Trapaeng Saray village; Lim Sokhom, Rayong 2 on slight slope near termite hill	Mar 07	11°12'30"	104°12'29"	80
	-6	Phnom Srourch,Treng Trayeung, Trapaeng Saray village; FPR variety trial near Mr. Lim Sokhom; sandy soil	Sep 07	11°12'29"	104°12'33"	86
	-7	Phnom Srourch, Treng, Trayeung, Trapaeng Saray village, FPR fert. trial on termite hill, cassava with Zn deficiency symptoms	Sep 07	11°12'29"	104°12'33"	86

Table 2. Soil samples taken in Cambodia from 2006 to 2009. (continued)

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Battambang	-1	Rattanak Mondoul, Andeuk Heap, Serey Von village, sticky black clay in variety trial	Oct 06	12°51'37"	102°58'14"	54
	-2	Rattanak Mondoul, Plav Meas, Teuk Sab village; red clay in NPK check plot	Oct 06	12°47'37"	102°53'15"	60
	-3	Rattanak Mondoul, Sdao commune, Don Meay village; FPR trial of Mr. Ran Kong; black clay	Sep 07	12°52'05"	103°00'06"	44
	-4	Rattanak Mondoul, Andeuk Heap, Prey Ampor village; FPR trial of Mr. Sok Remí; very fertile sticky clay	Sep 07	12°51'15"	103°00'26"	40
	-5	Rattanak Mondul district, Sadao, Don Meay village; Mr. Heun Chek FPR variety trial; black sticky clay; very vigorous cassava	Nov 08	12° 51' 21"	103° 00' 31"	44
	-6	Rattanak Mondul district, Sadao, Don Meay village; Mr. Heun Chek FPR fertilizer trial; check plot with poor growth; black sticky clay	Nov 08	12° 51' 05"	103° 00' 35"	37
	-7	Banan, Baydam Ram, Prey Totueng village; FPR trials Mr. Chourp Saveung; very poor cassava		12°59'38"	103°08'38"	15
Preah Vihear	-1	CARDI station, outside variety trial	Mar 07			
Svay Rieng	-1	Kampong Trach district; 1st cassava field, poor growth; sandy loam soil	Feb 08	11° 24' 04"	105° 51' 46"	4
	-2	Kampong Trach district; 2d cassava field, good growth, sandy loam soil	Feb 08	11° 24' 15"	105° 51' 16"	4
Kratia	-1	Snuol district; along highway Kratia to Stung Treng; black clay soil	Nov 08	12° 40' 44"	106° 06' 36"	47
Stung Treng	-1	Stung Treng district, Stung Treng commune; cassava field with green variety; sandy loam soil	Nov 08	13° 29' 36"	105° 59' 56"	92
Pursat	-1	Krovash, Ptash Rony Preah Rom, Bot Ramduol village; in cassava leaf trial, sandy soil	Sep 07	12°25'21"	103°43'41"	26

Table 3. Chemical and physical characteristics of cassava soils in Cambodia, 2006 to 2009.

		Chemical characteristics														Physical characteristics			
			%	ppm	← me/100 g →					%	← ppm →					← % →			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Phnom Penh	-1	6.86	0.31	11.99	0	7.89	2.64	0.19	0.17	0	0.65	2.24	121.6	1.83	69.1	10.9	50.0	39.1	si.c.l.
	-2	6.06	0.48	3.06	0	3.47	1.33	0.11	0.68	0	0.59	1.03	43.1	0.72	34.2	41.8	29.0	29.2	c.l.
Kampong Cham	-1	5.37	2.82	2.99	0.36	2.25	1.06	0.20	-	9	0.77	0.31	285.2	2.01	15.2	8.0	21.8	70.2	clay
	-2	6.02	4.41	10.61	0	13.14	4.55	0.16	0.04	0	0.80	2.81	81.0	0.58	7.6				
	-3	5.52	1.18	4.12	0.00	4.38	1.85	0.06		0	0.90	10.78	247.2	2.09	16.6	4.4	30.0	65.6	clay
	-4	4.57	0.83	9.16	1.72	0.94	0.50	0.11		53	0.68	2.80	157.6	1.62	18.8	16.5	23.4	60.1	clay
	-5	5.29	3.55	11.18	0.73	2.79	1.11	0.41	0	14	0.96	7.74	113.3	1.73	30.2	14.4	24.2	61.4	clay
	-6	5.68	2.64	66.73	0	5.12	4.31	0.17	0.04	0	0.81	4.80	67.3	2.57	20.4	22.6	23.5	53.9	clay
	-7	5.23	0.76	110.39	0.21	2.84	1.35	0.67		4	0.66	6.62	226.0	1.85	15.2	15.9	33.3	50.8	clay
	-8	5.38	1.06	67.97	0.21	4.54	2.02	0.64		3	1.12	9.35	177.7	1.50	12.4	4.3	32.3	63.4	clay
	-9	5.44	0.93	106.02	0.26	4.23	1.80	0.55		4	0.79	5.76	145.9	1.15	11.5	8.5	31.0	60.5	clay
	-10	6.21	1.03	4.59	0.00	6.66	2.23	0.36		0	0.65	3.07	146.9	0.94	7.6	42.9	22.3	34.8	c.l.
Kampong Speu	-1	6.10	0.63	2.39	0	0.97	0.41	0.03	0.00	0	0.58	0.73	80.3	0.21	34.9	62.2	18.0	19.8	s.l.
	-2	6.52	1.01	3.14	0	2.30	0.28	0.04	0.02	0	1.09	0.86	65.5	0.19	13.7	63.3	16.8	19.8	s.l.
	-3	5.39	0.75	17.71	0.16	0.99	0.32	0.04	-	10	0.37	0.73	49.4	0.23	29.2	61.4	18.4	20.2	s.c.l.
	-4	6.09	1.00	22.48	0	2.73	0.37	0.10	0.02	0	0.56	0.68	40.6	0.10	10.3	61.2	17.6	21.2	s.c.l.
	-5	5.91	1.11	20.95	0	1.65	0.50	0.08	0.02	0	0.42	0.81	50.2	0.10	20.4	57.6	21.3	21.1	s.c.l.
	-6	5.94	2.04	5.52	0	1.71	0.51	0.07	0.01	0	0.83	1.29	39.3	0.23	44.1	59.0	20.9	20.1	s.c.l.
	-7	8.03	0.74	9.89	0	15.01	4.97	0.07	0.20	0	1.13	0.01	72.5	0.06	0.0	47.1	26.2	26.7	s.c.l.
Battambang	-1	7.14	2.66	4.57	0	51.02	7.61	0.62	0.03	0	0.83	0.58	56.9	0.22	0.3	7.2	21.3	71.5	clay
	-2	6.58	2.55	2.65	0	9.98	3.64	0.15	0.00	0	0.87	1.38	207.9	0.34	10.5	24.1	33.9	42.0	clay
	-3	7.61	6.01	13.77	0	75.41	3.78	0.89	0.04	0	1.80	0.07	1.7	0.04	0.0	24.0	28.7	47.3	clay
	-4	6.97	3.47	2.22	0	42.21	4.83	0.76	0.02	0	0.90	0.54	56.4	0.26	0.8	15.0	26.8	58.2	clay
	-5	7.70	1.58	12.67	0.00	62.31	3.56	0.71		0	1.41	0.0	3.6	0.01	0.0	14.1	41.0	44.9	si.c.
	-6	6.87	1.35	2.47	0.00	27.52	4.65	0.20		0	0.71	1.25	87.0	1.25	2.5	13.2	35.6	51.2	clay
	-7	7.03	2.75	166.23	0	4.62	4.07	0.57	0.19	0	1.27	11.17	89.8	0.79	12.6	17.0	39.7	43.3	clay

Table 3. Chemical and physical characteristics of cassava soils in Cambodia, 2006 to 2009 (continued).

		Chemical characteristics														Physical characteristics			
			%	ppm	me/100 g					%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Preah Vihear	-1	6.95	0.70	36.93	0	2.47	0.44	0.34	0.03	0	0.52	0.66	32.3	1.49	59.1	71.5	8.4	20.1	s.c.l.
Svay Rieng	-1	4.86	0.46	3.10	0.68	0.43	0.18	0.07		50	0.43	0.27	21.9	0.04	15.6	57.3	21.7	21.0	s.c.l.
	-2	5.71	0.38	3.92	0.00	0.97	0.28	0.09		0	0.46	0.53	62.2	0.09	16.4	41.1	37.9	21.0	loam
Kratia	-1	7.09	1.22	4.22	0.00	15.12	1.62	0.13		0	0.47	0.82	89.6	0.39	4.1	38.2	41.3	20.6	loam
Stung Treng	-1	5.26	0.44	2.93	0.36	0.86	0.23	0.10		23	0.57	0.34	5.86	0.27	46.4	59.3	16.7	24.0	s.c.l.
Pursat	-1	5.59	0.77	33.15	0	0.48	0.17	0.12	0.01	0	0.93	0.95	33.5	0.29	47.8	64.4	15.4	20.2	s.c.l.

[1)]s.c.l. = sandy clay loam.
si.c.l. = silty clay loam
s.l. = sandy loam
c.l. = clay loam

Table 4. Soil samples taken in China from 2006 to 2008.

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Hainan	-1	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_0P_0K_0$	Jan 06			
	-2	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_0P_2K_2$	Jan 06			
	-3	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_1P_2K_2$	Jan 06			
	-4	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_2P_2K_2$	Jan 06			
	-5	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_3P_2K_2$	Jan 06			
	-6	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_2P_0K_2$	Jan 06			
	-7	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_2P_1K_2$	Jan 06			
	-8	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_2P_3K_2$	Jan 06			
	-9	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_2P_2K_0$	Jan 06			
	-10	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_2P_2K_1$	Jan 06			
	-11	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_2P_2K_3$	Jan 06			
	-12	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_3P_3K_3$	Jan 06			
	-13	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_1P_1K_1$	Jan 06			
	-14	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_1P_1K_1$+ 15 t/ha burned soil	Jan 06			
	-15	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_1P_1K_1$+ 30 t/ha burned soil	Jan 06			
	-16	Danzhou, CATAS, NPK trial before planting 16 th cycle. $N_1P_1K_1$+ 60 t/ha burned soil	Jan 06			
	-17	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_0P_0K_0$	Jan 07			
	-18	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_0P_2K_2$	Jan 07			
	-19	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_1P_2K_2$	Jan 07			
	-20	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_2P_2K_2$	Jan 07			
	-21	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_3P_2K_2$	Jan 07			
	-22	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_2P_0K_2$	Jan 07			
	-23	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_2P_1K_2$	Jan 07			
	-24	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_2P_3K_2$	Jan 07			
	-25	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_2P_2K_0$	Jan 07			
	-26	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_2P_2K_1$	Jan 07			
	-27	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_2P_2K_3$	Jan 07			
	-28	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_3P_3K_3$	Jan 07			
	-29	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_1P_1K_1$	Jan 07			
	-30	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_1P_1K_1$+ 15 t/ha burned soil	Jan 07			
	-31	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_1P_1K_1$+ 30 t/ha burned soil	Jan 07			
	-32	Danzhou, CATAS, NPK trial before planting 17 th cycle. $N_1P_1K_1$+ 60 t/ha burned soil	Jan 07			

Table 4. Soil samples taken in China from 2006 to 2008. (continued)

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Hainan	-33	Danzhou, Haitou, Jilong village, yellow sandy soil in SC 5 field	Oct 06	19°31'30"	108°57'27"	12
	-34	Danzhou, Haitou, Shuyuang village; grey sandy soil in SC 5 field	Oct 06	19°30'01"	108°59'02"	40
	-35	Qiongzhong, Hongdao farm; first crop after forest, SC 5 field on slope	Oct 06	19°02'36"	109°52'16"	232
	-36	Qiongzhong, Jiadra farm; black sandy loam in very good SC 5 field	Oct 06	19°03'26"	109°50'33"	270
Guangxi	-1	Wuming, Taiping town, Qingle village; yellow clay loam in variety trial	Oct 06	23°07'47"	108°22'46"	122
	-2	Wuming, Lingma town, Gaoyuan starch factory; SC 205 using factory waste water	Oct 06	23°25'04"	107°56'41"	246
	-3	Long An, Nanxu town, Luan Zheng village; rocky yellow clay in PRDU village	Oct 06	23° 08'00"	107°32'28"	254
	-4	Beihai city, Hepu county, Shi Kang town, Hong Lao village; Mr. Ye Quan 15 ha cassava plantation; sandy soil	Sept 08			
	-5	Qinzhou city, Jiu Long town, Pingxin village; contract cassava multiplication field; red clay loam soil, cassava with Mg deficiency symptoms	Sept 08	22° 00' 15"	108° 42' 14"	16
	-6	Nanning city, Wuming county, Taiping town, Qingle village; orange clay soil in cassava variety trial; vigorous cassava	Sept 08	23° 07' 44"	108° 22' 43"	127
Guangzhou	-1	Gaozhou county, Shigu town; recently planted Nanzhi 199 intercropped with peanut; sandy loam	April 08	21°44'48"	110°43'18"	14
	-2	Gaozhou county, Shigu town; recently planted cassava GR 911 on slope with serious erosion	April 08	21°44'52"	110°41'25"	13

Table 5. Chemical and physical characteristics of cassava soils in China, 2006 to 2008.

		← Chemical characteristics →													← Physical characteristics →			
			%	ppm	← me/100 g →				%	← ppm →					← % →			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Hainan	-1	4.62	0.27	8.10	0.68	0.35	0.09	0.08		57	0.26	0.63	16.1	0.11	15.2	56.8	16.7	26.5	s.c.l.
	-2	4.79	0.21	29.29	0.62	0.44	0.10	0.14		48									
	-3	5.01	0.30	61.62	0.42	0.76	0.19	0.10		29									
	-4	4.77	0.44	32.29	0.62	0.47	0.08	0.10		49									
	-5	4.63	0.29	26.39	0.73	0.42	0.07	0.08		56									
	-6	4.54	0.38	6.48	1.46	0.25	0.06	0.10		78									
	-7	4.35	0.42	28.11	0.73	0.52	0.09	0.09		51									
	-8	4.78	0.32	63.60	0.73	0.52	0.09	0.10		51									
	-9	4.73	0.31	27.54	0.62	0.47	0.10	0.07		49									
	-10	4.92	0.30	46.25	0.52	0.58	0.11	0.07		41									
	-11	4.78	0.40	19.31	0.73	0.39	0.07	0.12		56									
	-12	4.85	0.34	68.06	0.57	0.64	0.09	0.12		40									
	-13	4.72	0.29	35.09	0.68	0.51	0.09	0.08		50									
	-14	4.99	0.41	20.89	0.47	0.66	0.11	0.08		36									
	-15	4.90	0.35	25.30	0.52	0.66	0.09	0.08		39									
	-16	5.12	0.34	56.13	0.31	0.93	0.11	0.08		22	0.30	0.85	17.6	0.11	16.5	56.8	16.7	26.5	s.c.l.
	-17	4.58	0.54	5.44	0.88	0.32	0.06	0.05		67	0.33	0.49	12.0	0.08	18.0	57.3	18.8	23.9	s.c.l.
	-18	4.79	0.54	29.93	0.62	0.58	0.08	0.13		44									
	-19	4.71	0.82	32.77	0.68	0.80	0.11	0.07		41									
	-20	4.40	0.72	21.24	0.78	0.48	0.06	0.08		56									
	-21	4.63	0.57	12.18	0.83	0.44	0.08	0.06		59									
	-22	4.59	0.74	5.62	0.94	0.38	0.06	0.08		64									
	-23	4.51	0.74	10.39	0.73	0.53	0.08	0.08		51									
	-24	4.46	0.73	48.39	0.73	0.63	0.08	0.07		48									
	-25	4.54	0.73	25.54	0.94	0.47	0.06	0.05		62									
	-26	4.75	0.72	16.28	0.88	0.41	0.04	0.08		62									
	-27	4.89	0.81	39.07	0.62	0.62	0.05	0.17		42									
	-28	4.92	0.95	46.12	0.62	0.84	0.13	0.10		37									
	-29	4.75	0.85	10.09	0.73	0.54	0.08	0.06		52									

Table 5. Chemical and physical characteristics of cassava soils in China, 2006 to 2008. (continued)

		← Chemical characteristics →													← Physical characteristics →			
			%	ppm	← me/100 g →				%	← ppm →					← % →			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Hainan	-30	4.92	0.80	10.38	0.68	0.66	0.10	0.06		45									
	-31	5.13	0.76	12.87	0.52	0.95	0.10	0.06		32									
	-32	5.46	0.81	24.11	0.31	1.20	0.11	0.06		18	0.65	0.95	14.5	0.06	12.9	57.2	18.8	24.0	s.c.l.
	-33	6.03	0.27	15.65	0	0.58	0.13	0.04	0.01	0	0.86	2.69	56.9	0.24	8.0	76.5	6.2	17.3	s.l.
	-34	5.75	0.30	12.23	0	0.51	0.28	0.12	0.00	0	1.04	0.80	33.3	0.12	7.9	67.7	13.7	18.5	s.l.
	-35	6.43	2.30	142.54	0	4.99	0.41	0.78	0.00	0	1.37	0.82	21.3	0.21	9.1	53.3	17.8	28.9	s.c.l.
	-36	4.33	2.83	9.26	2.55	0.69	0.34	0.18	-	68	0.69	0.67	20.6	0.29	27.0	53.3	12.7	34.0	s.c.l.
Guangxi	-1	4.16	2.22	54.35	3.54	0.51	0.12	0.38		78	0.74	0.62	4.8	0.35	18.1	24.8	10.6	64.7	clay
	-2	4.52	1.87	39.31	2.76	0.47	0.38	0.55		66	0.77	1.66	60.7	0.48	10.5	5.6	29.6	64.8	clay
	-3	6.75	4.41	48.13	0	8.87	1.05	0.26	0.03	0	1.39	4.59	127.1	0.44	5.8	21.3	22.2	56.5	clay
	-4	5.24	0.66	410.17	0.26	5.53	0.11	0.10		4	1.00	7.16	6.9	4.15	34.8	67.6	12.2	20.2	s.c.l.
	-5	4.16	0.95	22.90	5.72	0.50	0.09	0.11		89	0.87	0.70	1.6	0.11	85.6	30.9	32.4	36.7	c.l.
	-6	4.13	0.99	83.23	3.49	0.41	0.14	0.34		80	0.64	0.59	3.3	0.52	21.5	25.9	13.5	60.6	clay
Guangzhou	-1	5.28	0.96	151.42	0.31	3.62	0.64	0.25		6	0.99	3.85	48.8	1.48	83.3	26.8	35.7	37.5	c.l.
	-2	3.99	0.82	20.39	2.60	0.31	0.07	0.14		83	0.83	0.58	4.9	0.12	29.9	38.6	19.7	41.5	clay

[1)]s.c.l. = sandy clay loam, s.l. = sandy loam

Table 6. Soil samples taken in East Timor from 2006 to 2007.

Sample no.		Sample location and description	Date	Coordinates S	Coordinates E	Elevation (masl)
Aileu	-1	Suco Liurai, FPR trial Manuel Saude; very poor cassava	Aug 06	08° 45'47"	125 ° 43'31"	921
	-2	Suco Liurai, FPR trial Alfonso Dacosta; very good cassava	Aug 06	08° 45'39"	125 ° 43'00"	940
	-3	FPR trial of Mario Viera; black clay in flat area	Jan 07	08° 45'17"	125 ° 34'05"	896
	-4	FPR trial of Armando Duos Santos; yellow clay on steep slope	Jan 07	08° 43'43"	125 ° 33'56"	939
Manufahi	-1	Same, near Betano; FPR trial Almeida Pereira, grey black clay loam	Jan 07	09° 08'45"	125° 42'56"	33
	-2	Same, near Betano; FPR trial Joao Mendez; grey silt loam	Jan 07	09° 09'15"	125° 41'24"	12
	-3	Same, near Betano; FPR trial Francisco Tilman	Jan 07	09° 08'54"	125° 43'22"	21
Bobonaro	-1	Maliana; FPR trial Domigoes, high cassava yields	Aug 06	08°55'47"	125°09'09"	138
	-2	Maliana; FPR trial Miguel, low yield	Aug 06	08°55'34"	125°08'55"	109
	-3	Maliana; FPR trial Antonio, high yield	Aug 06	08°55'41"	125°08'41"	106
	-4	Maliana; FPR trial Manuel Leite; grey-black clay loam	Jan 07	08°55'45"	125°10'30"	133
	-5	Maliana; FPR trial Zeremiaz Dasi; grey-yellow silt loam	Jan 07	08°57'14"	125°10'20"	154
	-6	Maliana; FPR trial Armindu Alfonso	Jan 07	08°54'57"	125°09'06'	109

Table 7. Chemical and physical characteristics of cassava soils in East Timor, 2006-2007.

		←Chemical characteristics→															←Physical characteristics→			
			%	ppm	←me/100 g→					%	%	dS/m	←ppm→					←%→		
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	Na	E.C.	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1]
Aileu	-1	5.31	3.31	6.48	0.94	1.78	0.55	0.48		25			0.54	1.41	158.0	1.61	68.4	35.3	19.0	45.7	clay
	-2	5.22	2.52	3.33	1.14	3.20	1.85	0.25		18			0.42	0.75	171.3	1.96	26.7	18.2	31.9	49.9	clay
	-3	7.28	6.15	38.68	0	26.27	2.33	0.85	0.05	0			0.96	0.57	44.8	0.08	0.1	14.5	40.3	45.2	si.c
	-4	4.87	2.25	6.23	3.48	0.59	0.30	0.20		76			0.83	2.45	24.7	1.42	64.5	32.5	25.7	41.8	clay
Manufahi	-1	7.48	2.40	492.28	0	30.79	2.75	3.92	0.09	0	0.2		1.19	0.33	81.7	0.15	0.1	21.9	29.7	48.4	clay
	-2	7.85	2.34	27.94	0	26.62	1.49	1.03	0.02	0	0.1		1.44	0.05	9.4	0.08	0.0	2.7	56.8	40.5	si.c
	-3	7.73	1.78	30.27	0	34.93	1.41	3.18	0.05	0	0.1		1.34	0.03	3.8	0.08	0.0	24.7	32.6	42.7	clay
Bobonaro	-1	5.36	1.53	2.98	0.68	7.52	1.64	0.23		7			0.45	0.35	115.1	0.43	4.1	24.8	23.6	51.6	clay
	-2	5.57	1.52	2.27	0	3.52	1.24	0.21		0			0.33	1.02	171.2	0.88	10.3	31.1	38.4	30.5	c.l.
	-3	5.43	1.21	2.68	0.42	2.86	0.76	0.18		10			0.29	0.41	159.7	0.78	9.8	31.1	33.3	35.6	c.l.
	-4	6.55	2.12	1.85	0	8.44	1.81	0.23	0.24	0	2.2		0.79	0.79	90.7	0.40	10.8	23.5	43.8	32.7	c.l.
	-5	5.63	1.44	2.36	0	5.00	1.92	0.28	0.04	0	0.6		0.73	0.56	189.3	0.78	23.2	23.2	40.2	36.6	c.l.
	-6	7.13	1.28	7.11	0	23.74	1.94	0.51	0.01	0	0		0.87	0.48	96.5	0.44	2.2	16.9	29.2	53.9	clay

c.l. = clay loam, si.c = silty clay

Table 8. Soil samples taken in Indonesia from 2006 to 2009.

Sample no.		Sample location and description	Date	Coordinates S	Coordinates E	Elevation (masl)
Lampung	-1	Tamanbogo-NPK trial before 16 th planting; $N_0P_0\ K_0$	Dec 06	05°01'10"	105°30'13"	35
	-2	Tamanbogo-NPK trial before 16 th planting; $N_0P_2\ K_2$	Dec 06	05°01'10"	105°30'13"	35
	-3	Tamanbogo-NPK trial before 16 th planting; $N_1P_2\ K_2$	Dec 06	05°01'10"	105°30'13"	35
	-4	Tamanbogo-NPK trial before 16 th planting; $N_2P_2\ K_2$	Dec 06	05°01'10"	105°30'13"	35
	-5	Tamanbogo-NPK trial before 16 th planting; $N_3P_2\ K_2$	Dec 06	05°01'10"	105°30'13"	35
	-6	Tamanbogo-NPK trial before 16 th planting; $N_2P_0\ K_2$	Dec 06	05°0'10"	105°30'13"	35
	-7	Tamanbogo-NPK trial before 16 th planting; $N_2P_1\ K_2$	Dec 06	05°01'10"	105°30'13"	35
	-8	Tamanbogo-NPK trial before 16 th planting; $N_2P_3\ K_2$	Dec 06	05°01'10"	105°30'13"	35
	-9	Tamanbogo-NPK trial before 16 th planting; $N_2P_2\ K_0$	Dec 06	05°01'10"	105°30'13"	35
	-10	Tamanbogo-NPK trial before 16 th planting; $N_2P_2\ K_1$	Dec 06	05°01'10"	105°30'13"	35
	-11	Tamanbogo-NPK trial before 16 th planting; $N_2P_2\ K_3$	Dec 06	05°01'10"	105°30'13"	35
	-12	Tamanbogo-NPK trial before 16 th planting; $N_3P_3\ K_3$	Dec 06	05°01'10"	105°30'13"	35
	-13	Tamanbogo NPK trial II T_5 without lime	Mar 07	05°01'10"	105°30'13"	35
	-14	Tamanbogo NPK trial III T_5 with 4 t/ha lime	Mar 07	05°01'10"	105°30'13"	35
	-15	North Lampung, Dayasakti village; in 2-month old cassava; yellow sandy loam	Feb 09	04°13'43"	104°55'37"	77
	-16	North Lampung, Dayasakti village; in 8-month old cassava; yellow sandy loam	Feb 09	04°15'14"	104°54'04"	68
C-Java	-1	Pati, Tayu district, Soneyan town, in Marconah field, red clay	Sept 06			
	-2	Pati, sample of Adi Widjaya; yellow-black clay	Feb 07			
	-3	Pati, sample of Adi Widjaya; red-yellow clay	Feb 07			
Yogyakarta	-1	Gunung Kidul, Jambu; FPR fertilizer trial C+M+R, T_B (2t/ha FYM, 100 urea); good cassava	Mar 07	08°03'41"	110°37'22"	288
	-2	Gunung Kidul, Jambu; FPR fertilizer trial C+M+R, T_A (no FYM, 200 urea)	Mar 07	08°03'41"	110°37'22"	288
E. Java	-1	Malang Kromengan, Ngadirejo; FPR trial Mr. Miseri, yellow clay	Aug 06			
	-2	Malang, Batu, cassava leaf production trial, black soil	Feb 07	07°54'47"	112°31'56"	927
	-3	Blitar, Karang Gayam; on-farm variety trial, sandy loam	Feb 07	08°05'58"	112°02'30"	117
	-4	Blitar, Selorejo; on-farm variety trial, red-brown clay	Feb 07	08°08'56"	112°26'07"	289

Table 8. Soil samples taken in Indonesia from 2006 to 2009. (continued)

Sample no.		Sample location and description	Date	Coordinates S	Coordinates E	Elevation (masl)
W. Kalimantan	-1	Mempawah, Paril Bangar village, mixed peat	Mar 07	00°20'04"N	109°01'52"	5
	-2	Mempawah, Paril Bangar village, "young" organic soil	Mar 07	00°20'04"N	109°01'52"	5
	-3	Mempawah, Paril Bangar village, "very yong" peat, poor cassava	Mar 07	00°20'04"N	109°01'52"	5
	-4	Mempawah, Sungai Kunyit, Skip 1; new field of peat soil	Mar 07	00°30'07"N	108°57'23"	7
	-5	Mempawah, Sungai Kunyit, Skip 1; yellow sandy clay on steep stope	Mar 07	00°30'20"N	108°57'11"	16
S. Kalimantan	-1	Pelaihari, Jorong, Pelaihari town, large cassava field, yellow clay loam	Sept 06	03°54'50"	114°49'23"	44
	-2	Pelaihari, Ujung Batu 2, transmigration area; good cassava	Sept 06	03°42'50"	114°42'45"	17
	-3	Pelaihari, poor cassava on sandy loam with pebbles	Feb 07	03°53'32"	114°43'28"	8
S. Sulawesi	-1	Maros, Moncongloe, Bonto Bungo village, field of Adira 1; reddish yellow clay loam	Jul 07	05°09'06"	119°33'44"	57
SE. Sulawesi	-1	Konowe Selatan, Landono, Talumbinga village; cassava field on slope; yellow clay loam	Jul 07	04°02'11"	112°16'26"	761
	-2	Sorini concession; brown clay loam	Jul 07	04°36'14"	121°57'10"	38
E. Nusa Teng.	-1	W. Manggarai, Lembar, Golorongot village; large cassava area of CASPRO variety; black clay	Jul 07	08°40'28"	120°08'53"	144
	-2	W. Manggarai, Lembar, farmer's backyard with various cassava varieties; black-brown clay	Jul 07	08°41'33"	120°13'04"	351

Table 9. Chemical and physical characteristics of cassava soils in Indonesia, 2006-2009.

		← Chemical characteristics →														← Physical characteristics →			
			%	ppm	← me/100 g →					%	← ppm →					← % →			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Lampung	-1	4.13	1.77	2.83	2.86	0.43	0.19	0.07		81	0.44	0.44	22.7	0.72	27.5	34.0	14.9	51.1	clay
	-2	4.01	1.87	10.69	2.65	0.46	0.12	0.09		80									
	-3	4.07	1.71	15.37	2.24	0.51	0.15	0.13		74									
	-4	4.02	1.61	23.42	2.39	0.63	0.14	0.09		74									
	-5	3.96	1.45	11.99	2.70	0.33	0.10	0.08		84									
	-6	3.98	1.51	5.24	2.50	0.20	0.10	0.10		86									
	-7	4.04	1.65	6.16	2.60	0.38	0.16	0.08		81									
	-8	4.12	1.65	47.85	2.24	0.83	0.16	0.09		67									
	-9	3.95	1.89	60.91	2.76	0.32	0.10	0.05		85									
	-10	3.95	1.88	48.64	2.55	0.37	0.10	0.06		83									
	-11	3.91	1.88	49.21	2.70	0.40	0.13	0.11		81									
	-12	4.01	2.08	82.89	2.60	0.60	0.14	0.12		75	0.47	0.46	17.3	0.78	29.7	35.4	13.6	51.0	clay
	-13	4.43	1.60	23.44	2.44	0.25	0.06	0.06		87									
	-14	4.62	2.09	8.13	2.03	1.00	0.15	0.06		63									
	-15	4.80	1.28	1.50	0.83	2.00	0.51	0.15		23	0.65	0.52	12.4	0.41	69.1	44.7	16.4	38.9	c.l.
	-16	5.32	1.19	3.42	0.47	1.45	0.39	0.10		20	0.70	0.85	17.4	0.30	40.7	62.5	10.1	27.4	s.c.l.
C. Java	-1	4.41	1.82	7.51	3.07	1.33	0.40	0.16		62	0.99	3.02	422.6	5.40	36.8	9.0	28.9	62.1	clay
	-2	4.39	2.72	1.08	2.76	0.08	0.07	0.06		93	0.37	0.48	2.2	0.19	146.3	48.8	8.2	43.0	s.c.
	-3	4.22	3.06	1.38	7.80	0.07	0.08	0.07		97	0.33	0.43	1.8	0.57	165.1	41.5	9.8	48.7	clay
Yogyakarta	-1	5.70	1.85	5.53	0	12.67	1.14	0.38	0.04	0	0.68	1.70	179.9	2.70	5.1	10.5	27.6	61.9	clay
	-2	5.66	2.13	6.83	0	11.81	1.52	0.43	0.03	0	0.70	2.41	195.2	3.03	4.2	8.9	25.6	65.5	clay
E. Java	-1	5.14	0.81	2.67	0.57	5.49	1.62	0.37		7	0.46	1.70	54.7	3.82	47.0	25.1	32.3	42.6	clay
	-2	5.82	2.14	30.75	0	8.53	2.67	0.58	0.05	0	0.53	1.92	83.6	1.39	12.7	37.6	27.3	35.1	c.l.
	-3	5.41	0.55	45.66	0.83	1.27	0.20	0.25		33	0.45	0.26	5.2	0.81	14.4	67.7	14.9	17.4	s.l.
	-4	4.75	0.83	1.99	1.61	2.62	1.27	0.44		27	0.44	1.06	114.3	2.28	58.2	24.1	31.4	44.5	clay

[1)] s.c.l. = sandy clay loam. s.c. = sandy clay c.l.= clay loam s.l. = sandy loam

Table 9. Chemical and physical characteristics of cassava soils in Indonesia, 2006-2009. (continued)

		Chemical characteristics														Physical characteristics			
			%	ppm	me/100 g					%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
W. Kalimantan	-1	5.54	16.77	8.44	0	5.83	2.79	0.66	0.07	0	1.00	1.10	24.7	0.20	32.3	41.2	20.1	38.7	c.l.
	-2	4.77	34.00	15.16	1.40	8.46	3.61	0.29		10	1.78	0.73	20.3	0.14	19.6	53.0	19.2	27.8	s.c.l.
	-3	5.10	64.73	42.15	0.31	23.53	9.50	0.08		1	4.21	0.27	24.3	0.05	2.0	-	-	-	-
	-4	4.61	40.60	59.78	5.62	5.61	1.24	0.23		44	1.65	1.91	11.8	0.14	30.6	-	-	-	-
	-5	4.71	3.19	11.38	1.66	0.44	0.12	0.05		73	0.51	0.41	3.6	0.12	42.4	50.4	8.1	41.4	s.c.
S. Kalimantan	-1	4.44	2.03	1.99	1.35	0.11	0.07	0.06		85	0.57	0.38	42.6	0.90	29.7	28.7	32.8	38.5	c.l.
	-2	4.96	3.93	58.49	1.40	0.83	0.37	0.09		52	0.64	0.50	76.3	0.97	16.7	22.9	18.3	58.8	clay
	-3	5.20	2.45	7.85	1.51	0.44	0.16	0.05		70	0.46	0.38	9.2	1.34	44.1	50.0	18.7	31.3	s.c.l.
S. Sulawesi	-1	4.72	4.01	2.66	2.70	2.93	1.18	0.27		38	0.63	2.47	100.1	0.87	18.9	31.4	15.5	53.1	clay
SE. Sulawesi	-1	4.03	2.71	2.60	5.20	0.15	0.19	0.09		92	0.72	0.56	3.4	0.26	154.8	31.8	27.7	40.1	clay
	-2	5.57	1.76	1.82	0	2.94	2.29	0.18	0.02	0	0.94	4.27	92.9	0.49	11.7	44.5	22.6	32.8	c.l.
E. Nusa Teng.	-1	5.90	5.35	5.76	0	9.53	3.09	0.25	0.11	0	1.32	1.64	99.5	1.05	12.2	36.1	34.4	29.5	c.l.
	-2	5.77	4.07	2.48	0	6.83	1.99	0.83	0.04	0	1.14	6.09	261.6	2.22	21.2	20.4	37.1	42.4	clay

[1)]s.c.l. = sandy clay loam.
s.c. = sandy clay
c.l. = clay loam
s.l. = sandy loam

Table 10. Soil samples taken in Lao PDR from 2006-2008.

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Vientiane	-1	Naphok Agric Research Center; new cassava experimental field	Mar 08	18° 09' 28"	102° 44' 14"	165
	-2	Xaythani district, Ban Bor Lex; cassava variety trial in farmer's field	Feb 08			
Oudomxay	-1	La district, Huay Xang village; very good cassava on steep slope with pineapple hedgerows	Feb 08	20° 51' 39"	102° 12' 23"	831
	-2	La district, Huay Xang village; cassava field with intercrops, poorer cassava	Feb 08	20° 51' 27"	102° 12' 20"	787
	-3	Xay district, Na Senkham village; Chinese varieties on slope above reservoir; good cassava	Feb 08	20° 40' 40"	101° 57' 19"	684
Luang Prabang	-1	Luang Prabang, College of Agric.; cassava variety trial	Jan 06			
	-2	Luang Prabang College of Agric.; cassava variety trial, very vigorous growth	Nov 08	19° 59' 20"	102° 14' 38"	284
	-3	Luang Prabang, Ban Bo He village; cassava variety trial	Mar 07	19°57'52"	102°18'53"	369
	-4	Pak Ou, Haat Pang village, FPR variety trial on 40% slope	Mar 07	20°17'09"	102°23'19"	368
	-5	Pak Ou, Huay Pan village, FPR variety trial Mr. Singthong	Mar 07	20°15'43"	102°21'27"	324
	-6	Luang Prabang, Ban Pick Noy; FPR variety trial of Mrs. Chanh Fong, sandy loam soil along river;	Aug 07	19°53'22"	102°13'34"	363
	-7	Luang Prabang, Ban Pick Noy; cassava field with several varieties on steep slope; sandy clay	Aug 07	19°53'08"	102°13'12"	313
Saravanh	-1	Saravanh; red clay	Aug 07			
	-2	Cassava field along road from Saravanh to Pakxe; very vigorous growth on red soil	Oct 07	15°31'39"	106°15'18"	371

Table 10. Soil samples taken in Lao PDR from 2006 to 2008. (continued)

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Xieng Khouang	-1	Paek, Na Larm village; FPR variety trial Mr. Phonxay, very good cassava	Sept 06	19°36'39'	103°19'22"	1218
	-2	Paek, Na Larm village; FPR variety trial Mr. Xieng Phong, rather good cassava	Sept 06	19°36'48"	103°19'09"	1240
	-3	Paek, Na Larm village; FPR variety trial Mr. Don, good cassava	Sept 06	19°36'48"	105°18'58"	1201
	-4	Paek, Na Larm village; FPR variety trial Mr. Xieng Thandaa, rather good cassava	Sept 06			
	-5	Paek, Na Larm village; FPR variety trial Mr. Xieng Wan, grey red clay loam	Feb 07	19°36'47"	103°19'28"	1215
	-6	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_0P_0K_0$	Feb 08	19° 29' 12"	103° 08' 49"	1,081
	-7	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_0P_2K_2$	Feb 08			
	-8	Paek district, Cattle Bank; long-term NPK trial during 2d cycle: $N_1P_2K_2$	Feb 08			
	-9	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_2P_2K_2$	Feb 08			
	-10	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_3P_2K_2$	Feb 08			
	-11	Paek district, Cattle Bank; long-term NPK trial during 2d cycle;$N_2P_0K_2$	Feb 08			
	-12	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_2P_1K_2$	Feb 08			
	-13	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_2P_3K_2$	Feb 08			
	-14	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_2P_2K_0$	Feb 08			
	-15	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_2P_2K_1$	Feb 08			
	-16	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_2P_2K_3$	Feb 08			
	-17	Paek district, Cattle Bank; long-term NPK trial during 2d cycle; $N_3P_3K_3$	Feb 08			
	-18	Paek district, Koeu village; cassava field of Mr. Kamphone	Mar 08	19° 34' 03"	113° 20' 06"	1,151
	-19	Phou Khout, Pung village; FPR variety trial Mr. Thumma, rather good cassava	Sept 06	19°39'55"	103°08'59"	1123
	-20	Phou Khout, Somboon village; FPR variety trial Mr. Khamphua, very poor cassava	Sept 06			
	-21	Phou Khout, Somboon village; FPR variety trial Mr. Phouma, rather good cassava	Sept 06	19°39'56"	103°06'20"	1106
	-22	Nong Het, 2-year cassava on steep slope; grey-purple clay	Feb 07	19°34'05"	104°03'22"	1290
	-23	Nong Het, highland variety evaluation trial, yellow-orange clay loam	Mar 07			
	-24	Nonghet district, Tamphang, Thumpheng village; highland variety trial '08, Reps I, II and III	Mar 08	19° 30' 34"	104° 04' 05"	1,389

Table 11. Chemical and physical characteristics of cassava soils in Laos PDR, 2006-2008.

		← Chemical characteristics →													← Physical characteristics →			
			%	ppm	← me/100 g →					%	← ppm →					← % →		
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Vientiane	-1	4.43	0.85	5.67	2.60	0.22	0.13	0.28		80	0.42	0.52	58.9	0.55	41.5	16.8	39.0	44.2	clay
	-2	4.69	1.04	9.10	2.81	3.03	1.29	0.33		38	0.60	0.55	18.9	0.30	36.2	48.2	13.6	38.2	s.c.
Oudomxay	-1	4.48	2.43	6.29	4.26	0.45	0.44	0.27		79	0.63	1.46	159.4	0.94	30.9	20.6	28.1	51.3	clay
	-2	6.02	2.32	20.30	0.00	8.77	3.41	0.59		0	1.02	3.47	118.4	0.28	5.1	31.2	33.0	35.8	c.l.
	-3	4.89	1.81	6.38	1.77	3.97	2.71	0.46		20	0.69	1.38	217.4	0.34	16.9	12.9	33.2	53.8	clay
Luang Prabang	-1	6.62	1.50	46.59	0	6.23	1.37	0.34	0.03	0	0.50	4.39	97.2	1.63	53.4	18.6	40.8	40.6	l.c.
	-2	5.73	1.00	18.64	0.00	4.85	1.56	0.28		0	0.62	3.59	107.7	1.33	54.9	16.4	48.1	35.6	si.c.l.
	-3	5.17	3.77	29.59	1.66	1.26	1.15	0.34		38	0.35	2.25	54.5	0.85	20.5	13.8	26.7	59.5	clay
	-4	5.36	3.18	22.13	0.57	2.62	10.02	0.32		4	0.57	1.28	95.6	1.79	10.2	18.4	20.5	61.1	clay
	-5	6.36	3.92	15.66	0	10.43	9.09	0.42	0.04	0	0.57	1.73	78.7	1.17	6.6	32.1	30.6	37.3	c.l.
	-6	7.53	0.95	26.41	0	7.68	0.60	0.08	0.01	0	0.00	2.02	78.5	0.86	81.7	54.2	30.6	15.2	s.l.
	-7	4.81	3.18	9.27	3.59	3.15	2.60	0.19		38	-	1.58	65.8	0.84	49.5	20.3	22.1	57.6	clay
Saravanh	-1	6.07	5.01	8.27	0	1.36	0.56	1.06	0.02	0	0.97	7.85	211.9	1.15	5.4	24.5	30.1	45.4	clay
	-2	6.61	4.25	14.91	0	6.19	3.28	1.02	0.02	0	0.90	14.80	142.3	0.90	4.9	21.6	33.1	45.3	clay

[1)] s.c.l. = sandy clay loam.
l.c. = loamy clay
s.c. = sandy clay
c.l. = clay loam
si.c.l. = silty clay loam

Table 11. Chemical and physical characteristics of cassava soils in Laos PDR, 2006-2008. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Xieng Khouang	-1	5.06	5.79	3.31	1.92	0.56	0.27	0.20		65	0.65	0.99	77.3	0.12	22.7	17.9	23.1	59.1	clay
	-2	5.19	6.27	5.02	1.66	0.75	0.44	0.64		48	0.70	1.63	82.7	0.28	18.9	20.3	20.5	59.2	clay
	-3	4.74	7.24	2.95	4.42	0.29	0.23	0.38		83	0.79	0.88	32.3	0.35	48.3	22.8	10.3	66.9	clay
	-4	5.27	6.20	3.50	0.88	2.29	0.64	0.30		21	0.59	1.51	61.9	0.28	31.5	45.8	11.5	42.7	s.c.
	-5	5.01	8.35	19.18	3.59	0.89	0.32	0.24		71	0.98	1.30	75.3	0.02	15.5	24.5	21.5	54.0	clay
	-6	4.93	1.75	2.14	1.66	1.02	0.82	0.09		46	0.34	0.33	1.0	0.31	34.0	28.0	33.8	38.2	c.l.
	-7	4.72	1.82	9.63	2.39	0.68	0.53	0.11		64									
	-8	4.60	1.84	8.13	2.08	0.82	0.59	0.11		58									
	-9	5.44	1.86	3.01	0.78	1.85	1.47	0.10		19									
	-10	4.81	1.80	5.76	2.55	0.60	0.40	0.13		69									
	-11	4.80	1.80	1.95	2.50	0.52	0.38	0.12		71									
	-12	4.76	1.74	4.04	2.55	0.60	0.44	0.10		69									
	-13	4.88	1.87	11.22	2.39	0.71	0.48	0.11		65									
	-14	5.06	1.65	18.64	1.51	1.06	0.81	0.09		43									
	-15	4.91	1.71	8.54	2.34	0.59	0.44	0.09		68									
	-16	4.79	1.78	3.86	2.44	0.56	0.41	0.12		69									
	-17	4.89	1.82	17.58	2.24	0.79	0.55	0.12		60	0.42	0.35	0.8	0.28	35.5	28.0	31.3	40.7	clay
	-18	5.54	1.68	17.15	0.00	4.49	1.33	0.47		0	1.09	7.49	41.1	0.71	68.5	36.5	23.2	40.3	clay
	-19	4.75	5.35	2.32	2.44	0.13	0.07	0.09		89	0.40	0.48	8.3	0.63	26.8	52.4	8.9	38.7	s.c.
	-20	4.85	5.54	4.53	1.98	0.55	0.22	0.15		68	0.34	0.86	30.1	1.51	38.6	46.9	11.5	41.6	s.c.
	-21	4.70	5.87	2.05	3.38	0.25	0.12	0.12		87	0.45	0.58	5.1	0.52	89.5	34.4	23.0	42.7	clay
	-22	6.25	7.12	19.41	0	11.18	2.78	0.46	0.02	0	1.08	2.41	201.2	0.12	11.2	31.1	27.9	41.0	clay
	-23	4.53	7.37	13.52	9.41	0.96	0.34	0.29		86	0.49	1.64	17.9	0.98	204.2	24.0	14.2	61.8	clay
	-24	3.91	3.18	2.22	14.50	0.35	0.23	0.22		95	1.22	2.68	9.1	0.31	167.4	39.0	19.8	41.2	clay

[1)]s.c.l. = sandy clay loam, l.c. = loamy clay, s.c. = sandy clay, c.l. = clay loam, si.c.l. = silty clay loam

Table 12. Soil samples taken in Thailand from 2007 to 2009.

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Pathum Thani	-1	Acid sulfate soil; black on 6 m wide bank without lime, with Jatropha	Jan 07	14°15'19"	100°54'41"	0
	-2	Acid sulfate soil; in ditch between 6 m wide banks	Jan 07	14°15'19"	100°54'41"	0
	-3	Acid sulfate soil; on bank with oilpalm, without fertilizer or lime	Jan 07	14°13'35"	100°55'07"	1
Prachinburi	-1	Kabinburi district, La Ta Kian subdistrict; FE Clean Energy cassava plantation site	Jan 09	13° 54' 58"	101° 40' 33"	19
Chachoengsao	-1	304 Industrial Park, site of ethanol factory and cassava field	Jan 09	13° 42' 27"	101° 29' 14"	25

Table 13. Chemical and physical characteristics of cassava soils in Thailand, 2006-2009.

		← Chemical characteristics →														← Physical characteristics →			
			%	ppm	← me/100 g →					%	← ppm →					← % →			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Pathum Thani	-1	4.16	1.84	16.59	10.45	4.43	0.76	0.24		66	1.29	1.59	17.3	2.69	93.6	7.9	19.8	72.3	clay
	-2	4.33	5.82	3.14	6.08	5.68	2.36	0.42		42	2.33	9.15	23.5	2.11	239.7	-	-	-	-
	-3	6.92	3.99	434.78	-	20.19	6.02	1.17	0.38	0	2.11	5.64	31.3	0.51	3.0	7.7	25.0	67.3	clay
Prachinburi	-1	6.15	0.91	8.66	0.00	2.41	0.96	0.81	0.05	0	1.68	3.05	187.4	1.66	13.5	38.6	36.5	24.9	loam
Chachoensao	-2	6.23	0.43	13.41	0.00	2.31	0.77	0.09	0.05	0	0.74	1.96	59.4	1.28	35.9	56.2	26.4	17.4	s.l

[1)]s.l. = sandy loam.

Table 14. Soil samples taken in Vietnam from 2006 to 2009.

Sample no.	Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Hue	-1 A Luoi, Hong Ha commune; erosion trial, 1m above pineapple hedgerow	Jul 07	16°17'41"	107°21'20"	80
	-2 A Luoi, Hong Ha commune; erosion trial, 1m below pineapple hedgerow	Jul 07			
Quang Tri	-1 Cam Lo district, Tan Lam commune; very vigorous KM 94; red clay loam in small cassava field	Feb 09	16° 47' 25"	106° 56' 02"	31
	-2 Huong Hoa district, Tan Lap commune, Langvay village; poor cassava on steep slope	Feb 09	16° 36' 11"	106° 40' 43"	
	-3 Huong Hoa district, Axing commune; very hard clay loam in plot without fert. in fertilizer. trial	Feb 09	16° 28' 35"	106° 42' 30"	249
	-4 Huong Hoa district, Adoi commune; grey clay loam in field with good cassava, 1st year?	Feb 09	16° 28' 20"	106° 44' 33"	317
	-5 Huong Hoa district, Thuan commune; hard pink clay loam; rather good cassava	Feb 09	16° 32' 38"	106° 39' 41"	221
Dak Lak	-1 Along road to Krong Bong district, KM 94 on steep slope, dark yellow clay	Jul 07			
	-2 Krong Bong, Cu Kty commune, Unit 6; in demonstration plot after 14 years of cassava on 15-20% slope, yellow clay loam	Jul 07	12°34'22"	108°21'49"	461
	-3 Krong Bong, Khue Ngoc Dien commune, Unit 1; off-season cassava field in sandy loam alluvial soil	Jul 07	12°32'09"	108°19'07"	420
Dong Nai	-1 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_1 = N_0P_0K_0$	Apr 06			
	-2 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_2 = N_0P_2K_2$	Apr 06			
	-3 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_3 = N_1P_2K_2$	Apr 06			
	-4 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_4 = N_2P_2K_2$	Apr 06			
	-5 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_5 = N_3P_2K_2$	Apr 06			
	-6 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_6 = N_2P_0K_2$	Apr 06			
	-7 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_7 = N_2P_1K_2$	Apr 06			
	-8 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_8 = N_2P_3K_2$	Apr 06			
	-9 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_9 = N_2P_2K_0$	Apr 06			
	-10 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_{10} = N_2P_2K_1$	Apr 06			
	-11 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_{11} = N_2P_2K_3$	Apr 06			
	-12 Thong Nhat district, Hung Loc Center; long-term NPK trial-17 th year (2006/07) $T_{12} = N_3P_3K_3$	Apr 06			
	-13 Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_1 = N_0P_0K_0$	Apr 07			
	-14 Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_2 = N_0P_2K_2$	Apr 07			
	-15 Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_3 = N_1P_2K_2$	Apr 07			
	-16 Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_4 = N_2P_2K_2$	Apr 07			
	-17 Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_5 = N_3P_2K_2$	Apr 07			
	-18 Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_6 = N_2P_0K_2$	Apr 07			
	-19 Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_7 = N_2P_1K_2$	Apr 07			

Table 14. Soil samples taken in Vietnam from 2006 to 2009. (continued)

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Dongnai	-20	Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_8 = N_2P_3K_2$	Apr 07			
	-21	Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_9 = N_2P_2K_0$	Apr 07			
	-22	Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_{10} = N_2P_2K_1$	Apr 07			
	-23	Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_{11} = N_2P_2K_3$	Apr 07			
	-24	Thong Nhat district, Hung Loc Center; long-term NPK trial-18 th year (2007/08) $T_{12} = N_3P_3K_3$	Apr 07			
	-25	Hung Loc Center; long-term NPK trial, before 19th planting, N0P0K0	May 08			
	-26	Hung Loc Center; long-term NPK trial, before 19th planting, N0P2K2	May 08			
	-27	Hung Loc Center; long-term NPK trial, before 19th planting, N1P2K2	May 08			
	-28	Hung Loc Center; long-term NPK trial, before 19th planting, N2P2K2	May 08			
	-29	Hung Loc Center; long-term NPK trial, before 19th planting, N3P2K2	May 08			
	-30	Hung Loc Center; long-term NPK trial, before 19th planting, N2P0K2	May 08			
	-31	Hung Loc Center; long-term NPK trial, before 19th planting, N2P1K2	May 08			
	-32	Hung Loc Center; long-term NPK trial, before 19th planting, N2P3K2	May 08			
	-33	Hung Loc Center; long-term NPK trial, before 19th planting, N2P2K0	May 08			
	-34	Hung Loc Center; long-term NPK trial, before 19th planting, N2P2K1	May 08			
	-35	Hung Loc Center; long-term NPK trial, before 19th planting, N2P2K3	May 08			
	-36	Hung Loc Center; long-term NPK trial, before 19th planting, N3P3K3	May 08			
	-37	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, with fert. (2006/07) T_1	Apr 06			
	-38	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, with fert. (2006/07) T_2	Apr 06			
	-39	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, with fert. (2006/07) T_3	Apr 06			
	-40	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, with fert. (2006/07) T_4	Apr 06			
	-41	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, with fert. (2006/07) T_5	Apr 06			
	-42	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, with fert. (2006/07) T_6	Apr 06			
	-43	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, with fert. (2006/07) T_7	Apr 06			
	-44	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, with fert. (2006/07) T_8	Apr 06			

Table 14. Soil samples taken in Vietnam from 2006 to 2009. (continued)

Sample no.		Sample location and description	Date	Coordinates S	Coordinates E	Elevation (masl)
Dong Nai	-45	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, no fert. (2006/07) T_1	Apr 06			
	-46	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, no fert. (2006/07) T_2	Apr 06			
	-47	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, no fert. (2006/07) T_3	Apr 06			
	-48	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, no fert. (2006/07) T_4	Apr 06			
	-49	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, no fert. (2006/07) T_5	Apr 06			
	-50	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, no fert. (2006/07) T_6	Apr 06			
	-51	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, no fert. (2006/07) T_7	Apr 06			
	-52	Thong Nhat district, Hung Loc Center; soil improvement trial-15 th year, no fert. (2006/07) T_8	Apr 06			
	-53	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, with fert. (2007/08) T_1	Apr 07			
	-54	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, with fert. (2007/08) T_2	Apr 07			
	-55	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, with fert. (2007/08) T_3	Apr 07			
	-56	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, with fert. (2007/08) T_4	Apr 07			
	-57	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, with fert. (2007/08) T_5	Apr 07			
	-58	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, with fert. (2007/08) T_6	Apr 07			
	-59	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, with fert. (2007/08) T_7	Apr 07			
	-60	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, with fert. (2007/08) T_8	Apr 07			
	-61	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, no fert. (2007/08) T_1	Apr 07			
	-62	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, no fert. (2007/08) T_2	Apr 07			
	-63	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, no fert. (2007/08) T_3	Apr 07			
	-64	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, no fert. (2007/08) T_4	Apr 07			
	-65	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, no fert. (2007/08) T_5	Apr 07			
	-66	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, no fert. (2007/08) T_6	Apr 07			
	-67	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, no fert. (2007/08) T_7	Apr 07			
	-68	Thong Nhat district, Hung Loc Center; soil improvement trial-16 th year, no fert. (2007/08) T_8	Apr 07			
	-69	Thong Nhat district, Hung Loc Center; soil erosion trial-11 th year, no fert. (2007/08) T_1	Apr 07			
	-70	Thong Nhat district, Hung Loc Center; soil erosion trial-11 th year, no fert. (2007/08) T_2	Apr 07			
	-71	Thong Nhat district, Hung Loc Center; soil erosion trial-11 th year, no fert. (2007/08) T_3	Apr 07			
	-72	Thong Nhat district, Hung Loc Center; soil erosion trial-11 th year, no fert. (2007/08) T_4	Apr 07			
	-73	Thong Nhat district, Hung Loc Center; soil erosion trial-11 th year, no fert. (2007/08) T_5	Apr 07			
	-74	Thong Nhat district, Hung Loc Center; soil erosion trial-11 th year, no fert. (2007/08) T_6	Apr 07			

Table 15. Chemical and physical characteristics of cassava soils in Vietnam, 2006-2009.

		← Chemical characteristics →														← Physical characteristics →			
			%	ppm	← me/100 g →					%	← ppm →					← % →			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Hue	-1	4.42	2.16	1.56	1.82	0.67	0.26	0.06		65	0.55	4.98	102.4	2.42	71.0	51.9	11.4	36.8	s.c.
	-2	4.37	2.27	2.42	2.39	0.48	0.25	0.07		75	0.61	2.77	124.9	2.63	84.3	44.2	16.4	39.4	c.l.
Quang Tri	-1	5.63	1.04	111.18	0.00	4.44	1.10	0.34		0	0.89	8.20	138.0	2.79	11.6	14.2	33.0	52.8	clay
	-2	5.57	1.34	1.57	0.00	5.31	3.00	0.77		0	0.88	4.88	198.2	1.77	9.3	24.5	30.8	44.7	clay
	-3	4.89	1.06	2.26	1.66	3.60	1.75	0.17		23	0.66	0.91	37.2	0.19	42.0	10.0	43.2	46.8	si.c
	-4	5.92	1.80	22.70	0.00	4.81	2.33	1.96		0	0.91	5.44	115.6	0.29	6.8	48.2	26.7	25.2	s.c.l.
	-5	4.73	0.68	3.30	2.81	1.69	0.98	0.13		50	0.53	0.49	22.7	0.43	35.0	18.2	46.7	35.1	si.c.l
Dak Lak	-1	4.35	3.27	4.25	2.13	0.93	0.33	0.12		61	0.55	1.80	38.5	1.03	57.8	21.4	31.6	47.0	clay
	-2	4.32	2.43	3.09	1.40	1.65	0.90	0.20		34	0.68	1.55	96.8	0.86	32.4	14.0	37.9	48.1	clay
	-3	4.72	1.10	15.46	0.73	1.14	0.51	0.16		29	0.58	2.74	33.5	0.85	179.0	59.7	15.1	25.2	s.c.l.
Dong Nai	-1	3.96	2.20	33.69	2.81	0.61	0.14	0.11		77	0.54	4.67	76.6	1.04	18.7	5.7	19.1	75.2	clay
	-2	3.78	2.01	42.59	3.22	0.67	0.12	0.13		78									
	-3	3.82	2.02	47.79	3.01	0.70	0.15	0.11		76									
	-4	3.72	2.18	50.57	3.33	0.70	0.11	0.14		78									
	-5	3.76	2.22	33.03	3.48	0.59	0.11	0.12		81									
	-6	3.74	2.27	17.55	3.38	0.46	0.14	0.17		81									
	-7	3.73	2.32	32.52	3.22	0.64	0.12	0.16		78									
	-8	3.91	2.12	71.16	3.12	0.97	0.14	0.12		72									
	-9	3.82	2.06	62.42	3.38	0.73	0.15	0.09		78									
	-10	3.73	2.31	48.57	3.28	0.74	0.11	0.10		78									
	-11	3.78	2.31	47.29	3.28	0.69	0.12	0.15		77									
	-12	3.79	2.50	94.71	3.17	1.17	0.15	0.18		68	0.52	1.99	108.2	0.82	16.8	4.2	20.4	75.4	clay
	-13	4.06	2.40	26.74	3.07	0.55	0.15	0.09		80	0.54	2.03	86.6	0.77	17.4	2.9	17.9	79.2	clay
	-14	4.20	2.45	45.26	3.02	0.58	0.10	0.14		79									
	-15	4.19	2.30	44.30	3.12	0.57	0.11	0.11		80									
	-16	4.26	2.29	47.00	3.07	0.79	0.13	0.15		74									
	-17	4.11	2.34	35.85	3.12	0.61	0.09	0.15		79									
	-18	4.19	2.34	23.10	2.91	0.53	0.13	0.17		78									

[1)] s.c.l. = sandy clay loam, s.c. = sandy clay, s.l. = clay loam, si.c = silty clay

Table 15. Chemical and physical characteristics of cassava soils in Vietnam, 2006-2009. (continued)

		Chemical characteristics														Physical characteristics			
			%	ppm	me/100 g					%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
DongNai	-19	4.16	2.53	27.88	2.96	0.62	0.11	0.14		77									
	-20	4.31	2.43	92.65	2.76	1.20	0.13	0.13		65									
	-21	4.14	2.33	46.52	3.28	0.51	0.10	0.07		83									
	-22	4.28	2.23	47.73	3.17	0.46	0.06	0.09		84									
	-23	4.32	2.47	53.07	2.70	0.79	0.11	0.28		70									
	-24	4.33	2.56	81.84	2.55	1.16	0.13	0.22		63	0.70	1.68	88.4	0.62	18.6	4.4	21.6	74.0	clay
	-25	4.74	0.89	31.38	3.12	0.47	0.14	0.12		81	0.44	1.64	53.8	0.75	14.6	4.9	17.7	77.4	clay
	-26	4.71	0.82	57.66	3.02	0.57	0.11	0.14		79									
	-27	4.73	0.86	35.22	3.02	0.58	0.15	0.14		78									
	-28	4.55	0.91	42.96	2.91	0.64	0.15	0.16		75									
	-29	4.61	0.88	37.87	3.17	0.53	0.11	0.13		80									
	-30	4.73	0.90	21.53	3.07	0.41	0.11	0.17		82									
	-31	4.66	0.89	32.56	3.02	0.52	0.12	0.19		78									
	-32	4.38	0.86	77.48	2.96	0.67	0.11	0.13		76									
	-33	4.62	0.77	58.44	3.33	0.41	0.07	0.08		86									
	-34	4.65	0.70	36.84	3.22	0.42	0.08	0.10		84									
	-35	4.64	0.90	37.81	2.81	0.52	0.09	0.22		77									
	-36	4.51	0.84	70.44	2.86	0.84	0.14	0.19		71	0.40	1.30	44.9	0.64	16.6	4.8	20.7	74.4	clay
	-37	3.90	2.42	18.33	3.22	0.70	0.16	0.13		76	0.58	1.81	95.4	0.87	20.0	3.3	16.5	80.2	clay
	-38	3.93	2.37	16.08	3.12	0.77	0.20	0.15		74									
	-39	3.91	2.41	14.34	3.02	0.77	0.18	0.11		74									
	-40	3.86	2.60	19.03	3.28	0.76	0.18	0.15		75									
	-41	3.90	2.46	16.98	3.02	0.73	0.18	0.16		74									
	-42	4.07	2.21	18.81	3.02	0.76	0.19	0.14		73									
	-43	3.90	2.74	20.61	3.12	0.83	0.26	0.17		71									
	-44	3.93	1.16	15.68	3.12	0.70	0.19	0.13		75	0.59	1.82	105.0	0.95	17.9	3.1	17.8	79.1	clay
	-45	3.98	2.31	18.96	2.76	0.48	0.17	0.20		76	0.67	1.73	101.2	0.58	14.4	1.8	20.4	77.8	clay
	-46	3.88	2.25	12.84	3.22	0.51	0.16	0.09		81									

[1)]s.c. = sandy clay, c.l. = clay loam, s.c.l. = sandy clay loam

Table 15. Chemical and physical characteristics of cassava soils in Vietnam, 2006-2009. (continued)

		← Chemical characteristics →														← Physical characteristics →			
			%	ppm	← me/100 g →					%	← ppm →					← % →			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Na	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
DongNai	-47	3.90	2.40	11.68	2.91	0.74	0.29	0.13		71									
	-48	3.82	2.40	14.30	3.07	0.52	0.19	0.11		79									
	-49	3.87	2.33	14.13	3.12	0.51	0.18	0.26		77									
	-50	3.93	2.28	11.89	3.02	0.52	0.18	0.14		78									
	-51	3.80	2.82	17.63	2.96	0.77	0.25	0.24		70									
	-52	3.87	2.67	13.98	2.81	0.95	0.31	0.27		65	0.74	2.00	127.1	0.58	15.6	2.7	17.9	79.4	clay
	-53	4.38	2.35	13.96	2.91	0.64	0.15	0.13		76	0.50	2.13	99.6	0.91	17.3	3.1	17.8	79.1	clay
	-54	4.43	2.52	16.31	2.81	0.63	0.14	0.15		75									
	-55	4.34	2.46	13.08	2.76	0.66	0.17	0.10		75									
	-56	4.35	2.59	26.39	2.86	0.71	0.14	0.12		75									
	-57	4.28	2.67	19.23	2.70	0.67	0.14	0.13		74									
	-58	4.30	2.56	16.26	2.76	0.62	0.16	0.13		75									
	-59	4.21	3.08	28.82	2.55	0.82	0.26	0.18		67									
	-60	4.20	2.62	21.77	2.76	0.63	0.17	0.14		75									
	-61	4.11	2.24	15.73	1.65	0.63	0.16	0.16		63	0.67	2.04	100.0	0.95	17.0	3.1	17.8	79.1	clay
	-62	4.09	2.46	14.53	2.96	0.58	0.15	0.13		77									
	-63	4.12	2.35	14.33	2.81	0.72	0.22	0.14		72									
	-64	4.06	2.48	18.86	3.07	0.55	0.16	0.13		79									
	-65	4.11	2.36	17.70	2.91	0.49	0.17	0.22		77									
	-66	4.14	2.44	15.00	2.81	0.66	0.15	0.16		74									
	-67	3.97	2.82	18.26	2.86	0.76	0.25	0.23		70									
	-68	3.98	2.51	15.33	2.86	0.78	0.25	0.22		70	0.71	3.67	136.9	0.98	18.2	5.5	14.0	80.5	clay
	-69	4.71	3.14	26.06	1.77	1.87	0.50	0.15		41	0.72	2.77	151.1	0.89	20.7	7.2	22.2	70.6	clay
	-70	4.50	3.22	35.37	2.34	1.49	0.31	0.22		54									
	-71	4.60	3.16	30.63	2.18	1.40	0.38	0.17		53									
	-72	4.70	3.34	27.51	1.98	1.89	0.47	0.15		44									
	-73	4.72	3.49	36.27	1.72	2.28	0.54	0.17		37									
	-74	4.63	3.34	33.49	1.77	2.18	0.53	0.18		38	0.89	2.83	136.1	0.86	20.8	5.7	18.4	75.9	clay

[1)] s.c.l. = sandy clay loam, c.l. = clay loam, s.c. = sandy clay