Cassava Research and Development in Asia:

Exploring New Opportunities for an Ancient Crop

Proceedings of the Seventh Regional Workshop
held in Bangkok, Thailand. Oct 28-Nov 1, 2002

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The Nippon Foundation

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Editor: R.H. Howeler

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Cover Photos:

Top: R.H. Howeler: Adoption of new technologies through FPR in Kanchanaburi, Thailand, has led to improved cassava production and yields

Bottom: Huang Jie: Farmers in Hainan, China, are very happy with the high yields obtained with the newly released variety, SC7

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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 cassava local 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 300 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 and in Ho Chi Minh city, Vietnam in early 2000. 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 25-35 years. The 7th Regional Cassava Workshop was held in Bangkok, Thailand in Oct/Nov 2002. Publication of the Proceedings of that Workshop has been delayed, but this book will hopefully soon be on the shelves of all cassava researchers in Asia, to provide important information about the latest developments and progress in cassava research in this part of the world.

Unlike the previous workshops, the 7th Workshop not only dealt with cassava breeding and agronomy research, as well as the progress made in the Nippon Foundation-funded FPR projects in China, Thailand and Vietnam, but also included the recent research conducted in various new topics, such as the use of cassava roots and leaves for animal feeding, the latest developments in cassava processing into starch and many starch-derived products, as well as the development of cassava growth models.

During the past decade important progress has been made, especially in the development, dissemination and adoption by farmers of new cassava varieties and improved cultural practices. Since the early 1980s over 60 cassava varieties have been released in seven countries in Asia, of which at least 45 varieties had been derived with some germplasm from Latin America. It is estimated that these new varieties are now grown in slightly over 1.5 million ha or 43% of the cassava growing area in Asia. This, and the widespread adoption of better cultural practices, including fertilization and soil conservation practices, have increased cassava yields in Asia from 12.93 t/ha in 1994 to 17.16 t/ha in 2004, corresponding to a annual rate of increase of about 3%. This increased yield, as well as the higher starch content of the roots, is annually providing cassava farmers in Asia with at least 400 million US dollars additional gross income.

This has been achieved through the close collaboration between the national cassava research and extension organizations in each country and among countries, as well as with the CIAT Cassava Program, both in Asia and in Colombia. During the past twelve years this net-working among countries, and especially the implementation of the Farmer Participatory Research Project, was only possible through the generous financial support from the Nippon Foundation in Tokyo, Japan. I want to take this opportunity to thank the Nippon Foundation for their continuous and generous support in this joint endeavor to provide a better future for cassava producers and consumers in Asia.

R.H. Howeler
CIAT, Bangkok
December, 2006

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OPENING ADDRESS

Dr. Suthep Limthongkul
Deputy Director General
Dept. of Agriculture of Thailand

Distinguished guests, ladies and gentlemen:

On behalf of the Department of Agriculture in Thailand we welcome you as participants of the 7th Regional Cassava Workshop. I hope that you will have a pleasant stay and will enjoy our Thai hospitality.

I understand that the objective of this Workshop is to increase the efficiency of cassava production, to improve processing of cassava-based products and to identify new markets for these products. This is a very laudable objective as millions of farmers in Asia depend on this crop as their main source of income, while in some countries cassava continues to be a very important food, especially for the poor.

During the past 15 years the Asian Cassava Research Network has already held six Workshops similar to the present one, each one in a different country, so that every three years one country can highlight their particular problems and present their strategies to overcoming the existing constraints. By sharing our knowledge and experience in all the different aspects of cassava, from land preparation to marketing and consumption, we can all contribute to overcoming those constraints.

In the past, one of the major constraints in the cassava sector of Thailand was the reliance on a single variety, Rayong 1, which was planted in over one million hectares. Now, through our collaboration with CIAT, we have introduced thousands of seeds from Latin America to substantially broaden the genetic base of cassava, which allowed us to breed, select, and release eight new high-yielding varieties over the past 20 years. At least 3-4 of these are now widely planted in over 90% of the cassava area in Thailand. I understand that some of these have also been released in other countries and have become quite popular. We are happy that our work has contributed to the well-being of farmers in other countries as well, and maybe some day, Thai farmers can benefit from varieties developed by some of your breeding programs. However, we have to remain very vigilant that no disease or insect problems are introduced through the careless movement of cassava vegetative planting material from one country to another.

Another constraint in Thailand, as well as in many other countries, is that continuous cassava production on the same land, may lead to soil degradation through nutrient depletion and erosion. Convincing farmers to use soil conservation practices is not an easy task. However, the farmer participatory approach used by the Nippon Foundation project has shown that it can be done, that farmers are more than willing to invest their time and money in improved soil management practices once they have seen on their own fields that soil erosion is indeed a serious problem and that various simple practices are highly effective in reducing erosion while also increasing yields and income. This project has achieved remarkable levels of adoption of improved practices in various countries in the region. The success in Thailand was at least in part the result of a highly effective collaboration between the Departments of Agriculture and Agricultural Extension, the Department of Land Development, Kasetsart University and the Thai Tapioca Development Institute, which all joined hands with CIAT, to not only develop but also disseminate those practices.

We are convinced that this kind of Workshops, with participation of people from so many different countries and from different organizations within each country, has contributed in the past to overcoming serious problems and constraints in the cassava sector. We hope that this will continue also in the future.

With this I declare this Workshop as opened.

I wish you all a successful meeting. Thank you.

A NEW OUTLOOK FOR CASSAVA IN THAILAND

-KEYNOTE ADDRESS-

Charae Chutharatkul[1]
President Thai Tapioca Development Institute, TTDI

Discovering during the 1960s, that low cost "cassava chips" could be utilized as "grain substitute" in the European feed industry, the export of cassava chips and pellets from Thailand to Europe grew rapidly from zero to 7 million tonnes, until both sides agreed to limit the export to 5.5 million tonnes per annum at a low tariff of 6%. To meet this lucrative export demand, production of fresh cassava roots increased by increasing the growing areas, mainly by moving from the Eastern sea coast (Zone 7) to the Northeastern region (Zones 2, 3, 4, 5 in **Figure 1**). Huge storage and transportation facilities were also developed to support the export of cassava chips, and later pellets.

While enjoying the export to EU at a premium price, exports to other countries as well as the domestic utilization of cassava were very limited. The industry became dependent on "one product to one market". To control the export so as not to exceed the agreed upon 5.5 million tonnes per annum, the government regulated the cassava trade. In addition, to support the farmers' demand for higher root prices the government initiated various forms of interventions and price support schemes.

Ironically, the management of the export quota became one of the "innovative management technologies"

The European Commission's Common Agricultural Policy Reform in the early 1990s signaled the danger of the "one product to one market" approach. Considering the diminishing competitiveness of Thai cassava in EU markets, the future of the cassava industry looked bleak. In order to survive, alternatives had to be found and new strategies had to be undertaken. A three-pronged strategy was agreed upon:

-Improve Thailand's competitiveness by reducing the cost of root production through introduction and planting of new high-yield and high-starch varieties.
-Develop new and competitive products, capitalizing on the lower cost of roots.
-Create a "Fund" to finance the endeavor, circumventing the bureaucracy by establishing an independent non-governmental organization to carry out the task.

In 1993, a "special fund" of US$ 30 million was established, and the Thai Tapioca Development Institute (TTDI) Foundation was formed. Two high-yield varieties, KU 50 and Rayong 5, were selected and multiplied at TTDI's 300 ha Research and Training Center in Huay Bong, Nakhon Ratchasima province. Subsequently, stems of these new varieties were distributed free of charge to farmers, who also received basic training to

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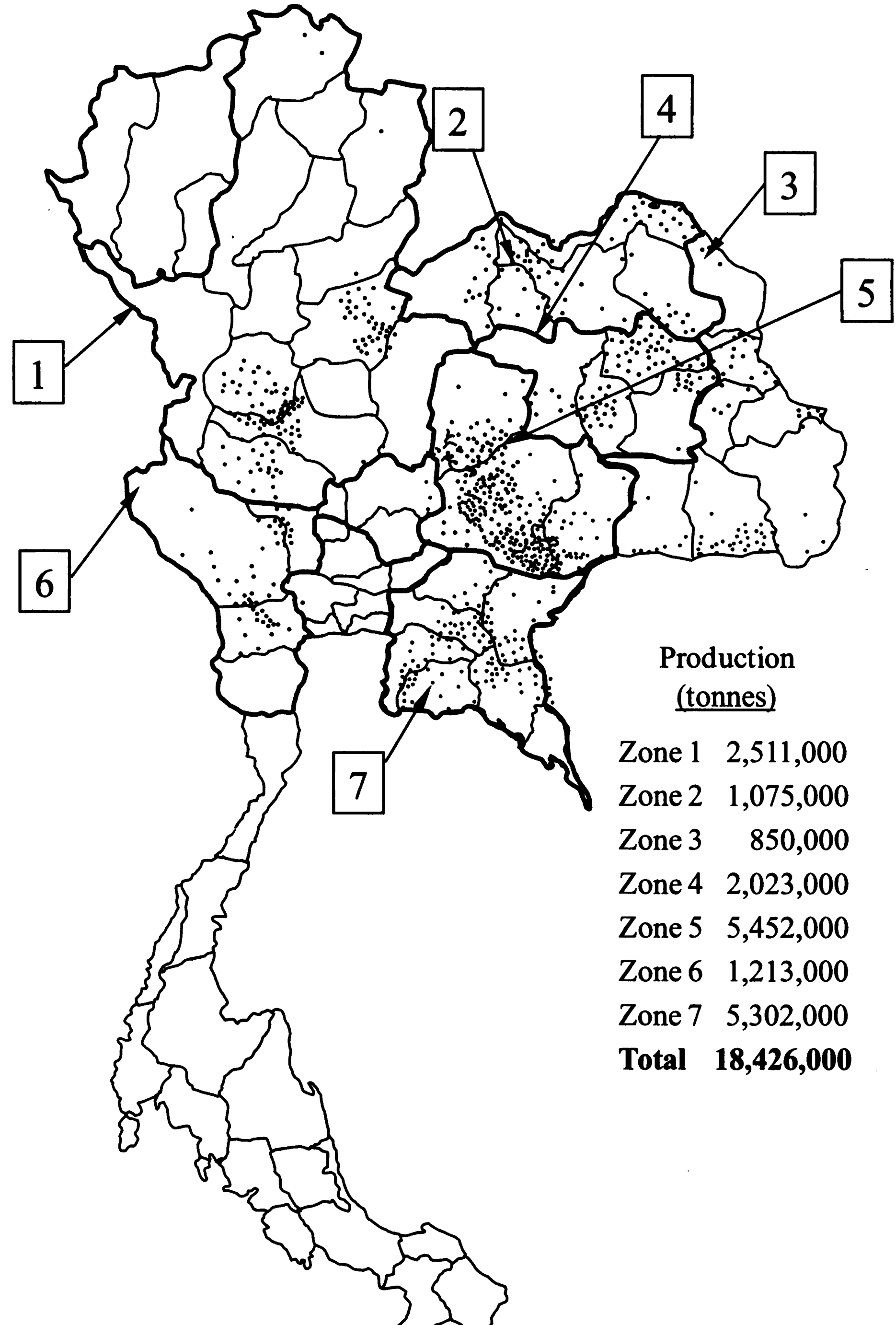

Production (tonnes)	
Zone 1	2,511,000
Zone 2	1,075,000
Zone 3	850,000
Zone 4	2,023,000
Zone 5	5,452,000
Zone 6	1,213,000
Zone 7	5,302,000
Total	**18,426,000**

Figure 1. Cassava growing areas and production in seven agro-ecological zones of Thailand in 1998. Each dot represent 1,000 ha
Source: *Dept. Agric. Extension, 1998.*

increase the crop's productivity. Over time, the farmers' interest in changing to high yielding cassava varieties grew and government agencies responded to this increasing demand for planting material of new cassava varieties. From a small beginning and within ten years, new varieties are now planted in 99% of the cassava-growing areas of about 1 million ha. The most popular variety is KU 50, which is planting in about 63% of the total area.

The new varieties made possible some fundamental changes in the cassava sector and further strengthened the already strong position of the Thai cassava industry in the world market. Numerous value-added products have been developed and commercialized, and the markets have continuously diversified (**Table 1** and **2**).

Table 1. Recent structural changes in cassava production and utilization in Thailand.

- Change to high yield-varieties completed
- Strong farmer interest to increase productivity: new varieties and improved cultivation techniques
- Yield increases to 17.0 t/ha
  -ex farm cost has decreased
  -starch content has increased
- Starch factories pay higher prices for roots
- Structural shifts in processing
  -from chips/pellets to starch and starch derivatives
  -from feed to industrial-based products
- >50% utilization of fresh roots for production of 2.5 million tonnes of starch = 11 million tonnes of fresh roots

Table 2. Recent changes in cassava processing and marketing in Thailand.

- Revival of chip production for the Chinese market
- Ten new cassava starch factories under construction in 2001 with a capacity to produce 2,700 tonnes starch/day = 4 million tonnes of roots a year
- Total 72 starch factories with a capacity to use 16.8 million tonnes of roots or 90% of production
- New usage: eight ethanol factories approved; expected to use 4 million tonnes of roots by 2004
- Continue expansion of starch derivative facilities: maltose, dextrine, dextrose, glucose, sorbitol, modified starch etc., especially production of ethanol and alcohol

The average cassava yield in Thailand has increased from 13.8 t/ha in 1994 to 17.0 t/ha in 2002, while the starch content increased from 24% to 27%. The cost of production per tonne of cassava roots decreased despite the increasing costs of production per hectare. Root production declined by 12% from 19.1 to 16.8 million tonnes even though the planted area decreased by 28% from 1.38 to 0.99 million ha. Higher starch content, better quality roots, and ample raw material supply at a reasonable price have made Thai cassava starch very competitive, while domestic demand for native starch grew to 1.0 million tonnes and export volumes reached 1.5 million tonnes in 2002 (**Table 3**).

Table 3. Production, domestic utilization and export of Thai cassava in 2002.

	Dry products (tonnes)	Fresh root equivalent (tonnes)	Fresh root equivalent (%)
Root production		**18,430,000**	97
Domestic utilization		**5,600,000**	30
-Chips/Pellets	500,000	1,100,000	
-Starch	1,000,000	4,500,000	
Export		**13,350,000**	70
-Chips/Pellets	3,000,000	6,600,000	
-Starch	1,500,000	6,750,000	
Total utilization and export			
-Chips/Pellets	3,500,000	7,700,000	41
-Starch	2,500,000	11,250,000	59
		18,950,000	**100**

While the export of cassava pellets to the EU decreased from 5.5 million tonnes in the late 1980s to 1.4 million tones in 2002, China's imports of cassava chips increased rapidly from nearly zero to 1.6 million tonnes. This practically compensated for the reduced exports to the EU market. The domestic utilization of cassava chips also improved to about 500,000 tonnes per year. Export of cassava starch increased at the rate of 10% per year, while domestic consumption surged to about 1.0 million tonnes and is still expanding at a rate of 10% per year. Many new and modern starch factories are being built, and production capacity will increase markedly, reaching 4 million tonnes.

At present, the market structure is well balanced with exports to Asian countries 50%, to the EU 20% and domestic use 30%.

Thus, against many odds, the Thai cassava industry has survived by quickly adapting to changing realities and is now strong and competitive. The future outlook, both in the medium- and the long-term, looks quite bright (**Tables 4-7**).

Table 4. Future outlook for cassava production in Thailand.

- No new marginal land available for area expansion
- Competition for land use among three crops: cassava, sugarcane and maize
- Production costs per tonne have decreased, due to higher yields through the use of new varieties and improved cultivation techniques
- Harvesting and transportation costs have increased
- Short-term target yield of 3 t/rai or 18.75 t/ha.
- Medium-term (3-5 year) target yield of 5 t/rai or 31 t/ha

Table 5. Future outlook for cassava processing in Thailand.

Short-term (2-3 years):
- Starch production will reach 3 million tonnes = 13 million tonnes of fresh roots in 2005

Medium-term (3-5 years):
- Ethanol and alcohol production will consume 4-8 million tonnes fresh roots/year
- Continued expansion of production of modified starch and starch derivatives

Table 6. Future outlook for the cassava industry in Thailand.

Short-term outlook
- Strong demand for chips from China at 2,000,000 tonnes/year at a higher price than FOB to the EC
- Starch exports will continue to expand world-wide, especially in Asia

Medium-term outlook
- Great potential for expansion of starch exports to China
- Ethanol production from cassava would reduce Thailand's dependency on exports, with >50% utilized domestically

Table 7. New government policies relating to the Thai cassava sector.

- Will maintain high price of roots for farmers through various intervention schemes

- Support and promote export of cassava products through:
  -Increased market access: WTO, AFTA, FREE TRADE AGREEMENTS
  -Export promotion activities

- No export controls, minimum regulations

However, there are three areas that could affect the future of the Thai cassava industry:

-No additional land is available for area expansion, leading to strong competition for land between cassava, sugarcane and maize.
-Shortage of labor and higher wages could hamper future cassava root production.
-It is government policy to increase the income of farmers. Its price intervention schemes could increase the root price to a level that would induce "farmers to grow more, but users to buy less".

We may conclude that, like the case of oil, the era of cheap cassava products is over.

Rethinking the future of the cassava industry, it is fair to say that the cassava industry has a strong potential to develop further. However, new areas of development must be explored, developed and undertaken, such as:
-Mechanization of root production
-Improvement of farm management
-Cost reduction through the planting of early-maturing varieties resulting in greater spread of harvesting times and longer operating periods of starch factories
-Development of new varieties suitable for specific end-uses
-Development of new usage, such as ethanol and bio-degradable plastics.

CASSAVA RESEARCH AND DEVELOPMENT STRATEGIES IN INDIA

S. Edison[1]

ABSTRACT

India, with an annual root production of about 6.18 million tonnes from an estimated area of 0.235 million hectares, has a unique status on the cassava map of the world for its highest yield (26.32 t/ha). This could be possible because of the availability of high-yielding varieties and the willingness of farmers, especially of the industrial belts of Tamil Nadu and Andhra Pradesh states, to readily adopt these varieties along with their improved management practices. The Central Tuber Crops Research Institute (CTCRI), the only institute in the world doing work exclusively on all aspects of tropical root and tuber crops, continues to play a significant role in the research and development of these crops in India. During its existence over the past four decades, CTCRI has released 11 high-yielding cassava varieties, improved their cultural techniques, and developed strategies to manage major field and storage pests and diseases; in addition, it has developed integrated cropping systems as well as processing technologies for diversified markets. These technologies have been taken to the clientele system through various first-line extension programs as well as through specialized programs.

Keeping pace with the changing global agricultural scenario in the era of globalization and liberalization, CTCRI redesigned its research and development strategies on cassava in the recent past. Besides conventional breeding methods, biotechnological approaches are being increasingly used to develop new cassava varieties with desirable attributes, like high starch content, low HCN, high carotene etc., and for *in vitro* germplasm conservation and cryopreservation. Acknowledging the fact that cassava in Kerala is becoming more and more a companion (inter)crop in already existing cropping systems (banana-based/coconut-based/rice-based), greater emphasis is being placed on standardizing the cassava component of the cropping system.

To make Indian cassava globally competitive, low input management practices are being perfected to reduce production costs. To combat the dreaded cassava mosaic disease, a multidisciplinary approach that includes resistance breeding, detailed serodiagnostic investigation, management techniques etc. are currently in progress. For more effective utilization of cassava, efforts are also being made to produce value-added products, such as modified starches, starch derivatives, convenience foods etc. We have collaborations with international (e.g. CIAT and CIP), and national (EMBRAPA, NRI etc.) institutes, development departments and non-governmental organizations (NGOs) to foster better linkages and cooperation for the development of cassava in India. Some of the recent development strategies of cassava, such as the Institution-Village Linkage Programme (IVLP) in Kerala; Project UPTECH, a joint venture with the State Bank of India for cassava development in Andhra Pradesh; and participatory technology development, demand assessment and market-oriented research. These are also being discussed in the paper.

INTRODUCTION

Root and tuber crops are plants which produce underground structures that are used as human or animal feed. They are the third most important food crops of human kind after cereals and grain legumes, and constitute either staple or subsidiary food for about a fifth of the world population. Tropical Root and Tuber Crops (TRC) have their own role as an important staple in several countries in South America, Africa, Southeast Asia, etc. Inspite of the near satisfactory level of production of cereals and grain legumes, the socio-economic condition of small and marginal farmers in most countries in the above-

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mentioned regions necessitated them to depend on TRC as their staple. Tuber crops have a higher biological efficiency as food producers and show the highest rate of dry matter production per day per unit area among all the crops. They are also recognized as the most efficient converters of solar energy, cassava producing 250 x 10^3 Kcal/ha and sweet potato 240 x 10^3 Kcal/ha as compared to 176 x 10^3 for rice, 110 x 10^3 for wheat and 200 x 10^3 for maize. The TRC crops are known to supply cheap sources of energy, especially for the weaker sections of the population. Tuber crops can be broadly classified as temperate and tropical groups. Potato is primarily a temperate crop whereas all other edible tuber crops come under tropical tuber crops.

Having been classified as the third most important food crops of man, they possess high photosynthetic ability coupled with the capacity to yield under poor and marginal soils, adverse weather conditions etc. These attributes make tuber crops ideal for cultivation in the Less Developed Countries (LDCs) of the world. Cassava and sweet potatoes account for about 30% of the total production of root crops from developing countries, the rest being made up of potatoes, cocoyams and others (Scott *et al.*, 2000). It is estimated that about 6% of the world's dietary energy is supplied by root crops, especially potatoes, cassava and sweet potatoes. Although root crops have generally been branded as "poor man's crops", supplying low cost energy and bulk to the diet and little else by way of nutrition (Horton, 1988), their potential as nutritionally rich sources of β-carotene, anti-oxidants, dietary fiber and minerals like calcium has begun to be recognized as a result of the multifarious research programs worldwide.

Importance of Tropical Root and Tuber Crops in India

Tuber crops are cultivated in India mainly in the southern, eastern and north-eastern states. Cassava is grown in India in an area of 0.23 million hectares with a total production of 6.5 million tonnes. Cassava production is mainly from the states of Kerala, Tamil Nadu and Andhra Pradesh. Trends in the area and production of cassava in these states during 1992-97 present a grim picture of only a marginal increase in 1996-97, the principal reasons being increased per capita income leading to better purchasing power of people, surplus availability of cereals to a major section of the society, shrinkage in area due to a shift to more remunerative crops etc. Lack of adequate expansion to non-traditional and backward areas is another factor, which has culminated from the poor awareness on the potential of tuber crops in meeting hunger and alleviating poverty.

Tuber crops like yams and aroids are even today considered as vegetables only and their full potential remains largely untapped. Commercial cultivation of yams and aroids is popular in Andhra Pradesh, Tamil Nadu, West Bengal, Uttar Pradesh and Orissa States, whereas the Salem belt in Tamil Nadu and the Samalkot belt in Andhra Pradesh are known for cassava as an industrial crop. Several minor tuber crops which possess medicinal properties are also available. In the context of surplus food sources, the role of tuber crops may seem to be trivial. However, being concentrated sources of energy, they can definitely turn out to be saviours of hunger in times of food crisis and famine.

With all the favorable attributes, there is a temporary set back of this group of crops in terms of its status in the agricultural economy of our country. The earlier emphasis on cereals to cope with the food production calls for a rethinking in the wake of disproportionate population growth and rapidly shrinking cultivable areas and increasingly fragile resources. Consequently, striking at alternate crops as sources of energy would lead to tuber crops as an inevitable choice to play the role. Further, tuber crops as such provide a vast scope for diversification and value addition, offering a great opportunity for non-traditional uses within the country and for exports.

Research on tuber crops in India is undertaken mainly at the Central Tuber Crops Research Institute (CTCRI) under the aegis of the Indian Council of Agricultural Research (ICAR). Since its inception in 1963, CTCRI has contributed enormously to the research and development of tuber crops and is presently an internationally recognized Premier Institution, dedicated solely to tropical tuber crops research. Nearly four decades of research have led to several innovations such as improved high-yielding early-maturing varieties, cropping systems for various agro-ecological zones, integrated pest and disease management packages for better production, technologies to reduce post-harvest losses and enhance the prospects of utilization in the food, feed and industrial sectors etc.

Research at CTCRI is accomplished through the Divisions of Crop Improvement, Crop Production, Crop Protection and Crop Utilization & Biotechnology, and the Section of Social Sciences. During the thirty five years of research, several technologies were generated on the production and utilization of tuber crops and scientific information was disseminated to extension personnel and farmers through training and outreach programs.

The important tropical tuber crops economically and socially are cassava, sweet potato, yams (greater yam, lesser yam, African yam), aroids (*Amorphophallus, Colocasia* or taro, *Xanthosoma* or tannia) and other minor tubers, namely Chinese potato, arrow root, yam bean, etc. **Table 1** gives some general details about these TRC.

A Look into Cassava in General and in India

Cassava is a perennial shrub native to South America that is now grown throughout the tropics. Cassava was brought into cultivation by the American Indians probably 4,000 years ago, was later introduced to West Africa in the sixteenth century, and then spread to other tropical regions of the world. Although the crop can be grown between the latitudes of 30°N and 30°S and at elevation up to 2000 meters above mean sea level near the equator, most cassava is grown where the annual mean temperature is above 20°C and rainfall exceeds 700 mm. A major factor behind the extensive production of cassava is its adaptability to a wide range of soil, land and moisture conditions. Except at planting time, cassava can withstand periods of prolonged drought and is, therefore, a valuable crop in regions of low or uncertain rainfall. Light, sandy loams of medium fertility give the best results, and the crop can be grown successfully on soils with a pH ranging from 4.5 to 9.0; however, poorly drained and swampy soils are not suitable for cassava production. Cassava is one of the most important energy sources in the diet of people in the tropics; recent estimates suggest that its storage roots provide eight percent or more of the minimum calorie requirement of more than 750 million people. Its starchy roots produce more calories per unit of land than any other crop in the world, except perhaps sugarcane.

Cassava roots are generally rich in calcium and ascorbic acid, and contain significant amounts of thiamine, riboflavin, and niacin. The cassava leaves are rich in high quality protein, and are consumed in most of the tropical countries. However, the swollen roots contain little protein. In India, its cultivation is mainly confined to the States of Kerala, Tamil Nadu and Andhra Pradesh. The area, production, yield, state wise distribution of cassava is shown in **Table 2**.

Table 1. Scientific and common names of the major tropical root and tuber crops.

Common name (English)	Scientific name	Family	Vernacular name
Cassava/Tapioca	*Manihot esculenta* Crantz	Euphorbiaceae	Maracheeni Kizhangu (M), Kappa (M) Maravalli Kizhangu (T), Ezhilai Kizhangu (T), Maraganasu (K), Karrapendalamu (TE).
Sweet potato	*Ipomoea batatus* (L.) Lam.	Convolvulaceae	Mitha Alu (H), Shakarkand (H), Cheeni Kizhangu (M & T), Madhura Kizhangu (M), Shakkarevalli Kizhangu (T), Ganasu (K), Chelangada (TE), Ratalu (MR), Lal alu (B), Ranga alu (B)
Greater Yam	*Dioscorea alata* (L.)	Dioscoreaceae	Pind Aaluk (H), Peruvalli Kizhangu (T), Vettilavalli Kizhangu (T), Kachil (M), Kavath (M)
African Yam	*Dioscorea rotundata* (Poir)	Dioscoreaceae	Safed Aaluk (H), African Valli Kizhangu (T), African Kachil (M).
Lesser Yam	*Dioscorea esculenta* (Lour.) Burk	Dioscoreaceae	Kayu (H), Cheruvalli Kizhangu (T), Cherukizhangu (M)
Taro	*Colocasia esculenta* (L.) Schott	Araceae	Arvi (H), Kachalu (H), Ghuiya (H), Kachu (S), Chempu (M), Seppan Kizhangu (T), Kachchi (K), Shamagadde (K), Chamadumpa (TE), Chemagadda (TE), Alu (MR), Kachu (B)
Tannia	*Xanthosoma sagittifolium*	Araceae	Palachempu (M & T)
Elephant Foot Yam	*Amorphophallus poeniifolius* (Dennst.) Nicolson	Araceae	Zamir-kand (H), Arsaghana (S), Balukand (S), Chena (M), Karunai kilangu (T), Suvarna gadde (K), Kanda (TE), Suran (MR), OI (B).
Chinese Potato	*Solenostemon rotundifolius*	Labiateae	Koorka-kizhangu (M), Siru kizhangu (T).

H-Hindi, M-Malayalam, T-Tamil, TE-Telugu, K-Kannada, B-Bengali.

Table 2. Area, production and yield of cassava in India in 1998/99.

State	Area ('000 ha)	Production ('000 tonnes)	Yield (t/ha)	% of cropped area
Kerala	142.0	2,588.3	20	4.7
Tamil Nadu	65.7	3,043.2	45	1.1
Andhra Pradesh	22.0	17.4	10	0.1
Karnataka	0.9	7.1	10	---
India (1998/99)	245	5,668	23.95	0.1
World (1998/99	1,619	158,620	9.79	

Improved Cultivation Practices of Cassava

Cassava is very flexible with respect to planting dates, and hence under irrigated conditions in the tropics, planting can be undertaken at any time of the year. Time of planting of cassava for the different states in India is shown in **Table 3**.

Table 3. Optimum time of planting cassava in four States of India.

States	Rainfed	Irrigated
Kerala	April - May September - October	December - January
Andhra Pradesh	June	March
Madhya Pradesh	June	March
Tamil Nadu	June	September (higher yield)

Land preparation

Loosening the soil to a depth of 20-25 cm, either by tractor plowing or spade digging, helps in better rooting. In drought-prone areas with infertile soil, deep plowing encourages deep root penetration. The systems of cultivation vary with the type and topography of the soil. For example, the mound system may be adopted in soils having high clay and restricted drainage, whereas the ridge system may be adopted on slopes to prevent soil erosion. Flat bed method of cultivation may be followed in level lands having good drainage. Under irrigated conditions, the ridge and furrow method of planting is practiced.

Spacing and plant population

Based on the branching behaviour, cassava genotypes can be classified into branching, semi-branching and non-branching types. Both branching and semi-branching types require a wider spacing, and hence planting them at 90x90 cm is optimum. Non-branching types grow well at a spacing of 75x75 cm. Cassava is flexible to spatial arrangement provided the plant population per unit area is maintained constant. Under medium level of soil fertility, branching and semi-branching types require a wider spacing of 90x90 cm accommodating 12,345 plants per hectare while non-branching types can be planted at a closer spacing of 75x75 cm, accommodating 17,770 plants per hectare. Normally one stake is planted per hill/mound. By adopting a spacing of 90 x 90 cm, about 2000 stems are required for planting one hectare of land.

Improved varieties

A large number of varieties/cultivars are grown in different regions of the country. An introduction from Malaya, called M4 (by the University of Kerala) in1940 is a popular variety used for culinary purpose in southern Kerala. A total of eleven improved high-yielding varieties have been released since 1971 from the Central Tuber Crops Research Institute (CTCRI), of which H-165 and H-226 are still the most popular varieties in the industrial belt of Tamil Nadu and Andhra Pradesh. The salient features of the improved varieties are given in **Table 4**.

Table 4. Characteristics of improved varieties of cassava released by CTCRI and TNAU[1)] in India.

Variety	Duration (days)	Starch (%)	Yield (t/ha)	Salient features
H-97	260-300	27-29	25-35	Good drought tolerance
H-165	220-240	22-25	33-38	Easy harvestability, early bulking, good root shape
H-226	260-300	28-30	30-35	Popular variety for starch production
Sree Sahya	300-320	29-31	35-40	Hardy and highly resistant to drought
Sree Visakham	270-300	25-27	36-50	Rich in carotene (446 IU/100g)
Sree Prakash	210-240	29-31	30-40	Early and shallow bulking type
Sree Harsha	300	38-41	35-40	Triploid variety, high starch content
Sree Jaya	180-210	24-27	26-30	Early maturing, excellent cooking quality
Sree Vijaya	180-210	27-30	25-28	Early maturing, good cooking quality
Sree Rekha	300	45-48	28.2	Excellent cooking quality. Suitable for general cultivation in upland and lowland
Sree Prabha	300	40-45	26.8	Suitable for general cultivation in upland and lowland
CO-1	260-275		30.0	Tolerant to CMD and scale insects
CO-2	260-275		37.5	Highly branched
CO-3	240-270		40	Branching type, high starch content, sweet taste
H-119	225	35.2	36	Non-branching, better consumer acceptance

[1)] Tamil Nadu Agricultural University

Planting

Cassava is a vegetatively propagated crop and is raised by planting stem cuttings. Disease- and pest-free stems of 8-12 months maturity having a thickness of 2-5 cm are to be selected for planting after discarding 1/3rd portion of the stem from the top and about five cm from the bottom. Stakes can also be raised in a nursery and the sprouted mosaic symptom-free plants may be uprooted carefully at about three weeks and planted in the field. While preparing stakes, it is better to have a smooth circular cut rather than an irregular cut for better root initiation. A stake length of 15-20 cm is ideal for high yield. Irrigation may be provided for establishment, in case rains are not received. Planting the stakes in a vertical position is better as compared to horizontal or slanted methods. The stakes may be planted to a depth of five cm; deeper planting results in swelling up of the mother stake with a consequent reduction in root yield. Root bulking begins during the second month after planting.

Gap filling/Thinning

Under field conditions, all the planted stakes may not establish due to the use of poor quality planting material and/or adverse weather conditions. At the time of planting itself, 5-10% of the setts may be planted at a close spacing of 4.5 x 4.5 cm with irrigation so that 20-25 day old plants can be up-rooted for 'gap transplantation'.

Replanting the unsuccessful stakes at 15 days after planting with fresh cuttings of longer size (40 cm) also helps to improve the yield of the replanted stake. Retaining two healthy shoots per plant at opposite sides was found to be better than retaining either many or one shoot. Removal of excess sprouts by nipping at the initial stages of establishment (10-15 days after planting) helps to reduce mutual shading and competition between plants.

Irrigation

Irrigation is not practiced in Kerala where cassava is grown as a rainfed crop. But cassava is raised under irrigation in many parts of Tamil Nadu and Andhra Pradesh, where one irrigation is given on the day of planting followed by another two irrigations at an interval of 3-5 days till the plants are well-established.

Manures and fertilizers

Traditionally cassava is grown with organic manures such as farm-yard manure (FYM) and wood ash. Farm-yard manures or compost may be applied at a rate of 10-15 tonnes per hectare at the time of land preparation. A fertilizer dose of 100 kg N, 50 kg P_2O_5 and 100 kg K_2O/ha is recommended for high-yielding varieties and half this dose is suggested for local varieties. For the short-duration varieties, like Sree Prakash, application of NPK at 75:25:75 kg N, P_2O_5 and K_2O/ha is recommended under a close spacing of 75 x 75 cm for Tamil Nadu. Cassava has a high potassium requirement. If potassium is not present in the soil in sufficient amounts, yields are reduced, and the roots have a lower starch and higher hydrogen cyanide (HCN) content.

Inter-culturing and earthing-up

Inter-culturing in the early stages of the crop is essential for proper control of weeds and for improving the soil condition. The first inter-culturing shall be sufficiently deep, done at 45-60 days after planting, and a shallow inter-culturing and earthing-up is made one month later.

Cropping system

In Kerala, cassava is grown as a monocrop in uplands, as an intercrop in coconut gardens and as a sequential crop after paddy in lowlands. In Tamil Nadu, the crop is mainly grown as a monocrop under irrigation for industrial processing into starch. In the Northeastern Hill region, cassava is grown mostly in mixed stands of shifting cultivation plots on the hill's slopes, mainly as a rainfed crop.

Intercropping

Legumes are the most suitable intercrops for cassava. Groundnut (bunch type TMV-2 and TMV-7) and french bean (cv'Contender') were found to be promising and economical. These crops can give an additional net income of Rs.3,000-5,000/ha within 3-3 1/2 months. In Tamil Nadu, the black gram variety CO-1 and bellary onion were also found to be suited for intercropping with cassava. In Andhra Pradesh, black gram or green gram is recommended, while in Assam soybean and French bean are found to be promising as intercrops for cassava.

Plant Protection

Cassava mosaic disease, caused by a virus transmitted by whitefly, is a serious problem affecting growth and yield under severe infestation. By systematic rouging, this disease can be controlled. Disease-free plants should be identified well in advance and used as planting material.

Spider mites, which occur in the dry season, can be controlled by spraying water at run off level on the foliage at 10-day intervals. In addition to this, scale insects have been found to affect stems when stored for subsequent planting. Spraying dimethoate or methyl parathion (0.05%) thrice at monthly intervals during January-February is effective in controlling these pests.

Harvesting and yield

Early bulking varieties can be harvested from the seventh month onwards. Retaining the plants in the field after attaining the optimum stage of harvest may lead to fiber formation inside the smaller roots. A normal crop of cassava yields on average 25-35 tonnes of fresh roots per hectare. Although it can remain in the ground for many months, once it is harvested, the roots deteriorate rapidly and begin to rot after 48 hours. Cold storage where possible at 0-2°C and 85-95% relative humidity has been reported to extend the storage life for periods up to 6-12 months. Storage of cassava planting material is necessary when harvest and subsequent planting do not coincide with each other. Healthy stems for subsequent planting may be collected from the field immediately after harvest and stored under tree shade or in thatched sheds in a vertical position. The stems so stored may be used for the subsequent planting within two months so as to get optimum sprouting.

Processing

A major problem with the use of cassava is the toxicity from the cyanide compounds found in fresh roots. The cyanide is concentrated in or near the skin of the root, and is freed into its active form when the skin is broken. The cyanide content, however, varies from variety to variety and changes under environmental conditions, such as humidity, temperature, and age of plants. Proper processing cassava for consumption is the most effective solution to solve this problem. This can be done in a variety of ways, but is often done by washing the cassava in clean water or by fermenting it.

Cassava can be processed into different forms for a wide variety of end uses, and much of this processing can be carried out locally, providing jobs and income to the rural population. It can be made into food products and also used as animal feed. It is now commonly used as a raw material in the manufacture of various industrial products like starch. In Brazil, the roots are sometimes used commercially to make alcohol.

In India, as far as utilization pattern is concerned, cassava is used as a secondary staple in Kerala, while it is used as raw material for production of starch and sago in Tamil Nadu and Andhra Pradesh. Annually 300,000 tonnes of sago and starch are being produced, of which Tamil Nadu's share is more than 80%. Chips is another value added product; nearly 70,000 tonnes are produced from cassava, more than 50% of it from Andhra Pradesh. The export items of cassava are starch, sago, flour and chips and the importing countries are Australia, EU, Bangladesh, Sri Lanka, Nepal, USA and Canada. Total amount of products exported annually ranges from 30,000 to 50,000 tonnes.

Research Strategies

Although enough infrastructure facilities have been created and are under use to meet the R & D requirements of cassava, some of the emerging areas are being attended by following a set of strategies as explained below:

a. Developing an alternate technology for the production of disease-free planting material of cassava through a nursery technique.

Spread of diseases through vegetative planting material is an inevitable feature in vegetatively propagated crops, and cassava is no exception. Cassava Mosaic disease, primarily transmitted through planting material, can cause yield losses ranging from 2 to 90%. Hence an alternative technology is advocated to contain if not eliminate the disease. In this technology, setts of 3-4 node cuttings derived from apparently disease-free plants are collected and planted in a nursery at a close spacing of 4x 4 cm so that about 500 setts can be accommodated in one square foot of land. Daily watering of the setts is done for the first 10 days and on alternate days thereafter. The CMD symptoms appear about 10 days after planting and the settlings showing even mild symptoms are removed and burnt. This rouging is continued up to 20-25 days; by that time healthy plants are transplanted to the main field. Supplementary irrigation is given in the transplanted field till the plants are well established. Screening for disease symptoms and rouging of infested plants is continued in the field at weekly intervals up to harvest. By adopting this technique, it is possible to produce healthy plants.

b. New processing technologies

Root and tuber crops offer immense scope as food, feed and industrial raw material. A wide variety of instant and ready-to-eat food products such as cassava rava and porridge, sweet potato energy drink, sweet potato jam, pickle, sauce, etc. can be prepared, which can enhance market appeal for tuber crops products. Similarly, there are several food products like cutlets, puffs and samusas, etc. for which these crops can also be used. Apart from the utilization as food and animal feed, cassava roots can be used in a vast number of industrial applications, such as alcohol, gums, dextrins and cold water soluble starch. Of late, the starch-based biodegradable plastics developed from cassava have received wide attention due to the ability to reduce pollution and being eco-friendly.

Many processing technologies to produce value-added products from tuber crops are being made available by R & D efforts of CTCRI. These technologies range from home front to the industrial front.

(i) Home front technologies

1. Method to prolong the shelf life of fresh cassava

Pits are made under shade and moist sand/soil is spread at its bottom (moisture 10-15%). Bunches of undamaged roots still attached to the stem are arranged layer by layer with moist sand or soil in between the layers. After arranging three layers, pits are covered with moist sand/soil. The germinated buds are to be removed frequently.

Low-cost value added intermediary products like jams, sauces, pickles, pregelatinized starches, instant drinks, etc. are readily available for transfer.

(ii) Farm front technologies

Conservation technologies like cassava ensiling for the *in situ* utilization of cassava as animal feed, by-product utilization of cassava starch factory waste as poultry feed etc. are available. Hand-operated, pedal-operated and motorized chipping machines, harvesting tools and a peeling knife were also developed by CTCRI.

1. Cassava ensiling technique

Whole roots of cassava are chopped and then exposed to sunlight to reduce the initial cyanogens load. Then mix the sliced cassava with rice straw in the ratio 90:10 and pack the mix tightly into plastic silos. The ensiling process is completed in three weeks and this stabilized silage can be preserved in the silo till it is opened for utilization.

2. By-product utilization of cassava waste (thippi) as poultry feed

Cassava flour and thippi are mixed in equal proportions (1:1). Steam treat the mix for 30 minutes. Dry the mix in sunlight. Mix with dehydrated fish meal, groundnut meal and vitamin-mineral premix. Granulate for better-feed efficiency.

(iii) Industrial front technologies

1. Development of starch-based adhesives

Adhesives can be prepared using cassava starch along with Polyvinyl Alcohol (PVA). The resulting adhesive has excellent sticking power in paper-paper, paper-card board, plywood-hardwood, ceramic-wood and ceramic-ceramic systems.

2. Starch succinate for the food industry

Starch succinate can be prepared by treating cassava starch with succinic anhydride I alkali (pH 8.5). The derivative can be used as a thickener in the food industry.

3. Cassava starch-based bio-degradable plastics

This technique is an eco-friendly way of meeting the demand for plastic packaging products from India. The process for production of starch-based plastics standardized at

CTCRI is a pioneering work. It involves blending of polyolefins with cassava or maize starch in the presence of a compatibilizer and other chemicals; the product has a biodegradability ranging from 6 months to 5 years depending on the composition. This eco-friendly technology has already been transferred to four licensees in the states of Delhi, Haryana, Himachal Pradesh and Karnataka through the National Research Development Corporation (NRDC), New Delhi, India. This technology has received a European patent.

4. Cassava starch for binding in fish feed and its use in tissue culture

Cassava starch has high viscosity enabling its use as a binding material in pelleted fish feeds. Cassava with its desirable attributes like high energy value and the adhesive quality of starch can be a forerunner crop. Research conducted at CTCRI has shown the potential use of sago (granulated cassava starch) as a solidifying agent in tissue culture media.

5. Microbial technique to extract starchy flour from cassava roots

A mixed culture inoculum with microorganisms, e.g. *Lactobacillus cellobiosus, Streptococcus lactis, Corynebacterium sp., Pichia membranaefaciens* has been developed to prepare sweet and sour flour.

The inoculum source is added to cassava roots (big pieces) and then fermented for 48-72 hours rendering the root pieces soft. Steep water is decanted, the fermented roots are dried, powdered and sieved to obtain a starchy flour. The flour can be used as an ingredient in bakery products.

6. Mobile starch extraction unit

Simple, electrically operated, low cost starch extraction unit, which can be transported from one place to other has been fabricated. This unit will grate the cassava roots, wash out the starch from the tissue and separate the starch. The unit has been tested in Kerala and Orissa states and has shown its potential scope. The unit has the capacity of extracting starch from 200 kg of cassava or 135 kg of sweet potato per hour with 84 and 75% of starch recovery from cassava and sweet potato, respectively. Approximate cost of the unit is Rs.60,000/-.

7. Method to eliminate cyanide and reduction of BOD (Biological OxygenDemand) & COD (Chemical Oxygen Demand) in factory effluents.

The effluent treatment system for cassava starch/sago factory waste waters developed by CTCRI include initial settling, anaerobiosis, filtration through sand, charcoal and gravel columns and final aerobic polishing. The gas generated (methane) can be used as a fuel, and the treated/cleaned water could be used to support aquaculture. The technology has been successfully demonstrated in the field.

CURRENT CHALLENGES IN RESEARCH

Many new challenges remain and research at CTCRI is now concentrating on the following areas:

a. Genetic Resources Management

Root and tuber crops germplasm is being conserved at CTCRI in field gene banks. The genetic diversity and genetic purity of the collections are being studied using isozyme patterns, RFLP markers and other DNA analytical methods or DNA fingerprinting in the Genetic Resources Management Unit. Another area of importance is the creation of computerized data banks for storing, analysis and retrieval of information for identification of core collections and genetic duplicates.

b. Biotechnology

Cryo-preservation methods for long-term storage of *in vitro* based gene banks have to be formulated. Developing transgenics in tuber crops (mechanical or vector mediated) for incorporating useful genes for disease resistance, suppression of anti nutrient factors as well as tolerance to stress are other challenges.

c. Triploid varieties for industrial use

As cassava is gaining importance as an industrial crop in Tamil Nadu and Andhra Pradesh, the need for developing high-yielding varieties having a higher starch content became essential. The triploidy breeding program has established the scope for such varieties at CTCRI. For example, the triploid cassava variety Sree Harsha has a yield potential of 60 t/ha with 38-41% starch. This research needs to be streamlined and strengthened in the future.

d. Integrated production systems

The cassava area under traditional upland rainfed conditions is declining gradually in Kerala. On the other hand, the area under lowland cultivation is increasing with the gradual replacement of rice by cassava. Therefore, research is needed to standardize the production technology of cassava under lowland conditions.

e. Cassava Mosaic Disease

Cassava Mosaic Disease is the most serious problem in all the cassava growing areas of India; no resistant varieties are yet available. Standardization of regeneration and transformation techniques for cassava for developing a CMD-resistant transgenic cassava is essential. CMD is reducing cassava yields by about 15-20%, especially in the industrial belt of Tamil Nadu.

f. Root rots

Root rots have become a very serious problem in cassava, especially in the irrigated areas of Tamil Nadu. Hence, investigations are needed to determine the host-pathogen-environment interaction, the mode of perpetuation and spread of the pathogen, and to develop suitable management practices, including biocontrol.

g. Production of disease-free planting material

This is a persistent problem to meet the requirement of the cassava growing farmers. There is an increasing demand for disease-free planting materials from Tamil Nadu, Andhra Pradesh, Gujarat and Kerala.

NEW DEVELOPMENTS IN THE CASSAVA SECTOR OF VIETNAM

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ABSTRACT

In Vietnam cassava has great potential both for export and for domestic consumption. In terms of cassava exports Vietnam ranks 2nd or 3rd in the world, behind Thailand and Indonesia. Exports of cassava starch are now reaching 180-350 thousand tonnes a year. Major markets of Vietnam's cassava exports are P.R of China and Taiwan, Japan, Singapore, Malaysia, South Korea and countries in Eastern Europe.

Cassava research in Vietnam has made remarkable progress since 1988 when Vietnam began its cooperation with CIAT and the Asian Cassava Research Network. Further progress was achieved when Vietnam established its Cassava Research and Extension Network, in close cooperation with starch processing factories, especially Vedan Vietnam Enterprise Corp. Ltd. Presently, we have 25 cassava processing factories currently in operation with a total installed capacity to process about 1.2-2.0 million tonnes of fresh roots per year (60-80% of cassava production). New, high-yielding cassava varieties, such as KM60, KM94 and KM98, and more sustainable production practices have increased the economic effectiveness of cassava production, especially in the Southeastern region. The use of farmer participatory research (FPR) in the development and transfer of new technologies to cassava households has been quite successful in mountainous and hilly areas of the North, the Central Coastal and Southeastern Regions. The use of cassava roots and leaves in animal feed is also being studied. The Vietnam Cassava Research and Development Project promotes the rapid multiplication and wide distribution of high-starch and high-yield varieties, and the adoption of sustainable cassava production practices, especially in the Central Coastal, Central Highland and Mekong Delta Regions.

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 first years of the 21st Century. Vietnam has become the third exporter of cassava products, after Thailand and Indonesia. Cassava is one of the seven new agricultural export products, which caught the attention of the government and local authorities. This paper covers three subjects: 1) New features of cassava production and consumption; 2) New progress in cassava research and extension; and 3) Investment in cassava development: opportunities and prospects.

NEW FEATURES OF CASSAVA PRODUCTION AND CONSUMPTION

High Cassava Price in 2001

The price of cassava increased, while those of coffee and black pepper decreased. Cassava farmers were very satisfied because the price of fresh cassava roots ranged from about 450 to 650 VND/kg (1US$ = 15,500 VND) in 2001. FAO reported that the trade of

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cassava products all over the world was about 7.3 million tonnes, including dried chips, pellets and starch (**Table 1**). Thailand and Vietnam were the two main tapioca exporting countries.

Table 1. World trade of cassava products (dried chips, pellets and starch) in millions of tonnes.

Market Region	Average of '83-'85	Average of '92-'93	Average of '95-'96	1998	1999	2000 prelim.	2001 forecast
World Exports	**7.0**	**9.8**	**5.9**	**4.4**	**7.0**	**6.9**	**7.3**
Thailand	6.4	8.3	4.6	4.0	6.4	6.5	7.0
Indonesia	0.4	1.1	0.6	0.2	0.3	0.2	0.1
China&Taiwan	0.1	0.3	0.4	-	-	-	-
Vietnam	-	-	0.1	0.2	0.2	0.2	0.2
Others countries	-	0.1	0.3	-	-	-	-
World Imports	**6.6**	**9.7**	**5.9**	**4.4**	**7.0**	**6.9**	**7.3**
EC	5.5	6.5	3.5	2.9	4.3	3.7	2.7
China&Taiwan	0.3	0.9	0.7	0.5	1.1	0.9	2.4
Japan	0.3	0.5	0.4	0.3	0.5	0.6	0.6
South Korea	0.2	0.7	0.3	0.4	0.1	0.1	0.3
Other countries	0.3	1.1	1.0	0.3	0.9	1.6	1.3

Source: *Henry and Gottret, 1996; Henry and Hershey, 1998; Hoang Kim et al., 2000; FAO, 2001.*

Although in Vietnam cassava processing is a relatively new business and export volumes are still low, the cassava processing factories are new and modern. That's why Vietnam's tapioca products have a competitive advantage in the world market. With higher profits, many cassava farmers have become rich. Market demand for cassava products increased and new high-yielding cassava varieties are being disseminated widely, resulting in higher profits for cassava farmers. Many farmers have become rich by growing cassava. For example, in An Vien commune in Thong Nhat district of Dongnai province, 97% of the agricultural land has poor gray sandy soil. Cassava is the main crop (1,099 ha), followed by cashew (534 ha) and other minor crops. Previously, farmers grew the old cassava varieties Gon and HL23 with an average yield of about 9-12 t/ha. In recent years, by growing new high-yielding varieties and applying improved cultural practices, the average yield in this commune increased up to 16-32 t/ha. Many farmers are now growing varieties KM94 and KM98, obtaining 25-35 t/ha in areas of 3-5 hectares. They have become rich by growing cassava.

Building of New Cassava Processing Factories

In Vietnam there are now 25 cassava processing factories in operation with a total processing capacity of 1.2-2.0 million tonnes of fresh roots/year. **Table 2** shows the location and production capacity of the cassava starch factories presently in operation or under construction in Vietnam. The nation produced about 400-600 thousand tonnes of dry cassava products. Export of cassava starch is now reaching 180-350 thousand tonnes a year. Major markets of Vietnam's cassava exports are the P.R. of China and Taiwan, Japan, Singapore, Malaysia, South Korea and countries in Eastern Europe. Vedan-Vietnam Enterprise Corp. Ltd. is one of the leading companies in cassava processing. In addition, animal feed factories also contributed significantly to the increasing demand for cassava roots.

Table 2. Cassava processing factories in Vietnam in 2001.

Region	Province	Number of cassava processing factories	Capacity (tonnes of cassava starch/day)	Production ('000 tonnes) of cassava fresh roots/ year	Note
Southeastern Region	Tay Ninh	06	420	479.1	in operation
		03	250		under construction
	Binh Phuoc	06	590	370.6	in operation
	Dong Nai	05	415	284.5	in operation
	Baria Vungtau	01	175	121.2	in operation
Mekong River Delta	An Giang	01	60	24.0	in operation
Central Highlands	Dak Lak	02	110	36.1	in operation
	Gia Lai	01	50	144.0	in operation
	Kon Tum	02	150	155.8	under construction
South Central Coast	Quang Nam	01	100	108.9	in operation
	Quang Ngai	01	50	63.9	in operation
	Phu Yen	01	50	33.7	in operation
	Thang Hoa	02	110	93.1	under construction
North Central Coast	Nghe An	01	60	63.1	under construction
	Quang Tri	01	60	27.4	under construction
	Thuathien Hue	01	100	28.3	under construction
Northeastern Region	Bac Can	02	180	123.3	under construction
	Yen Bai	01	50	76.2	under construction
	Phu Tho	01	60	92.5	under construction
Northwestern Region	Son La	03	150	142.8	under construction
Total	19/61	42	3,190	2,069.5	

Wide Dissemination of New High Yielding Varieties

In the 1991-2000 period, the Institute of Agricultural Science of South Vietnam (IAS) and the Vietnam Cassava Research and Extension Network (VNCP), in close cooperation with CIAT, Vedan and other starch processing factories have released six new varieties: KM60, KM94, KM95, KM95-3, SM937-26 and KM98. New high-yielding cassava varieties and more sustainable production practices have increased the economic effectiveness of cassava production, especially in the Southeastern region (**Table 3**).

With the establishment of new processing factories in recent years, cassava has changed from being a food crop to being an industrial crop in Vietnam. In 2001/2002 more than 94,500 ha of new varieties were grown, mainly in the Southeastern Region. This corresponds to about 33% of the total cassava area in the country.

Increases in yield and starch content resulted in increased production of 450 thousand tonnes of fresh roots or 126 thousand tonnes of starch; this means that approximately 252-378 billion VND (16.8-25.2 million US$) per year were added to farmers' income.

Table 3. Approximate cassava area, production and yield as well as the spread of new varieties in various regions of Vietnam in 2001/2002.

Regions	Cassava production (1,000 t)	Fresh root yield (t/ha)	Total area ('000 ha)	Total area with new varieties ('000 ha)	% with new cassava varieties
Total Vietnam	**3,145.1**	**10.9**	**288.4**	**94.5**	**33**
-Red River Delta	74.3	9.4	7.9	0.5	6
-Northeastern, Region	443.4	9.2	48.2	4.5	9
-Northwestern Region	261.3	7.8	33.5	1.0	3
-North Central Coast	269.5	7.0	38.5	1.5	4
-South Central Coast	413.7	10.5	39.4	17.8	45
-Central Highlands	515.9	11.0	46.9	12.6	27
-Southeastern Region	1,097.3	16.5	66.5	54.0	78
-Mekong River Delta	69.7	9.3	7.5	2.6	35

Source: *adapted by Hoang Kim from MARD, 2002a; MARD, 2002b; Statistical Yearbook, 2001.*

NEW PROGRESS IN CASSAVA RESEARCH AND EXTENSION

Selection and Development of High Yielding Varieties

The aim of the Vietnam Cassava Research and Development Project (VNCP) in the 2001-2005 period is: 1) to increase the growing area of KM94 and other promising varieties up to 150 thousand hectares, or close to 55-60% of the total cassava area in the country; 2) to select and release 1-2 new varieties with 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; 3) to select short-duration varieties of high quality, suitable for fresh human consumption and animal feeds.

In the 2001-2002 period, five million stakes of new varieties, mainly KM94 and KM98, were distributed to various provinces in this program; 250 cassava accessions were maintained in the germplasm bank; 12,000 hybrid seeds were either collected or introduced; more than 780 promising clones have been selected, of which KM140, KM146 and KM163 will be further tested and possibly selected for release; trials and multiplications were conducted in 25 provinces (Hoang Kim *et al.*, 2002).

In the 2003-2005 period, VNCP will promote the rapid multiplication and wide distribution of high-starch and high-yield varieties, and the adoption of sustainable cassava production practices, especially in the Central Coastal, Central Highland and Mekong Delta Regions.

Farmer Participatory Research (FPR)

The project of "Improving the Sustainability of Cassava-based Cropping Systems in Vietnam" sponsored by the Nippon Foundation, was implemented with CIAT's technical support. The use of Farmer Participatory Research (FPR) in the development and transfer of new technologies to cassava households has been quite successful in mountainous and hilly areas of the North, the Central Coast and Southeastern Region.

Several suitable cassava cultural practices were developed: 1) erosion control by growing vetiver grass and other plant species along contour lines; 2) balanced fertilizer application of about 60 kg N, 40 P_2O_5 and 120 K_2O/ha, together with animal manures; 3) intercropping cassava with peanut and/or mungbean; 4) planting new high-yielding varieties; 5) using the herbicide Dual (2.4 l/ha); and 6) using silage of cassava leaves and roots for animal feeding (Tran Ngoc Ngoan and Howeler, 2002; Nguyen Huu Hy *et al.*, 2002; Thai Phien and Nguyen Cong Vinh, 2002). The project was actively supported by farmers, because it helped them make effective use of available local resources and developed better cassava cultural practices through their own selection (Nguyen The Dang, 2002; Nguyen Thi Cach *et al.*, 2002; Tran Thi Dung and Nguyen Thi Sam, 2002).

Use of Cassava Leaves and Roots in Animal Feeds and Food Processing

Cassava leaves have a high protein content (20-25% of dry leaves), while cassava roots have 25-30% starch but are low in protein (1-3%). High yielding cassava varieties usually have high HCN contents, limiting the use of roots and leaves for animal feed. Drying or ensiling of cassava leaves and roots will markedly reduce their HCN content. Many studies have shown the effect of different processing methods on the chemical contents and nutritional values of cassava leaves and roots (Pham Sy Tiep, 2001); the use of cassava roots and leaves for feeding pigs (Le Duc Ngoan and Nguyen Thi Hoa Ly, 2002); young stems and leaves for feeding cows (Doan Duc Vu, 2001); the use of cassava dried leaf powder as animal feed for chickens and pigs (Duong Thanh Liem *et al.*, 1998); feeding cassava leaves to silkworms (Tran Cong Tien *et al.*, 2001); using cassava stems to grow mushrooms (KCM TN, 2002). Studies about the use of cassava leaves in industrial processing and for feed by Glon-Sanders Inc. and Proconco Company were conducted in the Southeastern Region (Froehlich and Thai Van Hung, 2001).

Applying Biotechnology in Cassava Breeding and Multiplication

Tissue culture techniques were applied to improve the cassava breeding and multiplication (Hoang Kim *et al.*, 2002). We are studying these techniques to maintain cassava germplasm *in vitro,* for rapid multiplication of new high-yielding varieties, to make wide hybridizations, and for mutation breeding.

Cassava Starch Industry and High Quality Products

The cassava starch industry is already highly developed in Thailand, China, South Korea and Japan. However, only a few studies have been conducted in Vietnam about the hydrolysis of cassava starch by amylase enzyme for alcohol production (Ngo Ke Suong and Hoang Kim Anh, 2001).

Cassava Market Information and Trade Contacts

FAO, IFAD and other international organizations have developed a global cassava strategy in order to cooperate and support cassava growing countries. Information on Vietnam cassava production can be found at http://www.globalcassavastrategy.net; http://www.ciat.cgiar.org; http://danforthcenter.org/iltab/cassavanet; http://www.agroviet.gov.vn; and http://mard.gov.vn and http://www.vneconommy.com.vn

INVESTMENT FOR CASSAVA: OPPORTUNITIES AND PROSPECTS

Increasing Demand for Cassava

Cassava roots have multiple end-uses, such as for the starch industry, for food and feed processing, for the pharmaceutical industry and for export.

Cassava is an easy crop to grow. It can grow in poor soils and produces high yields with suitable management. The crop can be grown in many areas. The average yield of cassava is now only 8-10 t/ha, but the yield can be doubled in many provinces. 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 roots and leaves. The situation has changed because of the development of sustainable cultivation techniques and new high-yielding varieties. Cassava has become a cash crop in many provinces of Vietnam. Cassava starch is now being produced competitively, and cassava markets are promising. The combination of growing and processing cassava has created many jobs, has increased exports, attracted foreign investments, and contributed to industrialization and modernization of several rural areas.

Development of the Vietnam Cassava Program

After ten years of development (1991-2001), intensive cassava research and extension have changed cassava from being a food crop to being an industrial crop. Vietnam cassava starch is now very promising for export and domestic use.

During the tenth Vietnam Cassava Workshop it was agreed to emphasize the following seven topics (Pham Van Bien *et al.*, 2001):

1) Determination of an appropriate strategy for cassava research and development
2) Selection and dissemination of high-yielding varieties with high starch contents
3) Transfer of appropriate cultivation techniques to farmers in different areas
4) Cooperation with processing factories in establishing areas with a stable source of raw materials
5) Research on the development of cassava processing technologies
6) Structural improvement and development of the extension network
7) Development of local and export markets for cassava products (Pham Van Bien *et al.*, 2001).

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CASSAVA PRODUCTION FOR INDUSTRIAL UTILIZATION IN CHINA – PRESENT AND FUTURE PERSPECTIVES

Wenquan Wang[1]

ABSTRACT

Although cassava is called in China "the underground food store", as it once acted as the key crop against hunger by supplying the main food energy for people of south China in specially difficult times, presently more than 60% of cassava produced is used for industrial purposes, 30% is used for animal feed and only 10% for human food. Cassava has a strong competitively advantage in the tropical and sub-tropical cultivation systems because of the following characteristics:

1. High efficiency in transforming sunlight into bio-energy, with one of the highest potential yields of any crop.
2. Tolerance to drought and poor soils, and wide adaptability to different climates and cropping systems.
3. High extraction rate and excellent physical and chemical characteristics of starch

Because of recent characterization of cassava starch properties, market demand for cassava for the production of starch-based products has increased rapidly. This has led to an increase in the cassava growing area, which has reached about 500,000 ha in the past two years. And the cassava production system is also changing from being a small-scale subsistence crop to a large-scale commercial crop.

Being an excellent source of starch, cassava in China has a huge development potential. There are now several hundred chemical products made from starch. Especially, considering the need to protect the environment and the limited mineral oil reserves in China, at the beginning of 2002 the federal government has started a new project of producing ethanol for use as fuel in automobiles. The production of fuel ethanol will be a Chinese "sunrise industry" with an estimated value of 2.5 billion dollar per year. The fuel alcohol market could amount to about five million tonnes, if alcohol were to be added to gasoline at a 10% substitution rate. But presently the total national ethanol production is only two million tonnes. Among maize, sugarcane and cassava, the main crops to be used for ethanol production in China, cassava has a competitive advantage because of its lower cost of raw material and a simpler ethanol processing technology. For that reason, it is expected that the Chinese cassava cropping area will expand to about 600,000 to 800,000 ha during the current decade.

It is very important that new high-yielding cassava varieties and highly effective cultivation technologies are developed, and that a well-integrated production, transport, processing and marketing system is put into place. In this way, cassava will become a key link in the industrial chain in Hainan, Guangxi and other less developed provinces, resulting in an increase in people's income, which in turn will lead to social progress.

INTRODUCTION

Although cassava is called in China "the underground food store", as it once acted as the key crop against hunger by supplying the main food energy for people of south China in specially difficult times, presently more than 60% of cassava produced is used for industrial purposes, 30% is used for animal feed and only 10% is used for human food. Cassava tuberous roots can be processed into many different products due to their high (28-35%) starch content. But production of starch and fuel ethanol will become the most important cassava-based industries in future China. All this will promote a great increase in the growing of cassava.

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1. Commercial Demand for Cassava in China

Starch Market

Cassava has the following advantages with respect to its utilization in the starch industry: 1. Low production cost; 2. Can be planted in poor soil; 3. Excellent starch quality for its white, sticky and lucent characteristics. According to statistical data, total national starch production reached 5 million tonnes/year, of which 11% is cassava starch, 80% maize starch and 9% starch from other crops. Total production of starch has been increasing in recent years, while that of cassava starch has increased at a similar rate (**Table 1**).

Table 1. Total and cassava starch production (million tonnes) in China from 1995 to 2000.

Starch type	1995	1996	1997	1998	1999	2000
Total starch	2.60	2.64	2.84	3.58	4.70	5.50
Cassava starch	0.228	0.273	-	0.291	0.369	0.588

***Source**: Yearbooks of Chinese Agricultural Development, 1995-2000.*

Cassava is particularly suitable for production of modified starch. Modified starch is a main product among starch derivatives because it has become a new raw material in multiple industries. For example, modified starch is the third most important material in the paper making industry, and large amounts are also used in the textile industry. Although the amount of modified starch produced is still relatively small in present-day China, it increased nearly six times during the past seven years, from 0.06 million tonnes (MT) in 1994 to 0.33 MT in 2001; and 26.5% of it was produced from cassava. The amount of modified starch used in different industries in the United States and in China are shown in **Table 2**. By comparing the consumption of modified starch between these two countries, we can see that there is a huge developmental potential in China. At present, China has one of the largest paper making industries, ranked third in the world, and the largest textile industry. It is estimated that the total amount of paper products produced reached 4 million tonnes in 2001, and with the increasing use of high quality papers, which requires more modified starch, the total consumption of modified starch was over 0.4 million tonnes.

The total amount of modified starch used in the textile industry in China will be much higher than that in the US. It should be pointed out that much of the modified starch used in these fields, such as paper making, food industry and fish feed is derived from cassava starch.

But several problems must be resolved in cassava starch production:

1) There are too many small processing units that have high production costs. It is essential to build new factories with over 0.2 million tonnes production capacity per year.
2) There are few factories producing starch derivatives and the amount is still small. Modified starch production is of primary importance.

3) The present cassava production system can not supply enough raw material for the cassava starch industry. Improved cassava production systems need to be developed.

Table 2. The total amount of modified starch and its proportional share used in different industries in the United States (1994) and China (1997).

Industry	United States (1994)		China (1997)	
	Percentage	Modified starch (MT)	Percentage	Modified starch (MT)
Paper industry	63.1	1.36	38.5	0.08
Food industry	27.9	0.60	8.7	0.018
Textile industry	3.0	0.065	26.4	0.055
Fish feed	-	-	24.0	0.05
Others	6.0	0.13	2.4	0.005
Total	100.0	2.155	100.0	0.208

Source: *Hua Ou Starchy Net.*

Fuel Ethanol Market

China has been developing a fuel ethanol plan since 2001. It plans to produce pure ethanol used as automobile fuel for the purpose of decreasing mineral oil imports and reducing environmental pollution; secondly, other grain crops should be used mainly for food production. All affairs related to this plan have already been carried out publicly and technologically. The alcohol market could amount to 5 million tonnes per year if fuel ethanol were added to gasoline at a level of 10%. But presently the total national ethanol production capacity is only 2 million tonnes. The development of the fuel ethanol industry will be China's "sun-rise industry", with a value of 2.5 billion dollars per year.

Internationally, the technology of fuel ethanol production has already been developed. In Brazil, production of fuel ethanol started in 1975, and over 10 million tonnes of fuel ethanol, equivalent to 43% of the gasoline consumption, is presently used. The fuel ethanol is being added to gasoline as a higher level of 22%. In the United States, production of fuel ethanol increased rapidly with about 6 million tonnes being produced in 2001. Many countries with rich agricultural resources have been pushing their fuel ethanol policy. All countries that developed large-scale fuel ethanol production have gained great benefits, such as the promotion of agricultural productivity, increased energy savings, creation of employment, increased public income and improved air quality.

Naturally, the economic benefits of fuel ethanol depend on its prize in relation to that of gasoline; the price is influenced by the cost of the raw materials and the processing costs. Maize, sugarcane and cassava are the main crops used for ethanol production in the world. Experts have pointed out that cassava is the best energy crop to produce ethanol. This is because the ethanol yield of cassava per unit land area is the highest among all known energy crops (**Table 3**). Moreover, it is less complicated to set up a cassava ethanol factory because of lower investment and a simpler processing technology due to the special starch characteristics of cassava. Production of useful by-products made from various parts of the cassava plant can also decrease the cost of cassava ethanol.

Table 3. Comparison of ethanol yield produced from different energy crops.

Crops	Yield (t/ha/year)	Conversion rate to sugar or starch (%)	Conversion rate to ethanol (L/tonne)	Ethanol yield (kg/ha/year)
Sugarcane	70	12.5	70	4,900
Cassava	40	25	150	6,000
Carrot	45	16	100	4,500
Sweet sorghum	35	14	80	2,800
Maize	5	69	410	2,050
Wheat	4	66	390	1,560
Rice	5	75	450	2,250

Source: *P.J.M. Rao, 2000.*

2. Cassava Production in China

Table 4 shows that the area of cassava cultivation has increased steadily between 1993 and 2001, but the yield is still rather low in China.

Table 4. Estimated total area, yield and production of cassava in China from 1993 to 2001.

Year	Area ('000 ha)	Yield (t/ha)	Production (million tonnes)
1993	280	11.43	3.20
1994	300	12.15	3.64
1995	323	13.68	4.42
1996	339	13.41	4.55
2001	412	14.21	5.85

Source: *Yearbook of Chinese Agricultural Development, 2001.*

During the past 50 years some newly developed varieties have replaced the older ones (**Table 5**). From the 1950s to the 1970s, several land races and locally selected clones were cultivated for the purpose of human food; these were characterized as being sweet, of high quality but with low yields. During the 1980s to 1990s, some new varieties with higher yield and better adaptation were bred by hybridization and were subsequently released; this promoted the rapid development of cassava production. Since 1995, high starch content and high yield have become the most important breeding objectives in response to the fast development of the cassava processing industry. Now, we have some excellent varieties with starch contents up to 35% and a high yield potential of over 75 tonnes/ha, such as SC 6 and SC 8013.

Table 5. Principal casava varieties used in China during the past 50 years.

Time	Variety	Starch content (%)	Characteristics
1950s	Mianbao (bread) cassava	30-35	early, good quality, sweet but low yield
	Nuomi (sticky rice) cassava	30-35	early, sweet and good quality
1960s	SC 205	28-30	dwarf, wind resistant, bitter
	SC 201	25-28	tall, long duration with red root inner peel
1970s	SC 6068	28-30	early, better quality
1980s	SC 124	28-30	tolerant to drought and cold, wide adaptation, high yield
	Nanzhi 188	27-29	early, resistant to diseases, high yield
1990s	SC 8002	28-30	high yield
2000s	SC 8013	28-32	high yield
	SC 6	28-35	dwarf, wind resistant, wide adaptation

Some of the limiting factors relating to cassava production in China include the following aspects:

1) Cassava is grown by small producers and in widely dispersed areas.
2) There is little communication between producers and the processing industry.
3) The processing industry is still underdeveloped.
4) Large areas suitable for cassava planting have not yet been exploited.

3. Establishment of the Cassava Industrial System

Being faced with the chance for rapid development and considering the present unsatisfactory state of cassava productivity, a proposal based on modern biotechnology is suggested as follows:

- Rebuild the present cassava starch factories into modern cassava starch and fuel ethanol processing enterprises with a production capacity of over 0.2 million tonnes per year. In fact, cassava fuel ethanol factories with 0.6 and 0.2 million tonnes production capacity are being built in Guangdong and Guangxi provinces, respectively.
- Breed more varieties with higher yield potential and starch content using modern methods of molecular biology.
- Develop tissue culture propagation techniques in order to supply massive numbers of plantlets of new varieties for large-scale planting.
- Map out specific cassava production districts that will supply the requirements of the local processing industries.

4. Perspective

Being a highly efficient energy crop, cassava has a strong competitive advantage in tropical and sub-tropical areas because of the following crop characteristics:

1. Highly efficient in transforming sunlight into bio-energy, with one of the highest potential energy yields.
2. Tolerance to drought and poor soils, and wide adaptability to different climates and cropping systems.

3. High extraction rate and excellent physical and chemical characteristics of the starch.

Although cassava is still a small crop in present-day China, with no more than 0.5 million ha area, it has the potential to become a major crop and increase its production several fold, following on the rapid increase that has already occurred up to 2000.

It is estimated that the Chinese cassava cropping area will expand to about 0.8 to 1.0 million ha in the current decade. Through the development of a *production-transport-processing* or so-called "*negotiation agriculture*" system, cassava will play a major role in the industrial chain in Hainan, Guangxi and other less developed provinces, resulting in an increase in people's income, which in turn will lead to social progress.

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CASSAVA PRODUCTION AND UTILIZATION IN CAMBODIA

Huang Jie[1], *Seng Srey*[1], *Kang Aun*[2], *Chiv Phiny*[3], *Suon Serey*[4] *and Tian Yinong*[5]

ABSTRACT

This paper reviews Cambodian cassava production from 1980 to 2001. Cassava is mainly grown in Kampong Cham province, while some cassava is also grown in areas bordering the Mekong river. The harvested area, yield and production in each year varied according to market conditions: in 1999, the harvested area, yield and production were 14,000 ha, 16.3 t/ha and 228,512 tonnes fresh cassava roots, but in 2001 these were only 13,600 ha, 10.5 t/ha and 142,262 tonnes cassava roots, respectively.

Most cassava is used for human food, while little is used for animal feed or for industrial purposes. Some farmers like to produce starch to make bread etc. in their small processing units, or they make dry chips for sale.

Farmers in Cambodia are planting only two important local varieties, namely Damlong Me (bitter) and Damlong Chheu (sweet). There are very few areas planted to new varieties and farmers do little land preparation, weeding, fertilization etc. Mong Reththy Plantation introduced Rayong 60 and Kasetsart 50 varieties from Thailand, and they also cultivate by tractor, but the yields are still low because of lack of proper management.

There are only three important cassava factories. The designed capacity of Mong Reththy Tapioca Flour Factory and T.T.Y. Tapioca Flour Factory are 50 tonnes starch per day, and the capacity of Lay Alcohol Factory is about 10 million liters of cassava alcohol per year. Because of low prices, difficulties in transportation, the existence of few organizations, such as extension services, that can give technical support for cassava production, the factories have a serious lack of cassava raw material.

If in Cambodia the role of cassava can change from a traditional fresh human food to an efficient crop for animal feed and starch production, cassava could become an important source of cash income for poor farmers. It is hoped that cassava can receive more support from the government and other organizations and companies, who should work together to create good market conditions and to improve cassava research and extension in Cambodia.

INTRODUCTION

Cambodia occupies 181,035 km^2, and is located between 102-108°E and 10-15°N. The population of Cambodia is 13.4 million. Cambodia has a tropical climate with two distinct monsoon seasons; the rainy season starts in mid-April and continues to October. Average annual rainfall is 1250-1750 mm. Sihanouk Ville has the highest average annual rainfall of 2996 mm. The mean temperature is about 23-32°C.

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Agriculture is the fundamental sector of the Cambodian economy. Small farmers dominate the agricultural sector of the country. Most farmers are still poor and face many constraints, both in their production activities and in marketing.

Normally, when farmers plant cassava, they use about 100 m-days/ha, equivalent to about 50 US$/ha. Some farmers can get 300-400 US$/ha income from fresh roots in Kandal province, and some farmers can get 500-600 US$/ha income from dry chips in Kampong Cham province. So, cassava is an important economic crop for some poor farmers in Cambodia.

Most cassava is used for human food, while little is used for animal feed or for industrial purposes in Cambodia. Farmers like to plant sweet cassava for earning money at the local market; the leaves can be used to feed sheep and cattle. Some fresh roots and dry chips may be sold to factories and small processing units, for production of starch and some favorite tapioca foods.

AGRICULTURE

1. Agricultural Production in Cambodia

Rice dominates crop production in Cambodia (**Table 1**). Nearly 90% of the cultivated area is planted to rice, 3% is planted on maize, and nearly 1% is planted to cassava.

Table 1. Agricultural production in Cambodia in 2001.

	Harvested area (ha)	Yield (t/ha)	Production (t)
Rice	1,980,295	2.07	4,099,016
Maize	67,213	2.76	185,589
Soybean	28,687	0.86	24,658
Mungbean	27,108	0.63	17,153
Sesame	17,444	0.51	8,957
Cassava	**13,590**	**10.47**	**142,262**
Peanut	11,271	0.29	8,913
Sweet potato	7,055	3.72	26,252
Sugarcane	7,727	21.91	169,302
Tobacco	8,540	0.55	4,662
Vegetables	34,569	5.34	184,640

Source: *MAFF, 2001*

2. Cassava Production in Cambodia and Other Asian Countries

Cassava production in Cambodian is characterized by low production, low yield and low harvested areas as compared to other countries in Asia (**Table 2**); it only produces about 0.3% of cassava in Asia.

Table 2. Cassava harvested area, yield and production in Cambodia and other countries in Asia in 2001.

	Harvested area ('000 ha)	Yield (t/ha)	Production ('000 tonnes)
World	***16,466***	***10.67***	***175,617***
Asia	**3,536**	**13.66**	**48,309**
-Cambodia	15	9.61	148
-China	235	15.96	3,751
-India	250	23.20	5,800
-Indonesia	1,360	11.62	15,800
-Laos	5	13.65	71
-Malaysia	38	9.74	370
-Myanmar	8	11.39	88
-Phllippines	210	8.09	1,700
-Sri lanka	29	8.82	260
-Thailand	1,150	15.90	18,283
-Vietnam	235	8.67	2,036

Source: *FAO, 2001*

3. Cassava Production in Cambodia

The Cambodian cassava harvested area, yield and production in each year varied according to market conditions (**Table 3**). The harvested area, yield and production were higher in years of favorable market conditions in 1980, 1981, 1988, 1992 and 1999. The harvested area, yield and production were 14,000 ha, 16.3 t/ha and 228,512 tonnes fresh cassava roots, respectively, in 1999. But when the market was not so good production was markedly reduced, such as in 2001 when the harvested area was only 13,600 ha, the yield was 10.5 t/ha and production was 142,262 tonnes.

a. Distribution of cassava production

Cambodian cassava is mainly grown in the central and southeastern parts of the country, especially in Kampong Cham and Kampong Thom provinces, while some is also grown along the Mekong river (**Figure 1**).

b. Cassava varieties

There are two main local varieties in Cambodia, one is sweet, the other is bitter. Mong Reththy Tapioca (MRT) plantation, located in Sihanouk ville, in southwest Cambodia, introduced Rayong 60 and Kasetsart 50 in 2000. In areas near the border, the farmers introduced some Vietnamese varieties (bitter) in Kampong Cham province, and a Thai company introduced some Thai varieties (bitter) in Battambang province. Because of a lack of extension, and farmers in many provinces having difficulty finding cassava markets for animal feed and industrial raw material, they generally don't like planting the new bitter varieties; they just want to sell in the local market sweet roots for fresh human consumption. The new varieties are not widely grown yet.

Table 3. Cassava area, yield and production in Cambodia from 1980 to 2001.

Year	Harvested area (ha)	Yield (t/ha)	Production (t)
1980	19,000	8.00	152,000
1981	25,000	7.28	182,000
1982	12,000	6.33	76,000
1983	11,000	3.82	42,000
1984	5,000	6.20	31,000
1985	8,000	2.13	17,000
1986	12,000	5.17	62,000
1987	10,000	4.60	46,000
1988	27,000	9.85	266,000
1989	10,000	6.30	63,000
1990	11,000	5.45	60,000
1991	11,000	5.09	56,000
1992	16,000	9.38	150,000
1993	9,800	5.23	51,292
1994	10,000	6.50	65,000
1995	12,410	6.60	81,950
1996	13,000	5.36	69,656
1997	10,056	7.68	77,266
1998	8,208	8.11	66,534
1999	14,003	16.32	228,512
2000	15,380	9.61	147,763
2001	13,590	10.47	142,262

Source: *MAFF, 2001.*

c. Cassava cultivation practices

The main adopted cultural practices for cassava in Cambodia are shown in **Table 4**. In the flood plain cassava is harvested just 6-8 months after planting; normally, when the flood waters recede, farmers stick the cassava stakes into the soft soil around November, and harvest before flooding occurs again in June. In the uplands, cassava is planted in the wet season and harvested after 9-12 months according to market requirements.

In Kampong Cham province farmers can earn money from selling cassava for processing, so most farmers like to apply intensive cultivation, resulting in the highest average yield and production in Cambodia. Kampong Cham farmers rotate with soybean for improving soil fertility after 2-3 years of planting cassava, and they also intercrop some cassava in young rubber plantations. But in most provinces, cassava is mainly for human consumption providing little income, so cassava cultivation practices are limited to minimum land preparation, weeding and fertilization.

MRT and T.T.Y. plantations plant cassava for their own tapioca factory. They did not apply fertilizers because the land is new, but MRT plantation harvested very low yields after three years planting in 2002. It means that cassava fertilization is also necessary in Cambodia. Because the MRT plantation is located in an area of heavy rainfall, it is difficult to use tractors for plowing and cultivation. For example, it is difficult to harvest by tractor because of heavy rain; also, some roots rot in the poorly drained lowland; and some plants are washed out by severe erosion in the uplands. So, in the future the company has to try to build a new cassava production base far from the factory.

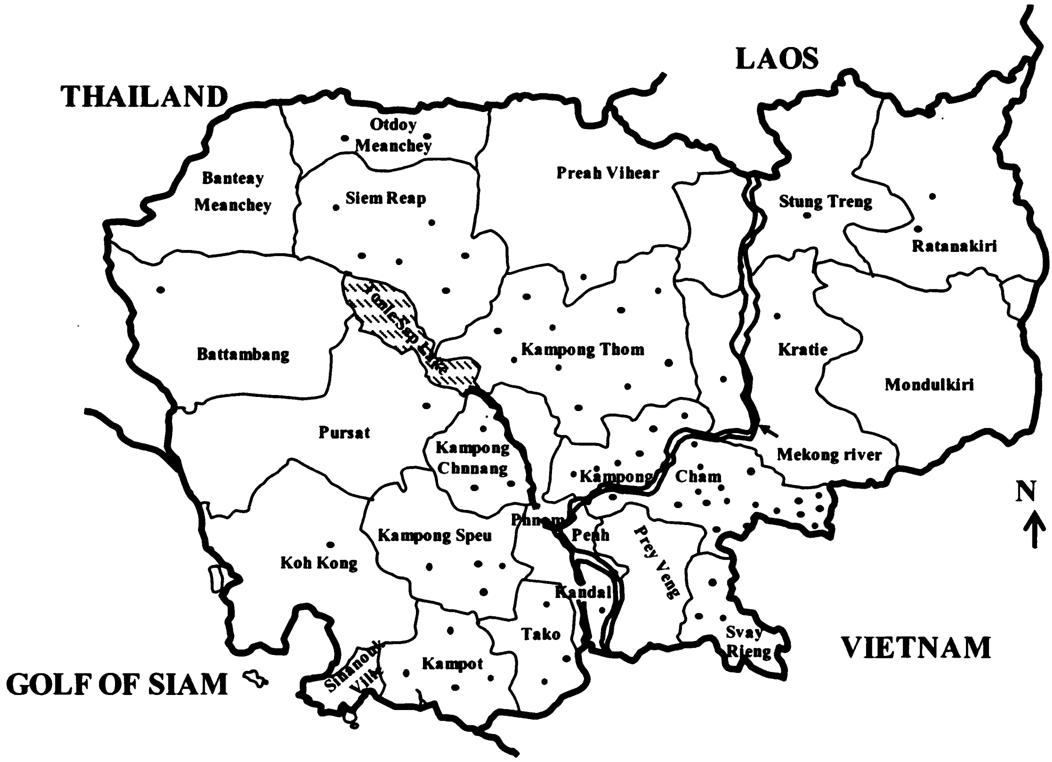

Figure 1. Distribution of cassava growing areas in Cambodia in 2001. Each dot represents 200 ha.

Table 4. The main cultural practices adopted for cassava in Cambodia in 2001, and by M.R.T. and T.T.Y. plantations in 2002.

	Farmers fields	Farmers fields	MRT plantation	TTY plantation
Cultivated soil	upland	flood plain	upland	upland
Main variety	local varieties	local varieties	Rayong 60 and Kasetsart 50	local varieties
Harvested area (ha)	12,457	1,782	1,800	2,500
Planting time	Mar-July	Nov-Dec	Apr-July	May-June
Land preparation	plow by oxen and tractor	plow by oxen	plow and ridge by tractor	plow by tractor
Planting distance (m)	0.5-1.0 x 0.5-1.0	0.5-1.0 x 0.5-1.0	1.2 x 1.2	1.2x1.5
Planting method	mainly inclined	mainly inclined	inclined	inclined
Weeding	hoe and shovel 1-2x	hoe and shovel 1-2x	hoe or knife 1-2x	hoe 2x
Harvesting time	Nov-July	June-Aug	Nov-July	Nov-Feb
Yield (t/ha)	average 10.07	average 13.75	12-20	20-25

Note: The MRT harvested area is not included in MAFF Statistics.

d. Characteristics of major cassava production provinces

Table 5 shows the cassava production and soil characteristics in six major producing provinces. Cassava plants had symptoms of aluminium toxicity in Sway Rieng and Prey Veng provinces.

Table 5. Characteristics of six major cassava producting provinces in Cambodia in 2001.

Parameters	Kampong Cham	Kampong Thom	Kampong Speu	Siem Reap	Kampong Chnnang	Kampot
Harvested area (ha)	4,740	1,880	870	865	613	770
Yield (t/ha)	14.15	10.46	8.00	11.84	7.23	5.18
Production (t)	67,051	19,660	6,960	10,243	4,435	3,990
Rainfall (mm)	1,310	1,631	1,623	1,557	1,184	2,295
Main crops	cassava, fruit, rubber	cassava fruit, rice	cassava, tea, fruit	cassava, rice	cassava, vegetables	cassava, vegetables
Soil	Regur and red soil	Grey-hydromorphic	Podzol	Old-alluvial	Sandstone	Coastal complex
Clay (%)	74	49	20	43	30	20
Sand (%)	11	27	69	21	42	50
Silt (%)	15	24	11	36	28	30
pH	4.0-5.0	5.6	5.4 - 5.7	5.2 - 5.9	5.1	5.3 - 5.7
OM (%)	1.72	0.78 - 1.2	2.00	1.60	0.68	0.93 - 1.30
P (ppm)	5.0	45.0	12.0	38.0	5.0	15.0
K (me/100g)	0.15	0.28	0.06	0.09	0.13	0.22
Ca (me/100g)	0.96	0.27	0.08	0.15	0.25	0.89
Mg (me/100g)	1.68	0.08	0.03	0.05	0.07	0.61

***Source:** Soil analysis from Kang Ann in RUA, others from Statistics Office, MAFF in Cambodia.*

e. Cassava pests and diseases

Some pests and diseases can be found in Cambodia. For example, whiteflies, mealybugs, bacterial stem rot, bacterial angular leaf spot, brown leaf spot, blight leaf spot and white leaf spot. But cassava production is not seriously affected. Particularly, there is very light damage along the Mekong River because of the short growing period.

INDUSTRY

Cambodian cassava is little used for animal feed or for industrial raw material. Most farmers just plant sweet cassava on small fields nearby the house for fresh human consumption; and some farmers like to produce various tapioca products, such as bread, cake, dessert, tapioca pearl etc in small processing units in Kampong Cham province. Some farmers also produce dry chips, as it earns more money in the local market or for export to Vietnam and Thailand.

According to information from the Cambodian Investment Board and the Ministry of Industry, the Cambodian government has approved a number of cassava plantations and tapioca factories from 1994 through 2001, but most companies have now disappeared, due to difficulties in planting and processing cassava in Cambodia.

Presently, there are three rather big factories processing cassava, but all factories are operating below capacity; this is generally due to high costs and low production, so the factories find it difficult to make profits (**Table 6**). The main problems of factories are:

Table 6. The main cassava factories in Cambodia in 2001.

	MRT Tapioca Factory	T.T.Y. Tapioca Factory	Lay Wine Factory	Cassava starch and food processing units
Location	Sihanouk Ville	Kampong Cham	Phnom Penh	Kampong Cham
Start operation	2000	2001	2001	Some time ago
Equipment and technology	Thai equipment	Thai equipment and technology	France yeast and technology	Manual or partially mechanized
Material (t/day)	250 t fresh roots	250 t fresh roots	55 t dry chips	Fresh roots
Price of materials	20 US$/t fresh cassava roots	22-25 US$/t fresh cassava roots	60-65 US$/t dry chips	22-25 US$/t fresh cassava roots
Starch content	24-25% in fresh roots	25-28% in fresh roots	64% in dry chips	25-28% in fresh roots
Production capacity	50 t starch per day	50 t starch per day	27,400 liters cassava alcohol (95°) per day	
Actual production in 2001	500 t starch	2000 t starch	1.6 million liters cassava alcohol	Tapioca pearls, noodles, cake, dessert etc.
Price of product	150-160 US$/t starch	150-160 US$/t starch	0.3 US$/liter cassava alcohol	
Marketing	Local market and export	Local market and export	Local market	Local market

1) **Mong Reththy Tapioca Flour Factory:** Because of the low cassava price and difficulties in transportation, the local farmers do not like to plant cassava. So 90-95% of the raw material has to come from their own plantation. The factory usually operates only 2-3 days per month; the actual production has been only 500 t starch per year in 2000 and 2001. The factory also lacked good management and technology, with too high costs in salaries and fuel. This has resulted in low efficiency and low income. Another big problem is that the company will have to build a new cassava production base far from the factory in the future, which will increase transport costs. Because MRT plantation had low cassava yields in 2002, it is in serious difficulty with respect to raw materials and processing.
2) **T.T.Y Tapioca Flour Factory:** All fresh roots were bought from farmers, and the actual production was 2000 t starch in 2001. The company plans to get 50% of the raw material from their own plantation and the rest from farmers in the future. Because the factory and their most important cassava production area are located

near the Vietnam border, the biggest problem is the highly competitive purchase price in Vietnam.

3) **Lay Cassava Alcohol Factory:** This company mainly buys cassava dry chips from traders in Kampong Cham province. Because this is about 200 km from the Lay factory, the factory gate, price includes 30% transportation cost. The factory was actually operating at 16% capacity in 2001. It also encountered strong competition from Vietnam in terms of purchase price near the border. It mainly sold the cassava alcohol mixed with rice wine in the local market. The main competition is sugar molasses alcohol which is imported from Vietnam. The main difficulties are raw material supply and marketing.

RESEARCH AND TEACHING

Little attention is paid to cassava production in Cambodia. The Ministry of Agriculture, Forestry and Fisheries has not yet drawn up a cassava research program and extension plan. MRT company and T.T.Y company also paid little attention to planting cassava, and the Lay factory just bought dry chips. Most research and teaching involves collaboration with international agencies and donors, and most research is supported by those agencies.

The main cassava research institute is the University of Tropical Agriculture (UTA), which has conducted research mainly on utilization of cassava leaves. Other agricultural units are mainly involved in teaching and practice about cassava (**Table 7**).

Table 7. The main cassava research and teaching institutions in Cambodia.

University of Tropical Agriculture	Mainly research on utilization of cassava leaves: 1)cassava leaf silage and fresh leaves for animal feed 2)intercrop *Gliricidia* sp, *Desmanthus* and water spinach with cassava, all kinds of leaves for animal feed. It has harvested on average 15-17 t/ha fresh cassava leaves at 2 months intervals
Royal University of Agriculture	Mainly teaching and student practices on cassava: 1)cassava agronomy 2)cassava leaf silage and fresh leaves for animal feed 3)cooked cassava roots and leaves for animals
National School of Agriculture Prek Leap	Mainly teaching and student practices of cassava planting and leaf silage for animal feed
National School of Agriculture Kampong Cham	Mainly teaching and student practices on cassava
Cambodian Center for Study and Development in Agriculture	Planting cassava in farming systems project; cassava roots and leaves for human food and animal feed

CONSTRAINTS FOR CASSAVA PRODUCTION

All interviewed people agree that the biggest problem is marketing due to many difficult conditions in Cambodia. Farmers think that cassava production has high costs and low prices, difficulties in transportation and selling. But the factories think cassava raw material has a high price. They also have difficulties in transportation and purchase. The factories have a serious lack of cassava raw material.

There are still many constraints for cassava production in Cambodia. For example: lack of support and organization from the government and factories; lack of research and extension services; lack of new varieties and technologies. There is poor coordination between international organizations and national agencies. All those areas need to be strengthened.

FUTURE POTENTIAL

Because there is a lot of waste land and cassava is a convenient crop for farmers, cassava production has a great potential in Cambodia. If we can create a good marketing system and achieve better coordination between farmers and factories, it will greatly improve cassava production.

If in Cambodia the role of cassava can change from a traditional fresh human food to an efficient crop for animal feed and starch production, cassava could become an important source of cash income for poor farmers.

It is hoped that cassava can receive more support from the government and other organizations and companies, who should work together to create good market conditions, and to improve cassava research, extension and production in Cambodia.

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PRODUCTION AND UTILIZATION OF CASSAVA IN INTEGRATED FARMING SYSTEMS FOR SMALLHOLDER FARMERS IN VIETNAM AND CAMBODIA

T.R. Preston[1]

ABSTRACT

A considerable amount of new research information about the use of cassava foliage as animal feed is becoming available from ongoing research in Vietnam, Thailand and Cambodia. Previously, cassava has been characterized as an "exploitive" crop, destructive of soil fertility. However, when cassava is grown as a component of a whole farming system, in which livestock and crops are closely integrated, its capacity to "exploit" the nutrients in livestock manure becomes a valuable asset.

Managed as a perennial forage, annual foliage yields equivalent to four tonnes of protein per hectare have been obtained, using heavy dressings of biodigestor effluent as fertilizer and with repeated harvesting of the foliage at eight week intervals. For cattle, fresh cassava foliage has been successfully fed as the only protein supplement in diets based on rice straw or molasses. Goats fed cassava foliage as a supplement have been shown to have negligible nematode worm infestations. For pig feeding the ensiled cassava leaves have a higher digestibility when the crop is managed as a semi-perennial forage and harvested at eight week intervals compared with ensiled leaves from cassava plants destined for root production and harvested at 8-12 months.

Key words: Cassava, foliage, livestock, nutritional value, integrated farming system.

INTRODUCTION

The role of cassava in integrated farming systems is closely linked with three major issues that must be addressed in the course of this century. The first issue is the need to develop new feed resources in order to respond to the predicted doubling of the demand for animal products in developing countries by 2020 (Delgado *et al.*, 1999). The second issue is the need to develop renewable sources of energy to compensate for the inevitable decline in fossil fuel supplies (ASPO, 2002). The third issue is to improve the environment and to reduce pollution. The question then is: how can the cultivation and utilization of cassava become a part of the above strategy?

The first point to be appreciated is that there is more than enough energy coming from the sun to cover our present and future needs for food and fuel (**Table 1**). At the same time, this only holds true if optimum use is made of our natural resources, the most important of which is solar energy.

Cassava as a Dual Purpose Crop

Cassava has one important characteristic, namely that it can be managed to produce carbohydrate (by harvesting the roots), or protein (by harvesting the leaves). For root production the growth cycle is from 6 to 12 months, at the end of which the entire plant is harvested. When maximum protein production is the aim, the foliage is harvested at 2 to 3

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month intervals by cutting the stems at 50 to 70 cm above the ground, thereby encouraging the plant to re-grow. In this case the roots act as a nutrient reserve to facilitate the re-growth of the aerial part. This process can continue for 2 to 3 years if the nutrients exported in the leaves are recycled as fertilizer (Preston *et al.*, 2000). Dual-purpose production systems are also possible whereby one or two harvests of the leaves are taken before the plant is allowed to continue the normal development of the roots.

Table 1. Relative use of solar energy for production of biomass and food/feed.

	Joules	Relative to sun=100
Sun	52×10^{23}	100
Biomass	4×10^{21}	0.077
Fuel energy	3.9×10^{20}	0.0077
Food/feed	16×10^{18}	0.003

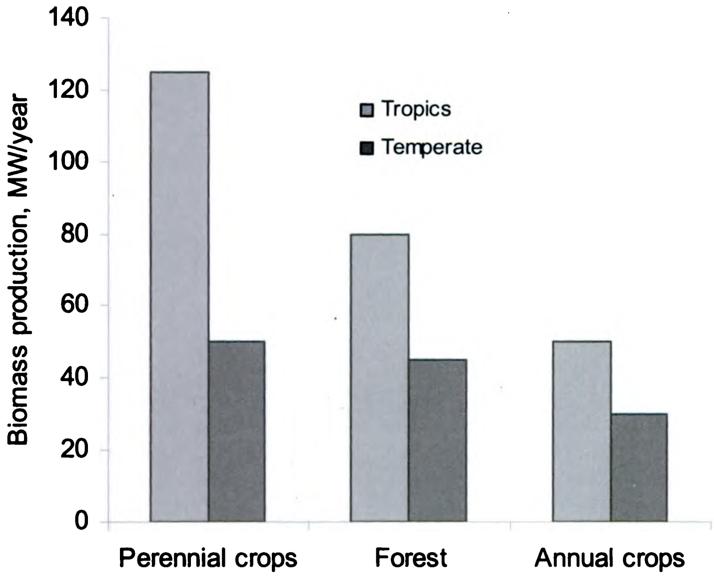

Figure 1. Biomass yield from different ecosystems.
***Source:** Kormondy, 1969.*

Cassava as a Perennial Forage

In tropical ecosystems, the cultivation of perennial crops is the most efficient way to capture solar energy in the form of biomass (**Figure 1**). Thus the management of cassava as a perennial forage is one way of responding to the need to use solar energy more efficiently. Growing and using cassava as a perennial forage was first proposed by Moore (1976) based on observations at CIAT in Colombia. High yields of foliage were obtained when cassava was managed as a semi-perennial crop with repeated harvesting of the foliage at 2 to 3 month intervals. This idea was taken up in the Dominican Republic by Ffoulkes and Preston (1978) who showed that the fresh foliage could be used as the sole source of protein and fiber for supplementing a liquid diet of molasses-urea for fattening cattle. Growth rates were over 800 g/day and were not improved when 400 g/day of additional soybean meal was given (**Figure 2**). However, although successful at the level of the animal, the system could not be sustained agronomically. Yields of foliage fell rapidly with successive harvests and were negligible by the fourth harvest, due to a lack of appreciation of the need to return to the soil the considerable amounts of nitrogen and other nutrients removed by repeated harvesting (T.R. Preston, personal observations).

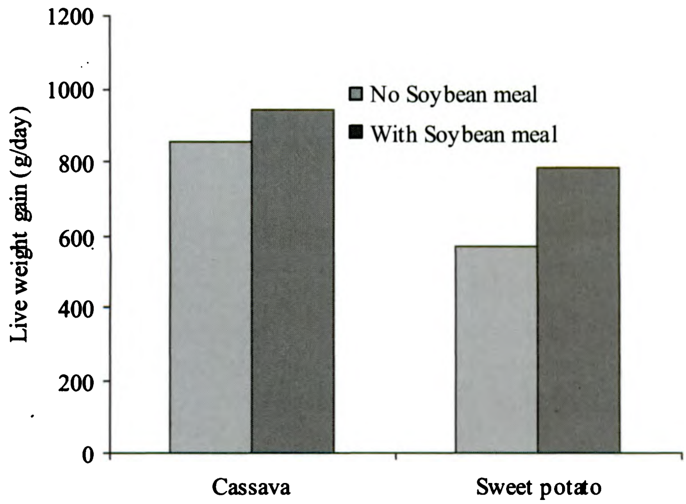

Figure 2. Cassava foliage can provide all the protein and fiber in a cattle fattening diet based on ad libitum molasses-urea, and is superior in this respect to sweet potato vines
Source: *Ffoulkes and Preston, 1978.*

More recent research, first in Vietnam (Preston *et al.*, 2000), then in Cambodia (Preston, 2001), has demonstrated that the cassava plant can be maintained as a semi-perennial forage crop for at least two years provided there is heavy fertilization either with goat manure (**Figure 3**) or with the effluent from biodigesters charged with pig manure (**Figure 4**).

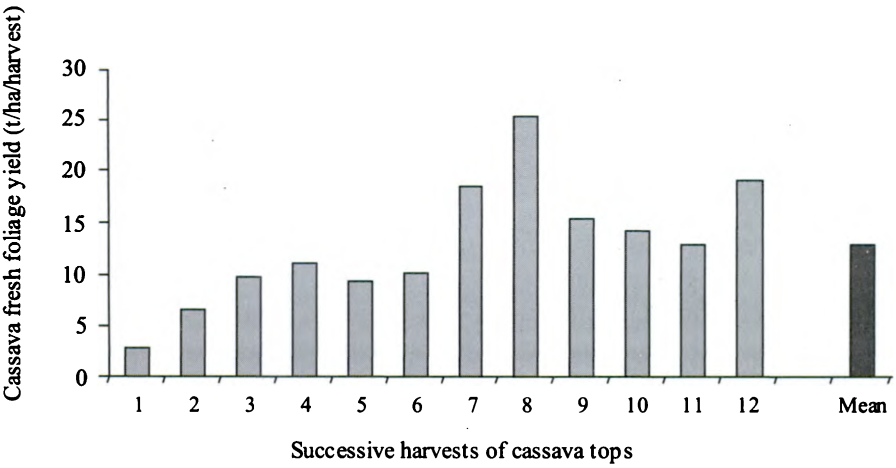

Figure 3. Fresh foliage yields of cassava managed as a semi-perennial forage crop in Vietnam, with repeated harvests at 50 to 70 day intervals and fertilized with fresh goat manure (20 t/ha/harvest)
***Source:** Preston et al., 2000.*

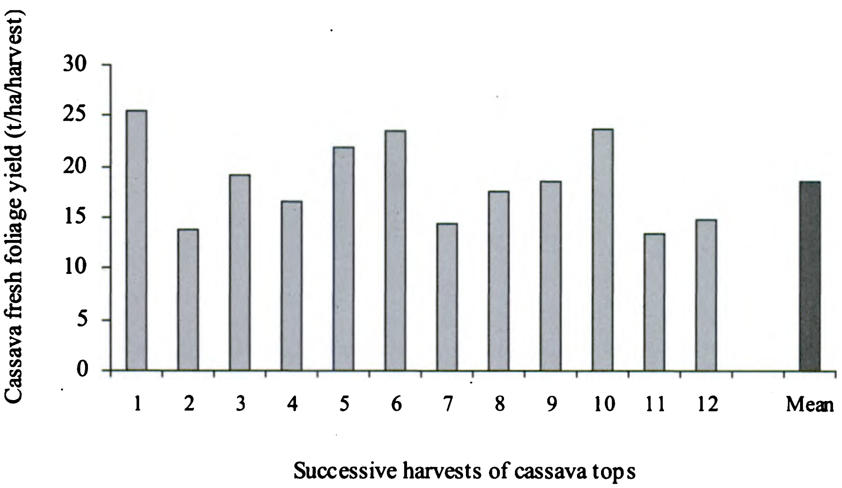

Figure 4. Fresh foliage yields of cassava managed as a semi-perennial forage crop in Cambodia with repeated harvests at 50 to 70 day intervals and fertilized with biodigester effluent (100 kg N/harvest).
***Source:** Preston, 2001.*

Cassava and Manure Recycling

In countries with industrialized agriculture the disposal of manure from large-scale livestock units situated close to urban areas has become a major problem (Narrod, 2001). This situation is exacerbated by the restricted growing season in temperate latitudes where industrialized livestock production is concentrated. For example, in Germany the maximum amount of nitrogen that can be applied as manure is only 170 kg N/ha/year. Tropical countries with year-round growth potential do not have this problem. Livestock manure is a major asset and crops such as cassava are capable of taking up as much as 1000 kg N/ha/year in the form of fresh livestock manure or effluent from biodigesters (Preston, 2001).

The processing of livestock manure in biodigesters results in the conversion of much of the organic nitrogen to ammonia (Pedrosa *et al.*, 2002; San Thy *et al.*, 2003). This makes the biodigester effluent a potentially better source of plant nutrients than the manure from which it is derived. Data in support of this hypothesis were reported by Le Ha Chau (1998) who showed that the effluent supported higher yields of cassava foliage with a higher protein content than the raw manure (either from cattle or pigs) used to charge the biodigesters (**Figure 5**).

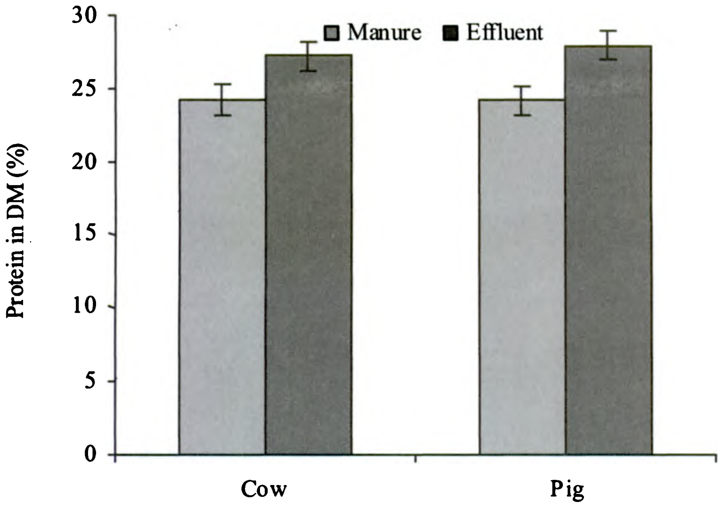

Figure 5. Protein content in cassava leaves is higher when fertilization is with biodigester effluent rather than the original manure used to charge the biodigester.
Source*: *San Thy et al., 2003.

Cassava as a Source of Biomass Energy

Irrespective of whether cassava is grown for root or forage production, a considerable part of the biomass is present in the stem. Some stem material is needed as cuttings for re-establishing the crop; however, when it is grown as a perennial forage this requirement is much reduced as the plant will continue to produce from the same root stock for at least 2 to 3 years, provided there is an adequate supply of nutrients.

The cassava stem is a potential source of energy and has been used successfully as a fuel source in a downdraft gasifier (Dinh Van Binh and Preston, unpublished observations). Cassava as a source of fuel (the stems) and protein (the leaves) is a logical complement to energy-rich sugarcane in a co-generation system to provide energy and animal feed (**Table 2**) from high biomass crops.

Table 2. Potential for production of electrical energy (by gasification of residual fiber from sugarcane and cassava) and feed energy and protein (high-test sugarcane molasses and dehydrated cassava leaves) in a co-generation system.

	Sugarcane (ha/yr)	Cassava (ha/yr)
Biomass, tonnes	190	120
Electricity, kwh	61,920	37,840
High test molasses, tonnes	16	
Leaf meal, tonnes		8
Protein, tonnes		2.24

Source: *T.R. Preston unpublished data.*

Cassava Foliage as Animal Feed

Recent work in Cambodia has aimed to evaluate cassava as a protein supplement for cattle and goats (the fresh foliage) and pigs (the ensiled leaves). Ensiling the leaves after chopping and wilting for 24 hours reduced HCN concentrations to levels that presented no deterrent to feed intake or N retention in growing pigs (Ly and Rodríguez, 2001). In several trials, the cassava silage has been fed successfully to pigs at up to 50% of the diet dry matter (Chhay Ty *et al.*, 2003a). In this connection, an important recent finding is that the digestibility of the organic matter and of the protein by pigs was significantly higher when the leaves were derived from fresh re-growths (from repeated harvesting at 2-month intervals) than from mature leaves harvested at 5 months from cassava grown for root production (Chhay Ty *et al.*, 2003b).

For ruminant animals, the approach in Cambodia and Vietnam has been on the use of the fresh foliage from cassava grown as a semi-perennial crop on a year-round basis. This is in contrast with the cassava research program in Thailand, which is mainly based on production and utilization of cassava dry hay for dry season feeding (Wanapat *et al.*, 1997; Wanapat, 2001).

Results from feeding fresh cassava foliage as a supplement to Brewer's grains for goats are summarized in **Figures 5** and **6**. There were positive effects of the cassava foliage in reducing nematode worm burdens (**Figure 5**) and in supporting growth rates (**Figure 6**). Similar findings have been recorded in Vietnam with goats fed rice bran supplemented with fresh cassava foliage or grass (Nguyen Kim Lin *et al.*, 2003). In a trial reported by Ho Quang Do *et al.* (2001), N retention in goats increased linearly when cassava foliage replaced elephant grass in the diet.

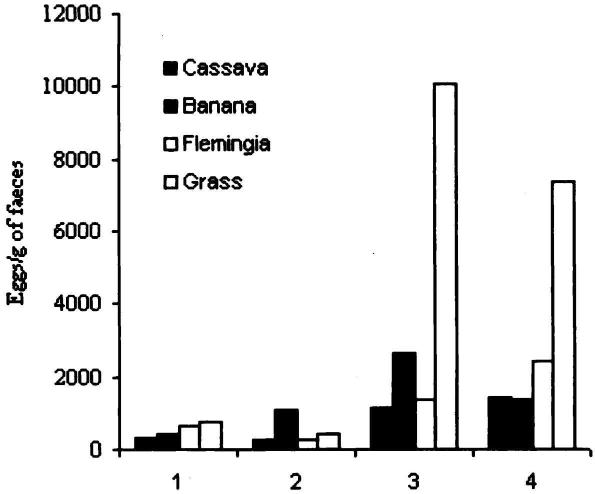

Figure 5: Effect of feeding goats with three types of tree foliages or grass on counts of faecal nematode eggs.
***Source:** Seng Sokerya and Rodríguez, 2001.*

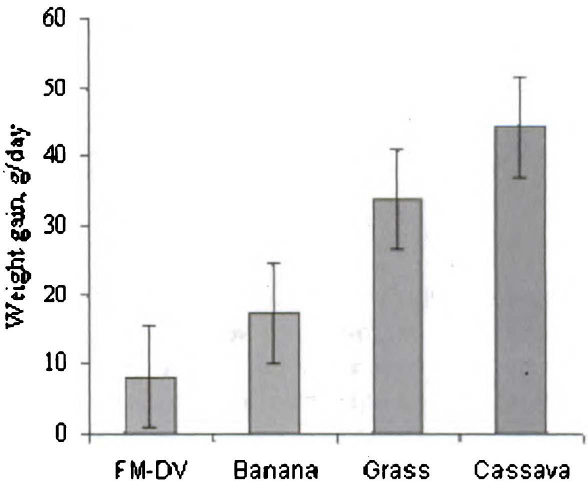

Figure 6: Effect of tree foliages on the growth rate of goats.
***Source:** Seng Sokerya and Rodríguez, 2001.*

For cattle the emphasis has been on the use of the cassava foliage to supplement untreated rice straw as a fattening system for local yellow cattle. The results are encouraging, especially when the cassava foliage was combined with a single drench of vegetable oil at the beginning of the fattening period (**Figure 7**).

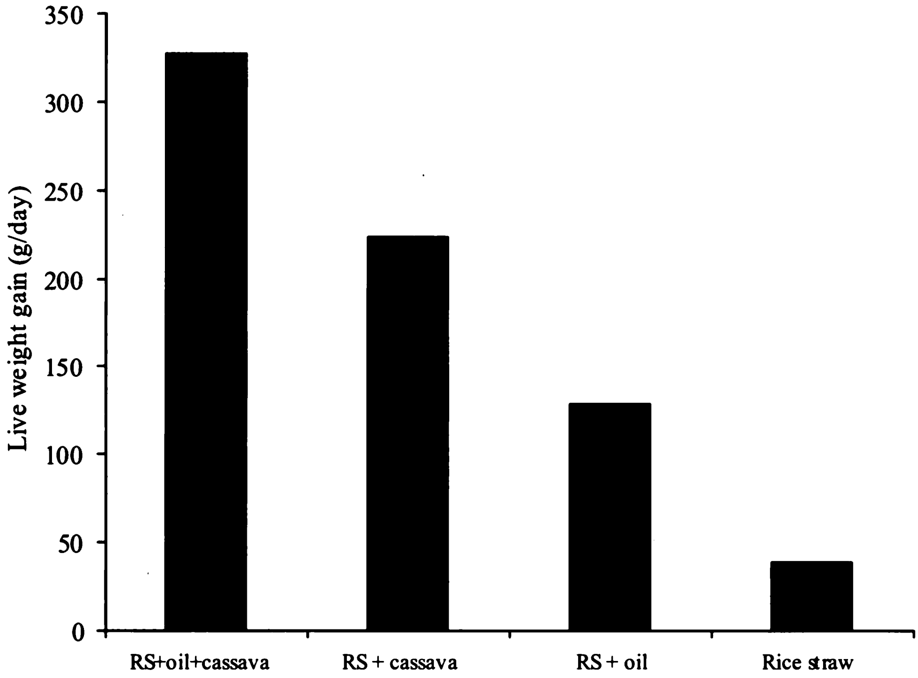

Figure 7. Effect of supplementing rice straw with cassava foliage and a single oil drench for local cattle in Cambodia (all had urea and minerals).
***Source:** Seng Mom et al., 2001.*

CONCLUSIONS

Cassava can produce very high yields, especially of protein (up to 4 tonnes/ha/year), which makes it an ideal element for taking advantage of recycled livestock wastes. This high yield potential is complemented by the high nutritive value of the leaves for cattle, goats and pigs. The presence of cyanogenic glucosides does not appear to be a problem in ruminants and can be neutralized by ensiling or drying the leaves before feeding them to pigs. Recent findings that the leaves have anthelmintic properties in goats and cattle confer further advantages on this crop as a component of integrated farming systems.

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CASSAVA GERMPLASM CONSERVATION AND CROP IMPROVEMENT IN THAILAND

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ABSTRACT

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. Cassava germplasm in Thailand has been introduced mainly from Latin America via CIAT since 1975. The Thai cassava germplasm collection also includes earlier introductions from the Virgin Islands and Indonesia. Formerly, the cassava germplasm collection was maintained only in the field. Some cultivars were lost due to stress environments, i.e. drought or excessive rain, as well as by insect and disease attack. An alternative conservation method to solve these problems is to maintain the collection also in the laboratory as *in-vitro* cultures. Rayong Field Crops Research Center (RFCRC) established a tissue culture laboratory for this purpose in 1993. Recently, CIAT collaborated with the Department of Agriculture (DOA) of Thailand to send a duplicate of the CIAT cassava core collection, containing about 630 accessions, to Thailand. The purpose of this collaboration was to keep those genetic resources *in-vitro* at another safe site away from CIAT, as well as to evaluate in the future these genetic resources for traits that may be useful in future breeding efforts. At the present, RFCRC has received 601 accessions in the form of *in-vitro* plantlets. At least five plants of each accession are kept *in-vitro* for conservation. These genetic resources are also multiplied in order to evaluate them in the field for specific traits under Thai conditions.

Most achievements of the Thai cassava breeding program were reported in the sixth Regional Cassava Workshop held in Vietnam in February, 2000. During the past 20 years seven cultivars have been officially released, five from DOA and two from Kasetsart University. These new cultivars are characterized by high yield capacity, high harvest index, high root starch content and early harvestability; they are all suitable for planting in the northeastern region of Thailand. From 1995 to 2000 some hybrids from crosses made in 1992 and 1993 were identified that were slightly superior to these cultivars in terms of root yield capacity and starch content. One of the 1992 hybrids, identified as CMR35-48-196, performed well under late rainy season planting conditions. The other three lines, i.e. CMR35-21-199, CMR35-22-196 and CMR35-64-1 yield fairly high and have high starch contents. They are being evaluated for ethanol yield at different ages. CMR36-55-166 and CMR36-30-329 are two of the 1993 hybrids which have high potential in various locations. All of these lines are now being further tested in the farmers' field for possible future release.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is grown in over 90 countries and provides a livelihood for half a billion people in the developing world. It is one of the most important calorie-producing crops in the tropics. It is efficient in carbohydrate production, adapted to a wide range of environments, and tolerant to drought and acidic soils (Jones, 1959; Rogers and Appan, 1970; Kawano, 1978; Cock, 1982). Thailand was the first country to exploit the industrial prospects of cassava on a large scale. Since the 1970s it has exported enormous quantities of dried cassava chips and pellets to the countries of the European Union, which use these as a carbohydrate source in animal feed. More recently it has been used

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increasingly for animal feed and industrial starch, and is becoming an important source of cash income for a large number of small farmers (Lynam, 1986; Bottema and Henry,1992).

The cassava breeding programs of the Department of Agriculture (DOA) and Kasetsart University (KU) were started in the early 1970s and 1980s, respectively. Due to a shortage of breeding materials, the researchers started by collecting local cultivars and conducted yield trials to select the best among those materials. One local variety appeared very promising and was released to farmers in 1975 under the name "Rayong 1". Since then, it has become a check variety in all yield trials and at the same time became on very important parent of many F_1 hybrids that have been evaluated and selected in Thailand as well as in many other cassava producing countries in Asia.

Hybridization started in 1975 with a very narrow genetic base until the early 1980s when the collaboration with CIAT was established. CIAT supported the Thai cassava breeding program by supplying thousands of F_1 seeds annually, and sometimes transferring elite clones from other countries. The broadening of cassava's genetic base through germplasm exchange became the major factor for the success of varietal improvement in Thailand. Most of the improved varieties that have been released contain some exotic genes from germplasm supplied by CIAT, but in different proportions. Rayong 3 and Rayong 2 are one hundred percent exotic, since they were selected directly from CIAT's F_1 hybrid seeds under Thailand conditions. Rayong 60, Rayong 90 and Rayong 5 are fifty percent exotic, since they were products of crosses between Thai and introduced parental materials. Kasetsart 50 and Rayong 72 have some exotic genes from one of their parents, i.e. Rayong 90 and Rayong 5, respectively (**Table 1**).

Table 1. Background and outstanding characters of eight released Thai varieties.

Variety	Year released	Parents	Background and outstanding characters
Rayong 1	1975	Unknown	Selected from local cultivar. Well adapted to low inputs. Excellent agronomic traits. Moderately resistant to major pests and diseases.
Rayong 3	1983	(F) MMex 55 (M) MVen 307	Selected from CIAT's F_1 seeds. High dry matter content. Rather low HCN.
Rayong 2	1984	(F) MCol 113 (M) MCol 22	Selected from CIAT's F_1 seeds. High carotene and vitamin A; low HCN. Recommended for human consumption.
Rayong 60	1987	(F) MCol 1684 (M) Rayong 1	Selection from DOA F_1 seeds. High fresh root yield. Early harvestability.
Rayong 90	1991	(F) CMC 76 (M) V 43	Selection from DOA F_1 seeds. High dry matter content. Relatively high yield.
Rayong 5	1994	(F) 27-77-10 (M) Rayong 3	Selection from DOA F_1 seeds. High yield. High dry matter content.
Rayong 72	1999	(F) Rayong 1 (M) Rayong 5	Selection from DOA F_1 seeds. Very high fresh root yield. Low HCN.
Kasetsart 50	1992	(F) Rayong 1 (M) Rayong 90	Selection from KU F_1 seeds. High yield. High dry matter content. Wide adaptability.

CASSAVA GENETIC RESOURCES CONSERVATION AND CHARACTERIZATION

The CIAT cassava germplasm collection has over of 6,000 clones, i.e. landraces, mainly from Latin America, but also about 300 from Asia, as well as some elite clones selected by CIAT and the International Institute of Tropical Agriculture (IITA) in Nigeria. A subset of these accessions, called "the core collection", has been assembled at CIAT to represent the genetic diversity of the complete germplasm collection in a more manageable size (Hershey *et al.*, 1994). Evaluation of a core group, which is a fraction of the total collection (5 to 10 percent) but representive of the total genetic diversity (Brown, 1989) can provide overall indicators of genetic diversity at a fraction of the cost. Such a cassava core collection, consisting of 630 accessions from the original germplasm bank, was recently established at CIAT and is now being evaluated for a range of traits, including cyanogenic potential and starch content, photosynthetic rate and nutrient use efficiency (Hershey *et al.*, 1994).

The genetic resources held in trust in the genebanks of CIAT in Cali, Colombia, have been assembled with the participation of the countries providing the material, on the understanding that it will be made available to the research community world-wide. For this reason, and because the use of plant genetic resources is central to any crop improvement program,.CIAT have followed a policy of allowing unrestricted access to the plant genetic resources in their collections. The materials in the CIAT cassava collection is partially duplicated in various national, regional and international research institutes

The core collection can be evaluated across different ecosystems in order to determine the genotype by environmental effects for important traits. Thailand is a suitable place for the safe duplication of this core collection. It is also an opportunity for Asian cassava breeders to use a wider genetic diversity in their breeding programs. (Wongtiem *et al.*, 2002).

The main objectives for transferring the core cassava collection to Thailand are as follows:

1. To establish another safe site and maintain a duplicate of these cassava genetic resources
2. To further evaluate for desirable traits in Thailand
3. To enhance the safe exchange of cassava germplasm between Asian countries

Materials and Methods

In 2001, CIAT and the Department of Agriculture of Thailand agreed to establish a duplicate of the CIAT cassava core collection, presently held in trust for FAO at CIAT headquarters in Colombia, for safe keeping and utilization in Thailand. Thus, from 2002 , the Rayong Field Crops Research Center (RFCRC) has received about 20 boxes of test tubes with *in vitro* cassava plants, with two tubes (each with one plant) of each clone. RFCRC has now received almost the total core collection of 601 accessions, which comprises most of the genetic variability of the crop.

In Vitro Conservation

After arrival in Thailand, these plants have been subcultured and all accessions are being preserved at RFCRC. For the *in vitro* collection, the tissue culture plants are maintained under slow-growth conditions i.e. at 23 ± 1°C constant temperature, with 1000-3000 lux illumination for 16 hours a day provided by cool white fluorescent lamps, and at 70-90% relative humidity. Ten plants of each clone are routinely maintained containing a modified Morishige and Skoog medium developed at CIAT. In addition, some of the plants are transferred to the greenhouse and then to the field for further evaluation.

Details about all the steps in this process are as follows:

1. After arrival, let plants recover in the original test tubes with adequate light for 2-3 weeks.
2. Subculture each of the two plants of each accession to 4-5 test tubes.
3. Keep in the laboratory for 2-3 months and subculture again for further multiplication.
4. Ten plants of each clone are routinely maintained for conservation in the *in vitro* germplasm bank.
5. The rest of the plants are subcultured again until a total of 50 plants are obtained.
6. These 50 plants are kept at room temperature for 1 week and then transferred to the partially shaded greenhouse.
7. Carefully transfer plants from the test tubes to black plastic bags filled with ground coconut husk to maintain good moisture in the rooting zone.
8. Keep plants under plastic cover for 4-5 days and open the plastic by about 20% each 4-5 days.
9. After the plastic has been completely removed, keep in shaded greenhouse for 2 weeks.
10. Transplant to bigger plastic bags containing soil+coconut husk+fertilizer; keep in greenhouse for one month.
11. Transfer plants to a shaded spot outside and keep for another one month.
12. Tranfer plants to the field and water once a day during the dry season.

Field Genebank

The plants are grown initially in the field in single rows at 1 m between plants and between rows for evaluation under normal growing conditions, while root and leaf samples are taken for conservation and characterization. These evaluations also serve to multiply the planting material needed for future evaluations in larger plots.

Germplasm Characterization and Evaluation

In order for the germplasm collections at Rayong Fields Crops Research Center to be a truly useful genetic resource, researchers and other users need reliable data about key traits of particular materials. To provide such information, cassava researchers at the Center routinely characterize and evaluate germplasm from the cassava collection in the field. A total of 266 accessions in the original germplasm collection (**Table 2**) have been evaluated in the field for yield and some other traits, such as morphological and physiological characters, starch content, as well as DNA finger printing using molecular markers. The same 266 accessions have also been evaluated for disease (mainly CBB) and pest (red spider mite, mealy bug and white fly) resistance, and root quality characteristics such as starch, protein, fiber, mineral nutrients, cyanide and amylose contents, as well as the physico-chemical characteristics of the starch using a Brabender visco-amylograph. In the future, the same traits will also be evaluated for the newly received accessions of the core collection and the data will be shared with CIAT for the cassava germplasm database.

Table 2. Cassava germplasm collection at Rayong Field Crops Research Center (RFCRC) in 2000.

Source	No of accessions	Scientific name
Thai local varieties.	10	*Manihot esculenta* Crantz
Other *Manihot* species	1	*M. glaziovii*
Imported varieties:		
-from Virgin Island	17	*M. esculenta*
-from Indonesia	5	*M. esculenta*
-from CIAT	48	*M. esculenta*
Selected breeding lines from RFCRC	185	*M. esculenta*

RESULTS

Thailand has very limited cassava genetic diversity as indicated by a very small number of local varieties (**Table 2**). In order to improve those local varieties and to widen the genetic base, the country has introduced many varieties from abroad, mainly from Latin America through CIAT since 1975, but also earlier introductions from the Virgin Islands and from Indonesia (**Table 2**). In addition, CIAT has provided every year since the early 1980s thousands of sexual seeds produced by the Cassava Breeding Program at CIAT in Colombia. This has greatly increased the genetic diversity of cassava in the country. After passing through many stages of selection some of the selected breeding lines were released as improved varieties, or they were further crossed with local material to increase their adaptation to local conditions (**Table 1**). Finally, starting in 2002 , Rayong Field Crops Research Center received *in vitro* plants with two tissue culture tubes of each accession of CIAT's core cassava collection. It has now received nearly the total core collection of 601 accessions (**Table 3**), which comprises most of the genetic variability of the crop.

Results of some of the characterizations for a few well-known varieties in the original germplasm collection are shown in **Table 4**.

PROGRESS IN CASSAVA VARIETAL IMPROVEMENT

After having achieved a large increase in yield and yield components in Kasetsart 50, Rayong 5 and Rayong 72, as compared to Rayong 1, it seems to be more difficult for cassava breeders to produce still better varieties. Thousands of F_1 hybrids produced during the 1990s were unable to compete with these earlier varieties and were discarded every year. Only a few breeding lines resulting from F_1 hybrids crossed in 1992 and 1993 can outperform these three varieties in at least some useful traits:

Table 3. Number and origin of the accessions in the CIAT cassava core collection received at Rayong FCRC in 2001 and 2002.

Varietal prefix	Origin	No. of Accessions	Varietal prefix	Origin	No. of Accessions
MArg	Argentina	8	MNga	Nigeria	3
MBol	Bolivia	3	MPan	Panama	9
MBra	Brazil	100	MPar	Paraquay	39
MChn	China	2	MPer	Peru	71
MCol	Colombia	139	MPhi	Philippines	2
MCr	CostaRica	20	MPtr	Puerto Rico	4
MCub	Cuba	18	MTai	Thailand	4
MDom	Dominican Rep.	3	MVen	Venezuala	52
MEcu	Ecuador	28	MUSA	USA	4
MFji	Fiji	2	HMC	ICA variety	1
MGua	Guayana	16	CG	CIAT breeding lines	12
MInd	Indonesia	7	CM	CIAT breeding lines	18
MMal	Malaysia	15	SG	CIAT breeding lines	2
MMex	Mexico	19			

Table 4. Root characteristics of important cassava varieties from Thailand, Indonesia, Philippines and Colombia present in the germplasm bank at Rayong FCRC in Thailand.

Variety/line	Paren-chyma color	Moisture content (%)[1]	Starch content (%)[1]	HCN content (%)[1]	Fiber content (%)[2]	Protein content (%)[2]	Amylose content (%)[3]
Hanatee	white	59.5	19.8	53	1.72	1.99	26.3
Rayong 1	while	60.7	22.8	56	1.86	1.15	22.3
Rayong 2	yellow	68.7	14.3	21	1.60	1.75	29.0
Rayong 3	white	54.0	26.5	32	1.92	1.85	26.6
Rayong 5	white	57.6	22.7	55	1.45	1.43	20.5
Rayong 60	creamy	63.0	19.9	175	1.57	1.78	24.8
Rayong 72	white	63.8	20.0	21	1.75	1.33	26.2
Rayong 90	white	60.0	24.1	85	1.47	2.06	25.6
KU 50	white	58.4	23.3	81	1.95	1.47	27.7
Sri Racha 1	creamy	61.0	23.7	64	1.86	1.43	25.3
Adira 4	white	63.4	21.1	62	2.26	1.05	25.2
Golden Yellow	yellow	68.2	12.5	26	2.31	-	25.2
MBra 12	white	69.2	16.8	43	2.07	1.63	28.1
MCol 22	yellow	63.2	20.5	30	1.58	1.73	28.9
MCol 1684	yellow	61.6	20.9	89	1.79	0.94	24.3
MMex 59	white	63.1	17.5	39	2.66	1.09	24.0
CM 523-7	white	57.4	26.3	25	2.23	0.84	26.4

1) on fresh weight basis
2) on dry weight basis
3)as percent of dry starch
Source: *Jinnajar Hansetasuk et al., 2006.*

1. CMR35-48-196

This is a very promising 1992 hybrid from the cross of a high-yield female parent, CMR30-71-25, and a high-starch male parent, OMR29-20-118. It was selected under late rainy season planting conditions. The average yield in 16 locations was higher than those of Kasetsart 50, Rayong 5 and Rayong 72 (**Table 5**). This clone will be tested in farmers' fields during the next 2-3 years, and it is expected that this line will be released as a variety, specifically for late rainy season planting.

Table 5. Average yields of CMR35-48-196, Kasetsart 50, Rayong 5 and Rayong 72 in seven Regional Trials and nine On-farm Trials during October 2000/01 and October 2001/02.

Variety/line	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)	Relative to Rayong 5 (%)
CMR35-48-196	34.68	27.6	9.80	124
Kasetsart 50	32.30	27.5	8.88	112
Rayong 5	31.23	25.1	7.92	100
Rayong 72	31.18	25.0	7.97	101

Source: *Rayong Field Crops Research Center, Annual Report 2002.*
Rayong Field Crops Research Center, Annual Report 2003.

2. CMR35-21-199, CMR35-22-196 and CMR35-64-1

Three promising clones were selected from 1992 hybrids due to their exceptionally high root starch contents (**Table 6**). They are currently being tested in farmers' fields under early rainy season planting conditions. The roots will also be evaluated for ethanol yield at the age of 8, 12 and 18 months after planting. Testing for ethanol yield of these three breeding lines as well as four check varieties, Kasetsart 50, Rayong 5, Rayong 72 and Rayong 90, will be conducted at the Thailand Institute of Science and Technological Research in Bangkok. The test will initially be carried out at the laboratory level using small amounts of dried chips as raw material. The laboratory test will later be repeated at a pilot project level with 2-3 highly promising varieties or lines using approximately 10 tonnes of fresh roots as raw material. This project is being conducted under the cooperation of Rayong Field Crops Research Center and the Thailand Institute of Science and Technological Research, and will need another two years to finish.

Table 6. Average yields of CMR35-21-199, CMR35-22-196, CMR35-64-1, Kasetsart 50, Rayong 5 and Rayong 72 in 38 trials conducted during 1995-2001.

Variety/line	Parents	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)	Relative to Rayong 5 (%)
CMR35-21-199	(F) R5 x (M) KU50	32.0	23.5	7.75	105
CMR35-22-196	(F) R5 x (M) OMR29-20-118	29.9	25.8	7.85	107
CMR35-64-1	(F) CMR31-19-23 x (M) OMR29-20-118	30.9	24.4	7.76	105
Kasetsart 50	(F) R1 x (M) R90	29.7	22.9	6.96	95
Rayong 5	(F) 27-77-10 x (M) R3	30.1	21.9	7.35	100
Rayong 72	(F) R1 x (M) R5	34.2	21.1	6.74	92

Source: *Rayong Field Crops Research Center, Annual Report 2001.*

3. CMR36-30-329 and CMR36-55-166

Two promising clones selected from 1993 hybrids were tested in 26 trials during 1996-2001. CMR36-30-329 has a high starch content, but the adaptability was not as good as that of the released varieties resulting in a lower average yield over locations and years. CMR36-55-166 is somehow opposite having a relatively high yield but lower starch content (**Table 7**). These two lines will be tested again together with the 1992 hybrids during the next two years to determine their true potential.

Table 7. Average yields of CMR36-30-329, CMR36-55-166, Kasetsart 50 and Rayong 5 in 26 trials conducted during 1996-2001.

Variety/line	Parents	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)	Relative to Rayong 5 (%)
CMR36-30-329	(F) R5 x (M) KU50	26.5	26.1	6.91	101
CMR36-55-166	(F) CMR30-71-25 x (M) R5	32.2	23.4	7.53	110
Kasetsart 50	(F) R1 x (M) R90	28.0	24.7	6.92	101
Rayong 5	(F) 27-77-10 x (M) R3	28.5	24.0	6.84	100

Source: *Rayong Field Crops Research Center, Annual Report 2001.*

FUTURE DIRECTION

In order to help cassava farmers in the country, cassava researchers from different institutes need to collaborate more closely, helping each other to do research based on their own strengths in terms of experience, resources and facilities. For example, the Department of Agriculture might concentrate on the identification and evaluation for agronomic traits of cassava germplasm, making crosses to improve the yield potential and root quality characteristics of new varieties to be released to the farmers. Researchers at DOA should work closely with the Department of Land Development and the Department of Agricultural Extention to develop new technologies suitable for different farmers in different agro-ecological zones. Kasetsart University and other educational institutes, which have excellent laboratories and staff, might concentrate on the identification and evaluation of the chemical composition and qualities of each part of the crop, and develop new value-added products and new biotechnology tools. The Thai Tapioca Development Institute (TTDI) and the Thai Tapioca Trade Association (TTTA) can contribute much to the expanding of domestic and international markets, initiate contract farming systems and supply farmers with new varieties and improved production technologies, to strengthen the ecological and economic sustainability of cassava production in Thailand.

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BREEDING AND DISSEMINATION OF NEW CASSAVA VARIETIES IN THAILAND

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ABSTRACT

The cassava breeding program in Thailand was initiated by the Department of Agriculture in 1937. Several cultivars were introduced from Malaysia and the Philippines, and later from the Virgin Islands and Colombia. However, substantial progress in breeding of high-yielding varieties was achieved only after the establishment of the Thai-CIAT breeding program in 1983. Varieties under the name of Rayong have been released from Rayong Field Crops Research Center, Department of Agriculture, since 1984; the most recent variety, called Rayong 72, was released in 1999. Earlier, Kasetsart University released Kasetsart 50 in 1992, while MKUC34-114-206 will be released soon.

Massive multiplication and distribution of new cassava varieties were undertaken by the Department of Agricultural Extension, the Cooperative Promotion Department, and the Thai Tapioca Development Institute Foundation. A recent survey revealed that more than 90% of the cassava planting area in Thailand (996,191 ha) is now planted to new cultivars. Kasetsart 50 is the most popular cultivar in that it is cultivated in about 56% of the total planting area. In addition to high yielding ability and good plant type, a successful cultivar should have a high root starch content, because the price of fresh roots is calculated according to their starch content. The average yield of these new cultivars, calculated for 1996 to 2002, was 99-135% of that of the traditional cultivar Rayong 1. The national average yield has increased steadily since 1997, from 14.80 t/ha (average for 1967-1996) to 17.53 and 17.06 t/ha in 2001 and 2002, respectively. According to a survey conducted in three starch factories, the root starch content during 1997-2001 was also significantly higher as compared to the 1982-1985 period.

INTRODUCTION

Since cassava has been one of Thailand's most important crops, comprehensive breeding has been conducted in coordination with CIAT since 1983. Several varieties have been released. Both government and private sector agencies have been involved in the massive multiplication and distribution of new varieties. New cultivars have now largely replaced the traditional cultivar, Rayong 1. Recently, the impact of three new cultivars on yield and root starch content has been observed on the national average cassava yield.

Breeding

Cassava breeding in Thailand started in 1937 with the introduction of 20 varieties from Malaysia and the Philippines. Later on, from 1963 to 1977 a total of 65 varieties were introduced from the Virgin Islands and Colombia. However, none of these introductions yielded greater than the local cultivar (Srinives and Rojanaridpiched, 1986). Rayong 1, which was the official name given to a local cultivar in 1975, was the most important cultivar in Thailand during the 1960s to 1990s. This cultivar has a moderate yield potential and root starch content, good stake germination, good plant type with very few branches, and wide adaptation to the Thai bio-physical environment. The success of the Thai cassava

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industry has been largely due to Rayong 1 cultivar. Kawano (1992) commented that Rayong 1, at that time was the world's most important cassava cultivar.

Major progress in breeding of high-yielding varieties has been achieved after the establishment of the Thai-CIAT breeding program in 1983. A number of breeders were trained at CIAT headquarters in Colombia, and several cultivars and lines as well as thousands of F_1 seeds were introduced for hybridization and selection. The following new varieties were released by Rayong Field Crops Research Center, Department of Agriculture: Rayong 3 in 1983, Rayong 60 in 1987, Rayong 90 in 1991, Rayong 5 in 1994, and Rayong 72 in 1999. In addition, Kasetsart University released Sriracha 1 and Kasetsart 50. A new promising clone MKU34-114-206 from the cross of Rayong 5 with Kasetsart 50 will be released soon. Based on data from 30 yield trials (**Table 1**), MKUC34-114-206 has 7% higher fresh root yield than Kasetsart 50, while the root starch content is slightly higher than that of Kasetsart 50.

Table 1. Fresh and dry root yield and other characters of MKUC34-114-206 as compared with recommended varieties. Data are average values from 30 yield trials during 1998-2000.

	Root yield				Root starch	
	Fresh		Dry		content	Harvest
Variety	(t/ha)	(%)	(t/ha)	(%)	(%)	index
MKUC34-114-206	35.94 a[1)]	107	13.36 a	107	25.4 a	0.63 b
Rayong 5	31.17 c	93	11.73 c	94	24.1 c	0.62 bc
Rayong 72	37.18 a	111	13.26 ab	106	23.5 d	0.69 a
Kasetsart 50	33.63 b	100	12.51 b	100	25.0 ab	0.60 d
Mean	33.13	-	12.45	-	25.0	0.61
CV (%)	15.4	-	20.0	-	6.8	8.7

[1)] Values within a column that are followed by the same letter are not significantly different by Duncan's Multiple Range test.

Table 1 also indicates that Rayong 72 has the highest fresh root yield potential when compared with Rayong 5, Kasetsart 50 and MKUC34-114-206. However, Rayong 72 had the lowest root starch content among these tested varieties. MKUC34-114-205, according to its high root starch content, has the same dry root yield potential as Rayong 72.

Rayong 72 was officially released only for planting in the Northeast, but was not for the Eastern part of the country due to its low root starch content there. After 1-2 years of promotion farmers were satisfied with Rayong 72. However, cassava chipping and drying factories do not like Rayong 72 because it requires longer drying time of chips and absorbs moisture again during storage. In contract, Rayong 72 roots are well accepted by starch factories.

It is still uncertain whether the new clone, KMUC34-114-206, will be widely adopted as it exhibits heavy branching in some locations and seasons.

At present, the starch industry in Thailand has become more important than the cassava chip and pellet industry. New cassava varieties should be bred specifically for traits demanded by the starch industry, such as high root starch content and good starch quality, such as white and clear color with high viscosity. Other agronomic characters that are important to achieve widespread farmer adoption are:

- good germination when planted in both the rainy and dry seasons
- vigorous growth and less branching
- ease of harvest
- high root yield and starch content
- long storability of planting material

The important Thai cassava varieties, Rayong 3, Rayong 60, Rayong 90, Kasetsart 50, Rayong 5, Rayong 72 and MKUC34-114-206 all originated from eight land races **(Figure 1)**, of which six from CIAT, i.e. MCol 22, MVen 270, MCol 1684, MMex 55, MVen 307, and CMC 76; one from the Virgin Islands, i.e. V43; and the Thai variety Rayong 1.

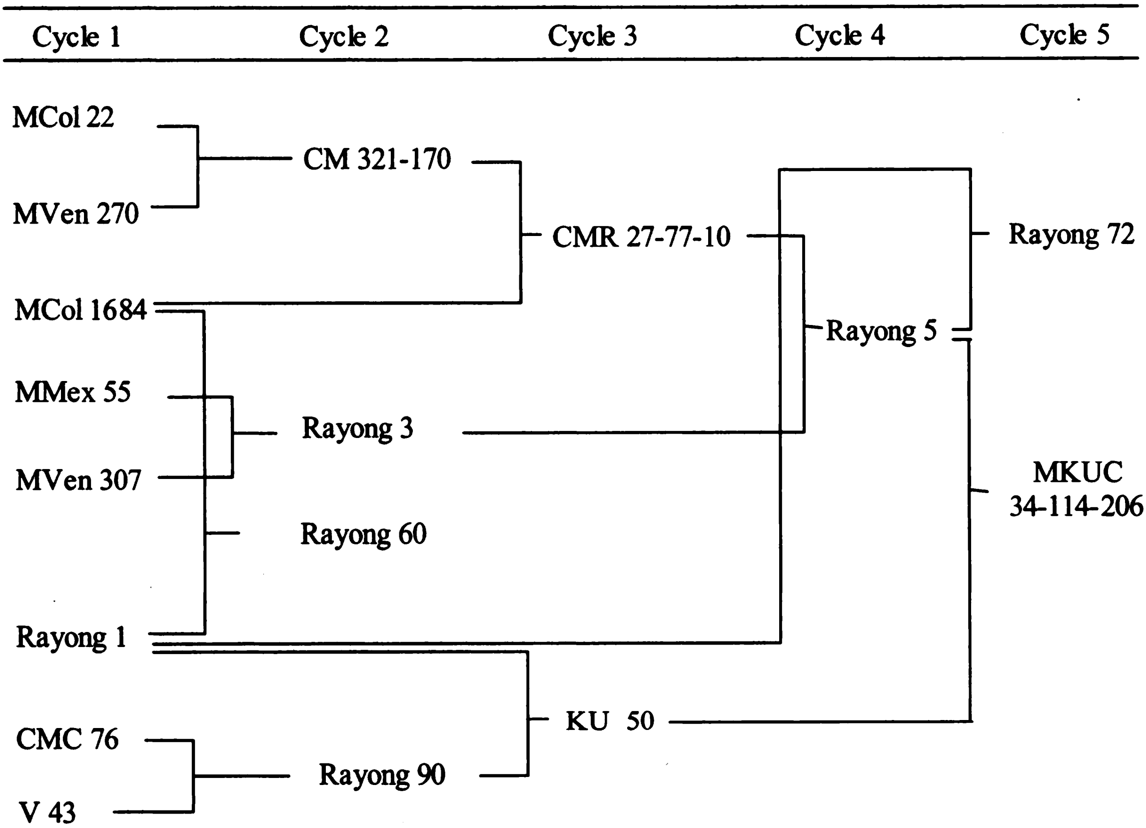

Figure 1. Pedigree of the most important Thai cassava cultivars.

Even though Rayong 1 is less important now, it was one of the parent of Rayong 60, Kasetsart 50 and Rayong 72. The new clone MKUC34-114-206 also contains genes of Rayong 1 through Kasetsart 50.

In order to breed for future varieties, it is necessary to have a new set of germplasm flow into the breeding program. Since 2000, CIAT has transferred the cassava core collection of about 600 clones of cassava to Rayong Field Crops Research Center in the form of tissue culture plantlets. This germplasm needs to be multiplied and evaluated. Any clones with good agronomic traits, high yield and root starch content should be used for crossing with local commercial cultivars.

Varietal Multiplication and Distribution

Cassava varietal multiplication and distribution has been supported financially by the Thai government through the Ministry of Agriculture and Cooperatives to the Department of Agriculture, the Department of Agricultural Extension, and the Department of Cooperative Promotion. The Thai Tapioca Development Institute Foundation, a non-profit organization, also took part in the program. It is important to summarize the major activities since 1994 by each of these institutions.

1. Department of Agricultural Extension (DOAE)

DOAE received a budget to multiply and distribute new varieties to farmers from 1994-1999. DOAE contracted the Department of Agriculture (DOA) and Kasetsart University to multiply the basic planting material of new varieties.

As such, only a part of the total number of cassava stakes required by DOAE were satisfied by DOA and KU. The rest was fullfilled by contracted farmers. From 1994 to 1999, 29,269 farmers received new varieties to plant in a total area of 37,020 hectare (**Table 2**). Planting material of Kasetsart 50 was distributed for 17,803 ha, followed by Rayong 5 and Rayong 90 with 8,548 and 7,105 ha, respectively. Rayong 60 and Rayong 3 were distributed for only 2,986 and 578 ha, respectively. Each variety was multiplied and distributed in different quantities according to farmers' own requests.

Table 2. New cassava cultivars distributed to farmers under contract by the Department of Agricultural Extension from 1994 to 1999.

Year	No. of farmers	Area distributed (ha)					Total
		Rayong 3	Rayong 60	Rayong 90	Rayong 5	KU 50	
1994	2,548	578	2,296	2,145	-	413	5,432
1995	3,839	-	690	2,685	1,772	1,368	6,515
1996	3,622	-	-	1,500	2,470	2,428	6,398
1997	6,649	-	-	110	2,144	4,266	6,520
1998	6,348	-	-	390	1,542	4,656	6,588
1999	6,313	-	-	275	620	4,671	5,567
Total	**29,269**	**578**	**2,986**	**7,105**	**8,548**	**17,803**	**37,020**

Source: *Department of Agricultural Extension.*

2. The Thai Tapioca Development Institute Foundation (TTDI)

TTDI is a non-profit foundation which was established in 1993 with an initial trust fund of US$ 24 million from the government. The main objective is to increase the productivity of cassava farmers, develop new cassava products and to develop new markets for cassava products. TTDI owns 260 ha of land in Huay Bong subdistrict in Nakhon Ratchasima province. During 1993-1994, Rayong 60, Rayong 90, Sriracha 1, Kasetsart 50 and Rayong 5 were planted at this Center for yield comparisions in large plots. It was found that Kasetsart 50 had high root yield, root starch content, and vigorous stems, suitable for efficient multiplication. Therefore, the TTDI committee decided to massively multiply Kasetsart 50 for the farmers in 1995-1998. Fifteen million stakes of Kasetsart 50 were distributed to 18,807 farmers, each of which received 1,500 long stems, enough for planting 0.8 ha **(Table 3)**. Before receiving stakes of new varieties farmers were required to attend a training course on how to increase cassava productivity. Since there was a high demand for planting material of new cultivars, after the harvest of these new cultivars, farmers had to give planting material free of charge to their neighbors. TTDI conducted several other activities, such as farm visits by TTDI's staff, and a cassava yield competition among recipient farmers. Several farmers participating in this project obtained cassava yields of 30-35 t/ha.

Table 3. Distribution of Kasetsart 50 to farmers by TTDI from 1995 to 1998.

Year	No. of farmers	No. of stakes distributed	Area planted (ha)
1995	1,301	1,825,500	1,040
1996	7,089	6,233,501	5,671
1997	7,031	4,806,825	5,624
1998	3,386	2,228,080	2,708
Total	**18,807**	**15,093,906**	**15,043**

Source: *Thai Tapioca Development Institute Foundation (TTDI).*

3. Cooperative Promotion Department (CPD)

More recently, CPD also received a budget for the multiplication and distribution of new cassava varieties to members of agricultural cooperatives. CPD received stakes of new varieties from DOA and also contracted farmers to multiply these. From 1999 to 2001, 11,297 ha of new varieties were planted by members of agricultural cooperatives, of which 8,638 ha were planted with Kasetsart 50, 5,250 ha with Rayong 72, 1,613 ha with Rayong 5, and 1,046 ha with Rayong 90 **(Table 4)**. Unfortunately, in the area planted with Rayong 72 problems arose as cassava chip factories refused to buy Rayong 72 roots because of the longer time required for drying, and cassava chips of this cultivar reabsorbing moisture during storage. Meanwhile, cassava starch factories did buy Rayong 72 roots. In mid 2002, TTDI held a meeting with cassava chip, pellet and starch factory owners and breeders and concluded that any promotion of Rayong 72 should be done in the vicinity of starch factories and only with advanced contracts by the factory.

Table 4. New cassava cultivars distributed to farmers by the Cooperative Promotion Department from 1999 to 2001.

	Area distributed (ha)				
Year	Rayong 5	Rayong 90	Kasetsart 50	Rayong 72	Total
1999	640	149	3,428	-	4,217
2000	491	350	3,474	-	4,315
2001	482	547	1,736	5,250	2,765
Total	**1,613**	**1,046**	**8,638**	**5,250**	**11,297**

Source: *Cooperative Promotion Department.*

4. Kasetsart University (KU)

Kasetsart University also multiplied and distributed 1 million stems of Kasetsart 50 to 800 farmers in 1999, which was enough for planting 500 ha.

In summary, the total area of new cassava cultivars, multiplied and distributed by DOAE, TTDI, CPD and KU from 1994 to 2001, is shown in **Table 5**. Kasetsart 50 was the most popular cultivar planted in an area of 41,984 ha; this was followed by Rayong 5 and Rayong 90 planted in 10,161 and 8,151 ha, respectively, while Rayong 3 was planted only in 578 ha and Rayong 60 in 2,986 ha. The future acceptance of Rayong 72, the most recently recommended cultivar, is still not clear.

Table 5. Total area planted with new cassava cultivars that were multiplied and distributed by DOAE, TTDI, CPD, and KU from 1994 to 2001.

Cultivars	Area promoted (ha)
Kasetsart 50	41,984
Rayong 5	10,161
Rayong 90	8,151
Rayong 72	5,250
Rayong 60	2,986
Rayong 3	578
Total	**69 110**

Varietal Adoption

Rayong 3 has a high root starch content and a root yield similar to that of Rayong 1. This cultivar is characterized by a very small and highly branched plant type as compared to Rayong 1, which makes this variety unsuitable for growing in poor soils. Since the release of Rayong 3 in 1983, considerable efforts were made to multiply and promote this cultivar. As such, in 1992 it was estimated that Rayong 3 was planted in 108,000 ha or about 7.30% of the total cassava growing area (Klakhaeng *et al.*, 1995).

Rayong 60 was released in 1987. It gave higher yield but had a similar root starch content as Rayong 1. This low root starch content resulted in a lower root price in the rainy season.

Later on, Rayong 90, Rayong 5, and Kasetsart 50 were released. Both root yield and root starch content of these varieties were higher than Rayong 1, and the adoption by farmers of these new varieties was faster. In 1992, the area planted to Rayong 1 was 92.7% of the total planting area; this decreased to 79 and 70.1% in 1994 and 1995, respectively (Rojanaridpiched *et al.*, 1995). It was predicted that the area planted to Rayong 5 and Kasetsart 50 was likely to increase dramatically in the future, while Rayong 90 would increase at a slower rate due to its poor germination when stems had been stored for more than three weeks.

Recently, the Office of Agricultural Economics surveyed the extent of adoption of cassava varieties in 1996, 1998, 1999, and 2002. As expected, the area planted to Rayong 1 had decreased very rapidly, from 60.0% of total planting area in 1996 to only 0.06% in 2002, as shown in **Table 6.** The survey conducted in 2002 indicate that the area planted to Rayong 1 all over the country was only 557 ha, which may be too low due to sampling errors as this variety in 1999 was still grown in about 146,297 ha, or 12.70% of the total cassava area.

Table 6. Planted area of the main cassava cultivars in Thailand from 1996 to 2002.

	Crop year							
	1996		1998		1999		2002	
Cultivars	ha	%	ha	%	ha	%	ha	%
Rayong 1	765,245	60.65	202,483	18.91	146,297	12.70	557	0.06
Rayong 3	78,725	6.24	42,248	3.94	27,004	2.34	5,016	0.50
Rayong 5	32,413	2.57	113,832	10.63	125,823	10.92	181,758	18.25
Rayong 60	255,255	20.23	260,546	24.33	216,898	18.83	77,427	7.77
Rayong 90	71,543	5.67	119,697	11.17	220,926	19.18	78,818	7.91
Kasetsart 50	53,486	4.24	328,889	30.71	410,853	3.67	564,521	56.67
Others	5,164	0.40	3,305	0.31	4,125	0.36	88,094	8.84
Total	**1,261 831**	**100**	**1 071,000**	**100**	**1,151 926**	**100**	**996 191**	**100**

Source: *Office of Agricultural Economics.*

Kasetsart 50 was the most popular variety, occupying 56.6% of the total cassava planting area, followed by Rayong 5 and Rayong 90 with 18.25 and 7.91%, respectively. The area under Rayong 3 had decreased dramatically, from 78,725 ha in 1996 to only 5,016 ha in 2002, whereas that of Rayong 60 had slowly decreased from 255,255 ha in 1996 to 77,427 in 2002.

Even though the role of Rayong 1 in the cassava industry of Thailand had ended by the end of the 20th Century, nonetheless, the most popular variety Kasetsart 50, was the

F_1 hybrid of Rayong 1 and Rayong 90. Half of Rayong 1's genes are still present in Kasetsart 50.

Yield and Starch Content

The area planted to the local variety Rayong 1 has been decreasing steadily since the late 1980s to less than 60% of total area in 1996. **Table 7** shows that during the 30 year period from 1967 to 1996 the average cassava yield in Thailand was 14.48 t/ha. This average yield was used as a benchmark to indicate changes over time in the national average yield. Since then these yields have steadily increased. The national average yield reached 15.49 t/ha in 1999, 16.85 t/ha in 2000, and 17.53 t/ha in 2001.

Table 7. Planting area, production and yield of cassava in Thailand up to 2002.

Year	Planting area ('000 ha)	Production ('000 tonnes)	Yield (t/ha)	Yield (%)
1967-1996	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

Source: *Office of Agricultural Economics.*

The yield of different cultivars grown in farmers' fields was surveyed by the Office of Agricultural Economics from 1996 to 2002. **Table 8** shows that on average the yield of Rayong 1 was 13.29 t/ha, while those of Rayong 5, Rayong 90 and Kasetsart 50 were above 17 t/ha, which is about 30% higher than Rayong 1. The yield of Rayong 60 was 14.83 t/ha, or about 12% higher than Rayong 1.

Table 8. Average yield of various cassava cultivars grown in farmers fields in 1996 -2002.

Cultivars	Yield (t/ha) 1996	1998	1999	2002	Average	%
Rayong 1	12.29	13.64	14.33	12.92	**13.29**	**100**
Rayong 3	14.84	11.79	12.25	13.55	**13.11**	**99**
Rayong 5	17.55	18.11	19.11	16.94	**17.93**	**135**
Rayong 60	16.28	14.68	13.74	14.61	**14.83**	**112**
Rayong 90	18.10	14.84	17.66	19.11	**17.43**	**131**
Kasetsart 50	22.02	15.26	16.77	17.63	**17.92**	**135**
Others	14.45	11.66	12.34	14.23	**13.17**	**99**
Total	**14.15**	**14.92**	**15.49**	**16.38**	**15.23**	**115**

Source: *Office of Agricultural Economics.*

The root starch content is very important since the price of fresh roots is calculated according to their starch content. **Table 9** shows survey results of the monthly starch content of cassava roots delivered to three starch factories in Nakhon Ratchasima. The data for 1982-1985, are for the average root starch content of Rayong 1. It is clear that during April-July the average root starch content was the lowest. It increased slowly after August and the highest starch contents were found in January-February.

Table 9. The starch content of cassava roots surveyed at three starch factories for different years and months of the year.

Month	Reference[1)] 1982-1985	Siam Quality Starch Chaiyaphum 1997-2001	Sanguan Wongse Nakhon Ratchasima 1999-2001	Corn Products Co. Nakhon Ratchasima 2001-2002
January	28.02	28.80	27.49	31.77
February	28.18	28.49	27.34	30.73
March	26.35	27.45	24.97	27.46
April	22.63	25.27	21.92	25.16
May	19.74	24.25	20.73	24.73
June	19.64	25.13	23.71	26.13
July	21.98	24.96	24.66	28.42
August	23.56	26.79	24.90	27.11
September	24.15	27.34	25.29	22.84
October	25.54	27.36	26.17	25.85
November	25.56	28.28	26.73	26.86
December	26.52	28.97	27.08	29.34
Average	**24.32**	**26.92**	**25.08**	**27.20**

[1)] *Data from Chaya, 1987.*

After the new cultivars had replaced Rayong 1, new data of root starch content were obtained from three starch factories in 1997-2002. One factory was Siam Quality Starch in Chaiyaphum, which collected data from 1997-2001; the second factory was Sanguan Wongse, the biggest starch factory in Thailand located in Nakhon Ratchasima, which collected data from 1999-2001; and the third was Corn Products Co., also located in Nakhon Ratchasima, which collected data from 2001-2002.

It was found that during the period of low starch contents during the early rainy season in May and June of 1982-1986 the root starch content was below 20%; the more recent data from three factories show that during the same two months the root starch contents were much higher than 20%. During most months the starch content during the 1997-2002 period was higher. However, for the peak period of January and February, the difference was narrower. Averaged over 12 months, the starch content from 1982-1985 was 24.32%, compared with 25.08-27.20% for the 1997-2002 period.

Future Direction

In order to achieve higher yields and more sustainable production, the government's policy concerning cassava production in Thailand should be as follows:

1. Replacing Rayong 60 and others (such as Sriracha 1 and various unnamed breeding lines) by higher yielding varieties such as Kasetsart 50, Rayong 5 and Rayong 90.
2. Giving more incentives to farmers by stabilizing the price of cassava roots. Zoning of cassava planting areas is important. Local utilization of cassava roots as for fuel-ethanol production is very promising in Thailand. Further research on new products made from cassava is also needed.
3. Soil conservation to maintain soil fertility is necessary for sustainable production. Farmer participatory research on soil conservation was a successful project. Further extension of the project on soil conservation should be continued.
4. New germplasm for higher root yield and starch content should be introduced and utilized in the breeding program, in order to develop still higher yielding varieties.

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CASSAVA GERMPLASM CONSERVATION AND CROP IMPROVEMENT IN INDONESIA

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ABSTRACT

Improved cassava cultivars are one of the most readily adoptable components for inducing better farm management, which in turn will lead to increased farm productivity and income. There are three phases needed for successful varietal improvement. The first phase corresponds to the collection as well as evaluation of cassava germplasm, the second phase corresponds to the generation of advanced breeding materials, while the third phase corresponds to the selection of new cultivars, their release and dissemination.

Up to the moment, there are 259 cassava genotypes conserved in one of RILET's substations as a field germplasm bank, which has to be rejuvenated each year. It consists of 145 local materials and 114 breeding materials from several sources, either introductions, mainly from the Thai-CIAT program, or from domestic institutes as well as advanced breeding materials obtained by RILET. The number of accessions will increase, since in 2002 another 50 local clones were collected under collaboration of RILET-CIAT-ACIAR. Some clones have been characterized as the gene sources for high dry matter or starch content, low HCN content, tolerance to red mite and adaptation to low soil fertility.

Advanced breeding materials are produced every year through the crossing of selected parents, either through controlled or open pollination. Due to limited resources, only about 2000 seeds can be produced each year. Every specific objective of character improvement will need up to five crossing cycles in an attempt to increase the chance of getting the required genotype. RILET has adopted the conventional breeding methodology developed by CIAT. At present we have materials at all breeding stages, beginning from hybridization up to multilocational tests. Since 2002 RILET has been using biotechnology tools such as marker-assisted selection using Randomly Amplified Polymorphic DNA (RAPD) for selection of tolerance to red mite.

Two cassava varieties have been officially released in 2000, both originally from Thailand, i.e. Rayong 60 renamed as UJ-3, and Kasetsart 50 renamed as UJ-5. Two other new varieties were officially released in 2001, which are Malang 4 and Malang 6. Malang 4 was selected among open pollinated lines from Adira 4 as female parent, whereas Malang 6 is the selected line from a cross made between MLG 10071 and MLG 10032 as female and male parents, respectively. There are several promising lines in the preliminary and advanced stages of selection, which are able to produce more than 10 tonnes of starch per hectare.

INTRODUCTION

Cassava in Indonesia is known as the "poor people's crop", since this crop is generally grown in marginal low-fertility soils with no or very limited external inputs; in agroclimatic zones where both intensity and distribution of rainfall are too risky for growing other annual crops; in locations where the topography is hilly or undulating with usually less developed infrastructure, especially for transportation. The debate about whether cassava is the cause or the result of poverty is never ending, since this phenomenon is analogous to answering which came first, the chicken or the egg. Whatever the truth, poverty and cassava are indeed closely linked.

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That cassava is one of the most efficient crops in converting radiation energy has already been stated many times before, particularly that cassava is highly adapted to adverse conditions and produces very cheap calories. This can be misleading, however. These statements are true when cassava is grown under unlimiting environments as well as in the context of crop comparison. Kawano (2001) stated that cassava can be a very problematic crop if the cultural practices used, or the environment, are not appropriate. So, it is not surprising that for those who are not familiar with the crop, cassava is often considered as an indefensible villain.

We, the authors, consider that the improvement and development of cassava as one of the potential tools in fighting poverty, is not only in the hands of cassava experts but also in the hands of decision-makers who may know little about cassava. The public usually considers cassava to be a cheap crop. Henry and Gottret (1996), as quoted in Hershey and Howeler (2001), showed that production costs, farmgate price of roots and the cassava starch price all increased markedly from Thailand to Brazil to Colombia. They suggested that the price differences among countries is mainly due to differences in production and processing costs, but we suggest that, to some extent, those price differences are also due to differences in social appreciation.

People who have to make decisions on budget allocations, but who know little about cassava may not see the need to approve money for breeding research when several varieties yielding more than 40 t/ha fresh roots are already available. However, high yields obtained in breeding plots are nothing more than the phenotypic expression of yield potential. We all know that "no matter how perfect the environment, high yield expressions can not be achieved if the genes required are not present", but those that do not know often do not realize that no matter how perfect the genetic constitution, this will not lead to high yields as long as the required environmental conditions are not present.

In the future, everyone concerned with cassava need to make more appropriate statements. Cassava is not very different from any other upland crop. When well-managed, and with proper inputs, the crop can offer great benefits. The crop's biological potential yield, sometimes up to 100 t/ha, is irrelevant under the conditions in which cassava is actually grown. Indeed, even up to the present the world's average cassava yield is only about 10 t/ha. Increasing the yield from 10 t/ha is analogous to climbing a mountain; it is impossible to do that in a straight line.

In Indonesia cassava remains a crop mainly grown by and for the poor, directly or indirectly affecting the lives of millions of people. In the future, it will most likely be grown with relatively low inputs, and certainly under unpredictable agroclimatic conditions. This leads to an array of production constraints. In that situation, breeding activities can be expected to offer one of the key components for achieving higher yield and production.

Hershey (1988) stated that the objectives of every breeding program at whatever level – international or national – should coincide with the needs of the targeted producers, processors and consumers. Furthermore, research must operate within an evolving context where the principle constraints on the development of the crop often shift from production to utilization to processing and marketing. The breeding objectives should be based on a clear understanding of the role of increased or stabilized crop productivity on agricultural policy. However, the rate of progress in genetic improvement is inversely proportional to the number of breeding objectives.

Iglesias *et al.* (1995) stressed that under yield limiting conditions, most of which are outside the farmers' control, one of the main objectives should be to develop improved cultivars that can produce reliable yields under field conditions. Given the wide range of environmental conditions and production systems, it is impossible to obtain a single genotype that is well adapted to the majority of growing conditions; in other words, developing specifically adapted genotypes is more appropriate than generally adapted ones. Ideally, the number of specifically adapted genotypes should be proportional to the number of specific growing locations. However, as the needed resources are limited we have to prioritize.

Two major environmental components are soil and rainfall, of which the former can be controlled to some extent while the latter can not. Howeler (1992) estimated that cassava in Indonesia is grown on the following soil orders: 24% on Alfisols, 22% on Ultisols, 20% on Entisols, 18% on Inceptisols, 8% on Vertisols, 6% on Mollisols, 2% on Histosols and 1% on Oxisols. Up to the present the two first soil orders have been used as selected soil environments for cassava breeding. Confounded within soil orders are rainfall pattern, which can be bimodal or unimodal. Lampung province, which has mainly Ultisol soils and a bimodal rainfall pattern was chosen as one representative location, while East Jave province, having a unimodal pattern and mainly Alfisols, was chosen as another location.

Cassava breeding was broken down into its three elements; these include the accumulating of a source of genetic variation, creating further genetic variations or recombinations by crossing, and subsequently selecting superior genotypes within this range of variation, finalizing with multilocation testing leading to varietal release.

CASSAVA GERMPLASM CONSERVATION

Germplasm Collection

The Research Institute for Legumes and Tuber Crops (RILET), located in Malang, East Java, Indonesia, was founded in April 1995. It was assigned the national mandate to generate technologies for legumes and tuber crops, focusing on the generation of new varieties and improved cultural practices. Thus, in 1995 cassava breeding was initiated. However, previously, when the institute was still called MARIF (Malang Research Institute for Food Crops) the embryo activity for breeding, which is cassava germplasm collection, had already been initiated.

In 1985, under the Agricultural Technical Aids 272 (ATA-272) Project, funded by the Dutch government, upland crop germplasm collections, including that of cassava, were started. The cassava germplasm was conserved as a field collection, which was replanted every year, while the accessions were documented in a catalogue containing the passport data. Unfortunately, all information has not yet been updated. The first collection consisted of 204 cassava clones. Passport date, giving information about the origin, name and code of an accession, the institute from where it was obtained, and, in case of locally collected varieties, the place of collection. Germplasm was coded MLG (abbreviation of Malang) followed by a number. The numbers 10001–12500 have been reserved for cassava. So, the first cassava germplasm collection consists of MLG 10001 to MLG

10207 (MLG 10005, MLG 10026 and MLG 10167 were lost). This first collection was acquired either from other institutes or from farmers.

Up to the moment there are 259 cassava genotypes conserved in one of RILET's substations as a field germplasm bank, which has to be rejuvenated each year. It consists of 145 local varieties and 114 breeding lines from several sources, either introductions, mainly from the Thai-CIAT program, or from domestic institutes, as well as advanced breeding lines of RILET. Since 2002, another 50 local clones have been collected under a collaborative agreement between RILET, CIAT and ACIAR.

Germplasm Evaluation

The germplasm was evaluated for general characteristics such as morphological or botanical traits and yield related characters, as well as specific traits, mainly resistance to brown leaf spot caused by *Cercospora henningsii*, resistance to red mites (*Tetranychus* sp.), and the dry matter content of peeled roots. Due to technical limitations, only 114 out of 204 clones have been evaluated. Some charactertics are shown in **Table 1**.

The correlation coefficients between several traits were determined, as well as a preliminary indication of broad-sense heritability, calculated according to Singh and Chaudary (1979). The results are shown in **Table 2**.

Besides for morphological traits, 51 local accessions have also been evaluated for physico-chemical traits. Characterizations include flesh color, taste, texture, water content, protein content, starch content, HCN content and the recovery percentage of chips at 6% water content. These general results are presented in **Table 3**.

In anticipation of breeding for specific adaptation to low soil fertility, 198 clones were evaluated in terms of their response to fertilizer application during 1998/99. Calculating their low-soil-fertility adaptation index, as described by Iglesias *et al.* (1995), 10 out of the 198 tested clones were identified as highly adapted, i.e. having an adaptation index above 2.

The frequency distribution of the index value was highly skewed to the left; this indicates that the number of accessions which adapted well to low soil fertility was lower as compared to those that were not adapted. Two clones which had an adaptation index of more than 3, MLG 10032 and MLG 10033, yielded 60.52 and 48.56 t/ha with application of fertilizer while without fertilizer they still yielded 33.90 and 38.25 t/ha, respectively. However, since these two local clones have the same local name and originated from neighboring districts, it is very likely that they are duplicates.

Characterization to determine the materials' suitability for cassava-based food products is ongoing. From preliminary results it can be concluded that only a few clones are suitable for making specific products, while a larger number of clones were found to be suitable for several other products.

Table 1. Characterization data of RILET cassava germplasm.

Parameter	Value	
1. Number of accessions in 1985	204	
- local varieties	151 (74.0%)	
- breeding lines	25 (24.5%)	
- released varieties	2 (1.0%)	
- *M. glaziovii*	1 (0.5%)	
2. Root parenchyma color of 114 accessions		
- white	91 (79.8%)	
- yellow	23 (20.2%)	
3. Outer root skin color		
- brown	104 (91.2%)	
- white	10 (8.8%)	
4. Branching habit		
- branching	52 (45.6%)	
- non-branching	62 (54.4%)	
5. Root number/plant harvested at 6 MAP	F_0	F_1
average	6.52	6.74
maximum	11.00	12.00
minimum	2.00	3.60
standard deviation	1.74	1.74
phenotypic C.V.	26.70	25.80
6. Root weight/plant harvested at 6 MAP		
average	0.83	0.63
maximum	2.38	1.23
minimum	0.28	0.27
standard deviation	9.33	0.20
phenotypic C.V.	39.30	31.20
7. Root number/plant harvested at 10 MAP		
average	7.89	6.52
maximum	11.80	9.80
minimum	4.70	2.80
standard deviation	1.56	1.47
phenotypic C.V.	19.70	22.60
6. Root weight/plant harvested at 10 MAP		
average	2.28	1.45
maximum	5.00	3.29
minimum	0.63	0.70
standard deviation	0.87	0.44
phenotypic C.V.	37.90	30.70

Note: Evaluation of 114 clones planted at 20,000 plants/ha (1.0 m x 0.5 m);
F_0 = without fertilizer; F_1 = 200 kg urea + 70 TSP + 150 KCl/ha.

Table 2. Correlation coefficients between traits and broad-sense heritability values of several traits.

Item	Value
1. Root number vs. root weight at 6 MAP without fertilizer, n = 112	0.53
2. Root number vs. root weight at 6 MAP with fertilizer, n = 116	0.66
3. Root number vs. root weight at 10 MAP without fertilizer, n = 114	0.50
4. Root number vs. root weight at 10 MAP with fertilizer, n = 116	0.65
5. Root number at 6 MAP vs. root number at 10 MAP with fertilizer, n = 116	0.52
6. Root weight at 6 MAP vs. root weigh at 10 MAP without fertilizer, n = 114	0.63
7. Specific gravity at 6 MAP vs. specific gravity at 10 MAP with fertilizer, n = 116	0.81
8. Broad sense heritability of root number at 6 MAP, transformed Vx	0.35
9. Broad sense heritability of root number at 10 MAP, transformed Vx	0.41
10. Broad sense heritability of root weight at 6 MAP, transformed logx	0.23
11. Broad sense heritability of root weight at 10 MAP, transformed logx	0.27
12. Broad sense heritability of root specific gravity at 6 MAP	0.80
13. Broad sense heritability of root specific gravity at 10 MAP	0.80

Note : MAP = months after planting

Table 3. Average, standard deviation, and coefficient of variation of several physico-chemical traits of 51 local accessions.

Item	Water content[1)] (%)	Protein content[2)] (%)	Starch content[2)] (%)	HCN content[3)] (ppm)	Chips conversion [4)] (%)
1. Average	63.38	1.68	53.83	29.79	38.20
2. Standard deviation	4.31	0.98	5.05	18.30	6.55
3. Coefficient of variation	6.81	58.58	9.38	61.41	17.14
4. Flesh color: 8 yellow; 43 white					
5. Taste: 5 bitter; 46 not bitter					
6. Texture: 6 glazy; 45 crumbly after cooking					

[1)] Water content: on wet basis
[2)] Protein and starch contents: on dry weight basis
[3)] HCN content on wet basis
[4)] Chips at 6% water content

CASSAVA IMPROVEMENT

The cassava breeding methodology used at RILET remains essentially the same as that described by Koes Hartojo *et al.* (2001). Non-bitter as well as bitter types are evaluated equally for all other traits. Both types were evaluated for high yield and starch content, while only selected genotypes that already had three of the most required characters were evaluated for adaptation to low soil fertility as well as tolerance to red mites. These evaluations were carried out by teams from the relevant disciplines, particularly soils and plant nutrition, plant protection and post-harvest technology.

During the period of 1998/99 to 2001/02 we produced about 2000 hybrid seeds, per year, either from controlled crosses or through open pollination. The substation at which we conducted these hybridizations is essentially rainfed, so the number of seeds produced is very dependent on the rainfall conditions. Sometimes it is much less than expected, sometimes more. During 1998/99, 1999/00, 2000/01 and 2001/02 we produced 952, 3604, 2,112 and 1,700 seeds, respectively. Thus, we produced a total of 8,368 seeds.

In 1999/00 we took 200 clones to Lampung and tested them there as well as in south Malang. As already described above, Lampung is representative of areas with Ultisols and with a bimodal rainfall pattern, while south Malang has calcareous Alfisols with a unimodal rainfall pattern. Only 171 clones out of 200 tested grew well, so statistical analysis were conducted only for those 171 clones which were present in both locations.

The interaction between location and genotype was highly significant. There was only one clone which could be selected for both locations at the 30% selection intensity. **Table 4** shows 14 clones which had yields of 35 t/ha fresh roots or more, averaged for the two locations, while the yield levels at 30% selection index were 24.25 and 48.30 t/ha for south Malang and Lampung, respectively.

Table 4. Fresh root yields and origin of selected clones in the Preliminary Yield Trials in south Malang and Lampung in 1999/2000.

	Clone No	Yield (t/ha)		Origin
		South Malang	Lampung	
1	MLG 10219	25.50	48.94	West Java
2	MLG 10172	34.75	(43.38)	East Java
3	MLG 10197	(5.13)	73.56	Central Java
4	MLG 10015	37.88	(39.13)	East Java
5	MLG 10186	34.63	(41.75)	Central Java
6	MLG 10027	(20.63)	52.19	East Java
7	MLG 10234	(21.50)	58.44	East Java
8	MLG 10127	(17.88)	57.50	East Java
9	MLG 10248	(15.38)	61.00	East Java
10	MLG 10032	(7.84)	71.25	East Java
11	MLG 10130	27.13	(43.75)	East Java
12	MLG 10124	(23.75)	49.81	East Java
13	MLG 10039	36.13	(45.13)	East Java
14	MLG 10134	(14.63)	57.25	East Java

Note: Figures in brackets means that the clones were not selected in the specified location.

The highly significant interaction between location and genotypes was also supported by other experiments which used the same germplasm but at a more advanced stage of selection. **Table 5** shows the ten genotypes which were selected in each location under 30% selection index. Again, the average yield in Lampung was significantly higher than in south Malang. Only two out of 25 tested clones could be selected for both locations. The two clones selected for both locations were out of seven and four clones selected for each location, i.e. south Malang and Lampung, respectively.

Table 5. Fresh root yields of selected clones in the Advanced Yield Trial in south Malang and Lampung in 1999/2000.

	Clone No	Yield (t/ha)		Origin
		South Malang	Lampung	
1	MLG 10200	(13.88)	45.00	Local Central Java
2	MLG 10034	31.13	(37.50)	Local East Java
3	MLG 10050	40.88	(35.50)	Local East Java
4	MLG 10020	(2.38)	48.13	Local East Java
5	MLG 10113	43.50	66.25	Breeding lines
6	MLG 10102	26.25	(27.50)	Local East Java
7	MLG 10018	20.75	(17.50)	Local East Java
8	MLG 10227	(10.38)	43.75	Local West Java
9	MLG 10025	34.25	(15.63)	Local East Java
10	MLG 10128	28.75	(33.75)	Local East Java

Note: Figures in brackets means that the clones were not selected under 30% selection indices, which were 19.44 and 41.61 t/ha for south Malang and Lampung, respectively.

From the above results it can be concluded that breeding cassava for a specific location is much more feasible as compared to breeding for general adaptation. The number of selected clones selected for each of these two locations was much higher. Since the multiplication rate of cassava is one of the most limiting factors for their rapid dissemination, the greater the number of varieties, the longer it will take.

As expected, during the period 2000–2001, the number of officially released varieties also increased (**Table 6**). Two varieties were released each year. The two varieties released in 2000 were introduced from Thailand. Rayong 60 and Kasetsart 50, which were released in Thailand in 1987 and 1992, respectively, were both released in Indonesia in 2000. Particularly Kasetsart 50, which according to Kim *et al.* (2001) has become the most popular new variety in Vietnam, is also doing well in Indonesia and already occupies at least half of Lampung's cassava area.

Table 6. High yielding cassava varieties officially released in Indonesia during 1978–2001.

	Variety name	Type of crosses	Year of release	Taste	Origin
1	Adira 1	Open	1978	Non-bitter	BORIF
2	Adira 2	Open	1978	Bitter	BORIF
3	Adira 4	Open	1986	Bitter	BORIF
4	Malang 1	Controlled	1992	Slightly bitter	CIAT, Colombia
5	Malang 2	Controlled	1992	Non-bitter	CIAT, Colombia
6	Darul Hidayah	Selfed	1998	Non-bitter	Indonesia
7	UJ-3 (Rayong 60)	Controlled	2000	Bitter	Thai-CIAT
8	UJ-5 (KU 50)	Controlled	2000	Bitter	Thai-CIAT
9	Malang 4	Open	2001	Bitter	RILET
10	Malang 6	Controlled	2001	Bitter	RILET

A vital part of any plant breeding program is the availability of adequate genetic diversity for all the traits for which improvement is sought. We think that we can not progress quickly using only a limited diversity. However, since our financial resources remain limited, we always welcome other national cassava programs to provide us with clones with superior traits. Within the RILET-CIAT-ACIAR agreement, initiated in 2002, we continue to collect our local cassava germplasm. Around 50 local accessions have already been collected and are ready to be evaluated in 2002/03.

Hopefully, from our 2001/02 multi-locational trials, other clones can be promoted based on the results from the Lampung locations only. In one location, which can be considered very marginal (Gunung Katun plantation) there were two prospective clones which significantly outyielded all UJ-clones developed by the Great Giant Pineapple Comp. in Umas Jaya.

If more high-yielding varieties would be available, there would be new ways to reduce poverty, either by stabilizing the production level by liberating areas previously used for cassava for other crops, or by stabilizing the cassava area as long as the demand for cassava increases.

We totally agree with Hershey and Howeler (2001) that it is not so easy to make the rural poor the beneficiaries of the highest possible proportion of cassava added value. But, although not easy, it is not impossible, and very likely it could be possible. If we, who are specialists in cassava production, are not firmly grounded in that conviction, what else can be expected from others?

CONCLUSIONS

- Even with very limited financial resources, Indonesia's cassava breeding program continues to progress. We admit that due to our limited program the chance for success is rather low. But with the help of "the invisible hands", we are never desperate or ashamed doing the best we can, whatever small our contribution might be.
- For rapid progress in breeding we can not rely on limited genetic variation, but for the sake of efficiency and effectivity we are inviting other strong national cassava programs as well as international centers to enrich our genetic stock, which is relatively limited but reliable. Let's together, hand in hand, contribute to the building of a healthy agriculture, scientifically, morally and legally.
- Considering that conventional breeding methods must deal with very large numbers of materials in the hope to find the most suitable genotype(s), we are now starting to use biotech to enhance our breeding efficiency. Significantly, the Donald Danforth Plant Science Center, through its International Laboratory for Tropical Biotechnology, has selected cassava as one of its mandated crops.

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CASSAVA GERMPLASM CONSERVATION AND IMPROVEMENT IN INDIA

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ABSTRACT

Genetic diversity of cassava (*Manihot esculenta* Crantz), obtained by open or controlled pollination and selection, as well as from germplasm introductions from abroad, is being conserved, both in the field and in an *in vitro* gene bank. Nine hundred and eighty five germplasm accessions are being conserved under slow-growth conditions using an osmotic retardant medium. The major thrust given in the varietal improvement program are on Indian cassava mosaic disease (ICMD) resistance, improvement of dry matter and starch content, early bulking and culinary quality. Collaborative activities with international organisations like CIAT, and EMBRAPA (Brazil) and with the national All-India Coordinated Research Programme (AICRP) on Tuber Crops have been beneficial.

Field evaluation of breeding lines received as *in vitro* cultures from CIAT has resulted in the identification of one line, MNga 1, showing resistance to ICMD. For the past eight years this line has shown only very mild symptoms of ICMD in the field. The resistant character was confirmed by a grafting test. This variety had a root yield of 34 t/ha, had 43% dry matter and 33% starch content, while showing normal flowering and seed set. This variety has now been crossed with both released and popular local varieties in order to incorporate the ICMD-resistant gene.

Interspecific hybridization of cassava with other *Manihot* species, such as *M. caerulescence, M.tristis, M. glaziovii, M. epruinosa, M. esculenta* var *flabellifolia, M. esculenta* var *peruviana* have been carried out at CTCRI for the past ten years with the objective of transferring ICMD resistance. The interspecific hybrid of cassava with *M. caerulescence* has shown stable resistance, which was confirmed through wedge grafting. The ICMD-free backcross breeding lines produced root yields ranging from 0.5 to 8.5 kg/plant, and had starch contents ranging from 19.2 to 36.6%. Efforts to improve the culinary quality and root shape continue. A new cycle of interspecific crossing has now started using *M. tristis, M. caerulescence* (both cultivated and wild), *M. catingae, M. dichotoma, M. pseudoglaziovii* and *M. epruinosa* as parents.

Starch and dry matter content have also been improved through triploidy breeding, which resulted in the release of the first triploid cassava variety, Sree Harsha, which is presently undergoing testing in industrial areas of Tamil Nadu. Triploids with early bulking and good cooking quality (at 7-month harvest) have been selected from an intervarietal cross of the local variety Ambakadan with H-2304 (4x); hyperploids of varieties with good culinary quality (M4, Sree Jaya, Sree Vijaya) have also been developed. Inbreeding was found to be very effective in breaking up of populations into widely divergent but reasonably uniform groups. Crossing of such early generation inbred lines with high-yielding hybrids like Sree Visakham has resulted in the production of superior top-cross hybrids. Sree Rekha and Sree Prabha with yields of 48.4 and 42.3 t/ha, respectively, with good culinary quality, and high starch content (28 and 27%) were released in Kerala State. They are now being tested and popularized in the other states.

True cassava seed (TCS) technology was developed to enhance the rapid spread of crops to far-away and non-traditional tribal areas, overcoming the problem of shortage of planting material. Crosses made between the male-sterile line Ambakadan and selected male parents resulted in progeny with nearly uniform root yields and starch contents comparable with those of H-165 and H-226. First clonals (C-1 clones) of Ambakadan hybrid generations were found to be suitable for the starch industry. The All-India Coordinated Research Programme (AICRP) on Tuber Crops has been instrumental in the collection and conservation of cassava germplasm at its various Centers in India, as well as the widespread testing of the new varieties in diverse locations.

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INTRODUCTION

Cassava is grown in India under different agro-climatic conditions and in different soil types, and for various end-uses, such as human food, animal feed and as industrial raw material. In most of the states it is grown as a rain-fed crop but in some districts of Tamil Nadu it is raised as an irrigated crop, giving very high yields. In Kerala, where the crop was first introduced in India, it is grown on open slopes or in coconut-based cropping systems in the uplands. But lately it has shifted to lowland rice-based cropping systems as the upland areas were being occupied by cash crops like rubber. This diversity in growing conditions of the crop has influenced the selection criteria in the varietal improvement program. Progress made in the varietal improvement program for the past 25-30 years in India has been summarized and presented in an earlier report (Abrahamet et *al.,* 2001). Conservation of germplasm through *in vitro* methods and the various breeding approaches presently being followed to meet the demands of the farmers and industry in the country are the subject matter of this presentation.

CASSAVA VARIETAL IMPROVEMENT

The major thrusts given in the varietal improvement program are on ICMD resistance, improvement of yield, high dry matter and starch content, early bulking and culinary quality. Tolerance to shade and drought also have been given importance. Value addition by way of reducing anti-nutrient factors like cyanogens, and increasing the nutrient contents like carotene and protein are the other improvement aspects being pursued. The programs undertaken and achievements made through different breeding techniques, like germplasm introduction, evaluation, direct utilization, hybridization and polyploidy breeding, have helped in strengthening the genetic base of the crop, which have enhanced its extending into non-traditional areas as well. Assistance provided by CIAT, Cali, Colombia, and EMBPRAPA, Brazil, in germplasm introduction, and by the All-India Coordinated Research Programme on Tuber Crops in extensive testing of the varieties, has contributed to the progress made in this program. The FPR program being conducted by the Division of Social Science of CTCRI has also contributed to the more widespread use of the improved varieties.

I. Cassava Germplasm Introduction and Conservation

The Central Tuber Crops Research Institute (CTCRI) in Thiruvananthapuram has a cassava collection of 1,633 accessions, of which 849 are indigenous and 784 exotic; these are mainly conserved in field-grown gene banks. Work on *in vitro* gene banks was started with the objective of eliminating Indian Cassava Mosaic Disease (ICMD) infection from the germplasm collection through meristem culture, and to conserve the accessions under medium term storage. This project was in operation from 1998 to 2001 with funding from the Indian Council of Agricultural Research AP (Agricultural Produce) fund scheme.

Meristem culture using Murashige and Skoog (1962) medium with 0.1µM of NAA, BAP and GA_3 was found effective for the initiation of cultures of diverse genotypes. The cultures were micro-propagated on the same basal medium. Nodal cultures from these *in vitro* plantlets were used for raising slow-growth cultures kept for medium-term storage (MTS). Slow growth was induced with osmotic retardants like sorbitol or mannitol. Studies were conducted on the effect of media constituents like sucrose, vitamins and growth regulators in controlling *in vitro* growth (Unnikrishnan and Sheela, 2000). Genotypic response variation was observed among the accessions in meristem culture, micro–propagation and in slow growth. Addition of $AgNO_3$ (0.001µM) and activated charcoal (0.1%) were found to help in reducing leaf shedding and preventing root browning in cultures stored for longer periods. Subculture cycles could be extended to 10 to 12 months (Unnikrishnan *et al.*, 2001). Nine hundred and eighty five accessions were stored in IVAG (*In vitro* Active Gene Bank) including indigenous (442), exotic (387), triploids and other breeding lines (156). CTCRI also has acquired facilities for initiating cryopreservation of germplasm with a view to build up IVBG (*In vitro* Base Gene Bank) in cassava.

Germplasm Introduction

During the last ten years CIAT in Colombia has supplied several cassava germplasm accessions and breeding lines as *in vitro* cultures and as true seeds. Open pollinated seeds of different *Manihot* species were also received from EMBRAPA, Brazil.

In vitro cultures of 20 breeding lines were received from CIAT in 1994 (**Table 1**). Most of the cultures were received in overgrown or infected stage due to delays in transit as well as handling problems. Only six cultures could be salvaged, micro-propagated and field-transferred. All the lines showed CMD infection except MNga 1.

Table 1. Cassava germplasm introduction in *in vitro* culture from CIAT-Colombia in 1994.

CM 3064-4	CM 3435-5	CG 1141-1	CM 3401-2
CM 3555-6	CM 3306-4	CM 5253-1	CM 3997-1
MBra 191	CM 523-7	CM 494-2	SG 804-5
CM 4484-2	CM 3311-3	CM 2177-2	MNga 1
CM 4365-1	CM 4729-4	CM 3380-7	MNga 2

Seeds of wild *Manihot* species were received from EMBRAPA, Brazil and from Dr. Najeeb Nassar, University of Brasilia, Brazil. The following species were received and planted at CTCRI:

**Manihot tristis*
**M. epruinosa*
**M. catingae*
**M. caerulescence*
**M. dichotoma*
**M. pseudoglaziovii*

2. Evaluation and Utilization

Indigenous germplasm

Evaluation of indigenous collections for yield, early bulking, dry matter, low cyanogen and high starch content has resulted in the release of short-duration, early-bulking varieties like Sree Prakash (S-856), Sree Jaya (CI-649) and Sree Vijaya (CI-731) for direct utilization (**Table 2**) (Unnikrishnan *et al.*, 2000). These varieties have become popular in Kerala as table varieties, and in Andhra Pradesh and Tamil Nadu for industrial use. They are being utilized in the genetic improvement program for incorporation of better root characters and compact, late branching plant type. All these varieties possess excellent culinary qualities.

Table 2. Germplasm selections for direct utilization.

Accession No.	Variety name	Root yield (t/ha)	Cyanogen content (μg/g)	Starch content (%)	Time to maturity	Plant type
S-856	Sree Prakash	30-35	30-50	29-31	7-8 months	Late branching
CI-649	Sree Jaya	26-30	40-50	24-27	6-7 months	Late branching
CI-731	Sree Vijaya	25-28	40-60	27-30	6-7 months	Late branching

Exotic Collections

Exotic collections have not yet been used for direct utilization. They have been used as parents in the hybridization program and have contributed to the development of varieties like Sree Visakham, Sree Sahya and H-97. Most of the exotic collections were found susceptible to ICMD as was the case with the indigenous collections.

Rampant spread of the Indian cassava mosaic disease caused by ICMD has made it necessary to identify disease resistance in cassava varieties or in other *Manihot* species. Evaluation conducted during previous years has resulted in locating this in the accession MNga1 as well as in the species *Manihot caerulescence*, which has led to the resistance breeding work that is now in progress.

MNga 1 as resistant source to ICMD

MNga 1 was one of the germplasm accessions received from CIAT-Colombia in 1994. It was received as *in vitro* cultures, which were micro-propagated, multiplied, hardened and field transferred. Field observations indicate that this line had only 0 to 1% ICMD infection when other lines showed severe infection (3 to 67%). This character was found to be stable in the observations conducted during the following years. The variety was found resistant on grafting it to a symptom-expressing-susceptible cassava variety used as root stock. MNga 1 was TMS-30001, one of the resistant lines against African cassava mosaic disease (ACMD) developed by IITA-Nigeria (Martin Fregene, CIAT, personal communication). This line showed root yields of 29 t/ha with 34% dry matter, 25.8% starch and a low cyanogen content of 38 μg/g in the preliminary evaluation trials conducted during 1998-2001 (**Table 3**). Besides, it also had good culinary quality. The line is presently being tested in different locations in India (Kerala, Tamil Nadu, Andhra Pradesh, Chathhisgarh and Bihar) under the All-India Coordinated Research Programme (AICRP) for evaluating direct utilization as a resistant variety with normal yield and root characters.

MNga 1 is an erect branching variety with grey stem color, green petioles and dark green, thick leathery leaves. Roots are compact, smooth and of cylindrical shape, with light brown skin and white flesh. It shows normal flowering and seed set; it is now being used as a resistant parent in the resistance breeding program.

Table 3. Root yield of MNga 1 in 1998-2001 in field trials at the Central Tuber Crops Research Institute in comparison with other selections.

Sl.No.	Varieties	Root yield (t/ha)		
		1998-99	1999-2000	2000-01
1	CI- 848	32.71	38.1	36.62
2	CI- 849	-	-	30.45
3	CI-850	-	-	35.39
4	**MNga 1**	**30.24**	**23.1**	**34.17**
5	H-152/93		35.8	39.09
6	H-282/94	32.9	32.6	39.92
7	H-740/92	-	38.9	38.68
8	TCH-2	-	-	37.04
9	TCH-1	-	-	38.68
10	Sree Visakham	-	-	34.98
11	CO-3	-	-	38.27
12	H-296	30.45	27.9	-
13	H-60	26.1	-	-
14	H-135	31.0	-	-
15	H-156	24.89	-	-
16	H-290	30.86	-	-
17	H-120	-	27.0	-
18	H-346	-	9.1	-
19	Sree Prakash	28.8	-	-
20	Sree Jaya	30.24	-	-
21	Sree Visakhom	-	34.4	-
CD (5%)		NS	6.77	4.548

Note: MNga 1 mean root yield = 29.17 t/ha

II. Cassava Breeding

1. Breeding for ICMD resistance

Breeding varieties with resistance to ICMD is being carried out through inter-varietal and inter-specific hybridization.

Inter-varietal hybridization

This program was started in 2001 after establishing MNga 1 as an ICMD resistant parent. Crosses were made with MNga 1, using four released varieties (Sree Jaya, Sree Vijaya, Sree Rekha and Sree Prabha) and to promising selections from indigenous germplasm (CI-732 and CI-848). 3,045 pollinations were made, which resulted in 1,243 seeds. Open pollinated seeds (3,340) of the parent varieties were also collected and sown. Germination was almost equal in cross-pollinated (64.2%) and open-pollinated (OP) seeds (61%). OP seeds of MNga 1 showed 32% germination while it was 66.8% (mean of 10) in the crosses made with MNga 1. The resulting seedlings were planted in the field for evaluation of disease resistance and yield characters. At the third month of growth observations were made for ICMD incidence. Initial scoring showed that open-pollinated populations showed less ICMD incidence than the crosses. **Table 4** shows that the OP progeny of MNga 1 had the lowest percentage of disease incidence. Symptom-free plants isolated will be subjected to graft testing and serodiagnostic testing before selection of resistant genotypes.

Table 4. ICMD incidence in seedling populations of crosses made with MNga 1 and OP populations

Seedling family	Percentage of CMD incidence
MNga 1 OP	15.7
MNga 1 crossed	37.0 (mean of 6)
Sree Rekha OP	21.3
Sree Prabha OP	23.0
Sree Vijaya OP	34.3

Inter-specific hybridization

At CTCRI, *Manihot* species, such as *M. glaziovii, M. caerulescence, M. tristis, M. esculenta* var *flabellifolia*, and *M. esculenta* var *peruviana* were used in the inter-specific breeding program with the objective to develop breeding lines resistant to Indian cassava mosaic disease (ICMD). Among the crosses, one inter-specific hybrid of cassava x *M. caerulescence* (CMC-1) exhibited disease resistance. The hybrid CMC-1 has remained symptom-free for the past twelve years. The resistance was tested through wedge grafting. The scion of the interspecific hybrid was grafted on highly infected root stock. The hybrid, CMC-1, was found to be immune without any symptoms while other field-tolerant interspecific hybrids developed very mild to severe symptoms. The hybrid is now being backcrossed with elite cassava cultivars having less cyanogens (40-60µg/g) for recovering quality attributes in roots.

The inter-specific hybrids had high cyanogen content (209.6 µg/g) while the back cross hybrids had a lower range, from 86.5 to 220.0 µg/g. The cyanogen content of the backcross progeny was further reduced to a range of 13.13 to 130.55 µg/g in the fourth backcross generation (**Table 5**).

Table 5. Biochemical traits of promising backcross lines.

Clone	Starch content (%)	DM content (%)	Sugar content (%)	Cyanogen content (µg/g)
CTM 4	20.45	30.15	3.26	108.92
CTM 5	30.00	37.05	2.92	92.18
CTM 10	25.86	36.15	3.08	13.13
CTK 4	24.45	32.30	2.31	15.45
CTK 5	30.00	38.70	2.84	130.55
CTK 9	25.86	35.25	2.36	22.66
CFM 3	22.50	31.10	3.42	145.23
CFM 4	26.47	39.70	2.74	126.94
CFM 7	23.43	39.95	3.40	29.87
M4	31.25	41.10	2.52	32.70

The backcross lines showing field tolerance to ICMD coupled with reasonable culinary quality are now being evaluated under yield trials. The promising backcross hybrids had high yields, ranging from 28.5 t/ha to 40.12 t/ha. These hybrids are being backcrossed for further quality improvement.

2. Polyploidy breeding

Ploidy manipulation gives breeders great versatility for moving genes between ploidy levels, and from wild species to cultivated forms. Successful polyploidization is the first step in polyploidy breeding. For this, the crop must be low in chromosome number, cross pollinated and grown primarily from vegetative parts. Cassava has almost all the necessary features required for successful polyploidy breeding since sterility is not a decisive factor in the crop and seeds are not used for commercial cultivation.

The cultivated varieties of cassava are diploids with 2n = 36. Preliminary studies on induction of tetraploidy and production of triploids in cassava were reported earlier (Magoon *et al.*, 1969; Jos *et al.,* 1970). However, detailed studies on the usefulness of polyploidy, especially triploids in cassava improvement, was only made recently at the Central Tuber Crops Research Institute, India.

Tetraploids in superior lines

Auto-tetraploidy was induced in eight agronomically superior varieties, i.e. S-300, H-1857, OP-4, Sree Sahya, Sree Visakham, M4, H-50 and S-1315. The induced tetraploids were more vigorous morphologically compared to diploids in having dark green, thick, broad leaves and strong stems. Flowering was delayed and pollen fertility was drastically reduced. However, the root yield of tetraploids was similar to that of diploids. Hence, triploids were produced from these tetraploids with a view to enhance the yield characters.

Production and evaluation of triploids

Triploids were produced in cassava by crossing diploids with induced tetraploids. Three hundred and fifty triploids were isolated from 18 different cross combinations. The plants were maintained in the field. In addition they were maintained in *in vitro* also. Triploids in general were intermediate in growth compared to diploids and tetraploids. The plants were tall with strong stem, late-branching with dark green thick broad leaves having acuminate leaf tips. The compact plant type and high harvest index allowed for closer spacing at 75 x 75 cm instead of the traditional 90 x 90 cm, resulting in higher yields. Systematic evaluation of the triploids identified several desirable clones. A selection with higher yield and high starch content was released under the name 'Sree Harsha', the first ever released triploid in cassava (Sreekumari *et al.*, 1999).

Yield, dry matter and starch content of triploids

An outstanding general feature of triploids was that, although they were intermediate between diploids and tetraploids in a number of characters, root yields were superior to that of tetraploids and elite diploids. Eighty percent of the triploids had root yields that were higher than that of the better parent, indicating that triploidy enhances the possibility of recovering a high frequency of high-yielding progeny (Sreekumari *et al.*, 2000).

In triploids the root dry matter (DM) content ranged from 38.0 to 50.0% and the starch content from 31.0-46.5%. In their corresponding parents, i.e. Ambakadan and Sree Sahya, the dry matter and starch contents ranged from 31.0-38.0% and 28.0-34.0%, respectively. This shows that triploids hold great promise for the starch industry, where the emphasis is on high dry matter and recoverable starch.

Shade tolerance in triploids

When grown under partially shaded conditions the productivity of triploids was found to be reasonable, i.e. about 1/3rd of the normal yield as compared to that of diploids. In Kerala, cassava is grown under varying shade regimes in the homesteads and garden lands which form a sizeable area under cultivation. Preliminary evaluation of 20 triploids grown under shade revealed the better performance of two of them (**Table 6**).

Table 6. Performance of some triploids and diploids under shaded and open conditions.

Clones	Root yield (t/ha)		Percentage shade/open
	Open	Shade	
2-14 (3x)	37.0	13.6	36.7
76-9 (3x)	38.9	13.8	35.5
Sree Sahya (2x)	30.8	7.4	24.3
Sree Visakham (2x)	29.6	6.2	20.9
M4 (2x)	24.7	2.5	10.1

Early maturity in triploids

The high yielding triploids, i.e. 1-1, 2-14, 2-17, 4-2 and 5-3 were found to be early maturing. Root yields did not differ significantly from the 7th month onwards up to the 10th month, indicating the early bulking of the roots of these triploids (**Table 7**).

Table 7. Evaluation of triploids at monthly intervals for root yield.

Clones	Mean root yield (t/ha)			
	7th month	8th month	9th month	10th month
1-1 (3x)	28.90	29.10	30.60	30.80
2-14 (3x)	30.60	31.80	32.50	34.60
2-17 (3x)	29.50	28.60	27.60	29.10
4-2 (3x)	30.80	30.10	31.80	33.30
5-3 (3x)	30.90	31.00	31.00	34.30

The possibility of developing clones with early bulking , high dry matter and starch characteristics, hitherto unreported in any elite diploid clones of cassava, and the easy mode of propagation and maintenance indicate the importance of triploidy breeding as a novel, additional tool in cassava improvement.

3. Heterosis breeding

In cassava, the basic aspects about the nature of the vigor expressed by the hybrids over the parents, i.e. hybrid vigor or heterosis, the magnitude of such vigor and the gene action involved in the expression of various characters were not known. Cassava being highly heterozygous is not ideally suited for genetic studies. A project on heterosis was started at CTCRI, with the objective of developing reasonably homozygous inbred lines of cassava, combining them into various hybrid combinations to exploit hybrid vigor and to study the nature and magnitude of heterosis using a 6x6 diallel cross of inbred lines of cassava to study these aspects in detail.

Heterosis in cassava: nature and magnitude

The nature and magnitude of heterosis in cassava were assessed for 15 characters. (Easwari Amma and Sheela, 1993). Though hybrids displayed substantial differences in their heterotic response, heterosis over mid-parental and better-parental values were recorded for all the characters under evaluation (**Table 8**).

Table 8. Nature and magnitude of heterosis in a diallel cross of inbred lines of cassava.

	Mean		Highly significant heterotic crosses (%)	
Characters	Parents	Hybrids	Mid-parent	Better parent
Height at first branching (cm)	44.3	51.8	60.0	40.0
Plant height (cm)	139.6	164.6	50.0	33.3
Petiole length (cm)	17.1	20.0	70.0	50.0
Length of middle leaflet (cm)	14.9	15.5	63.3	26.7
Breadth of middle leaflet (cm)	3.9	4.3	73.3	46.7
Spread of foliage (cm)	148.0	169.5	10.0	36.7
Root yield (kg/plant)	0.9	1.6	96.7	93.3
Number of roots	5.4	7.3	93.3	86.7
Length of roots (cm)	20.1	25.8	96.7	70.0
Girth of roots (cm)	13.0	13.8	66.7	50.0
Mean weight of roots (g)	171.1	215.3	-	-
Total biomass (kg/plant)	2.4	3.6	100.0	83.3
Harvest index (%)	37.5	44.7	63.3	36.1
Dry matter content (%)	30.2	38.3	100.0	100.0
Cyanogen content (μg/g)	139.7	120.8	70.0	93.9

Hybrid vigor for root yield over better-parental values ranged from 6.3 to 100% in 28 out of 30 cross combinations. The highest yielding hybrid, P3 x P5, excelled the mid-parental and better-parental values by 136.0 and 79.0%, respectively, and the released variety Sree Visakham by 27.0%. Heterosis for root yield in the material was generally associated with heterosis for yield components, i.e. number of roots, length of roots, girth of roots and mean weight of roots. All the crosses registered highly significant positive heterosis for total biomass and dry matter content over mid-parent. Negative heterosis of considerable magnitude was obtained for cyanogen content of roots. The high magnitude of desirable heterosis obtained for various traits indicate the possibility of identifying superior hybrids for yield, yield components and quality characters by combining advanced generations of inbred lines of cassava.

4. Top-crossing in cassava and release of 'Sree Rekha' and 'Sree Prabha'

In cassava, inbreeding has been found to be very effective in seperating the population into widely divergent but reasonably uniform groups. Crossing of such early generation inbred lines with the promising released variety Sree Visakham resulted in the production of superior top-cross hybrids (Easwari Amma *et al.,* 1993). A comparative evaluation of the performance of top-cross with that of the parents (S_0) inbred lines, OP population and diallel cross hybrids revealed top-crossing as an efficient method to improve root yield, plant type and important quality traits in cassava (Easwari Amma *et al.,* 2000).

Twenty top-cross hybrids selected from a population of 750, were evaluated in advanced yield trials for three seasons. From four elite top-crosses earlier identified in 18 multi-location on-farm trials, two were finally selected (TCH-1 and TCH-2). These two superior top-cross hybrids had a mean root yield of 48.1 t/ha and 42.3 t/ha, respectively, and a yield potential as high as 80 t/ha. TCH-1 and TCH-2, which combine high yield, good culinary qualities and good plant type, were released by the Kerala State Variety Release Committee under the names 'Sree Rekha' and 'Sree Prabha' in December 2000 for general cultivation in Kerala. Sree Rekha has 37.7% dry matter, 28.2% starch and 49.9 μg/g cyanogens content. The root flesh color of Sree Prabha is yellow due to the high content of carotene; and it has 36.6% dry matter, 26.8% starch and 50.8 μg/g cyanogens. The development and release of the top-cross hybrids 'Sree Rekha" and 'Sree Prabha' indicate that, in addition to being a viable method of testing combining ability of inbred lines, top-crossing could be utilized as a successful method of crop improvement of cassava.

5. Recombination breeding

Seedling progeny of cassava produces a lot of recombinants due to the heterozygous nature of the crop. Evaluation of the progenies of selected crosses and the half-sib open pollinated progenies for yield, dry matter, early bulking and culinary quality of roots is being carried out as a continuous program. Early bulking lines, i.e. CI-848 and H-28, produced yields of 41-45 t/ha at 7 months, as well as H-740, H-152 and H-282, producing 38-49 t/ha at 11 months, are undergoing evaluations in farmers' plots. Another set of 24 selections are in preliminary evaluation trials. The selections had 30-46% root dry matter contents.

6. Gene pool development for enhancement of nutritional qualities of roots

Increases in the β-carotene contents of roots could be achieved through poly-cross methods and collecting seeds from randomly-mated parents showing low levels of carotene (650 to 670 I U) grown in an isolated block. The carotene content could be enhanced to 1.38 mg/100 g (2200 I U) (Jos *et al.*, 1990). Thirty four lines isolated from later seedling generations are being maintained for utilizing this character directly or in future varietal improvement programs.

III. True Cassava Seed

True cassava seed (TCS) technology was developed to enhance the rapid spread of crops to far-away non-traditional areas and for areas like Salem and Peddapuram for industrial use. It is mainly for overcoming the problem of lack of planting material, increasing the multiplication rate several times, keeping cassava mosaic disease (CMD) under check, longer viability, easy storage and transport of "seed".

Preliminary screening was done for isolating male-sterile lines with regular flowering and seed set. Ambakadan, an indigenous cultivar, was found to be a male sterile clone having good yield and culinary quality along with profuse flowering and seed set throughout the year. The open pollinated (OP) seeds from Ambakadan were used to study germination, seedling and first clone (C_1) performance. Germination and seedling vigor were found to be high in seeds soaked for one day in 1% KNO_3 or 300 ppm GA_3 (**Figure 1**). Due to this treatment the time of transplanting of tap root-removed cassava seedlings, can be reduced from 45 to 30 days after seeding.

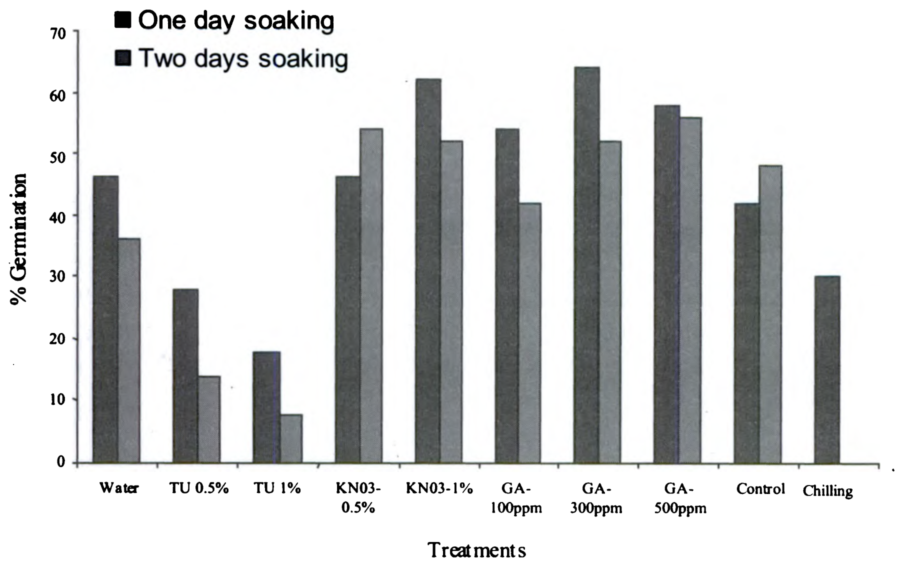

Figure 1. Germination of true cassava seeds at 17 days after sowing.

The OP seedling progenies had high root yields of 20-25 t/ha while the first clonal stage had yields of 30-35 t/ha. The performance of first clones (C_1) was significantly superior to the seedlings. The dry matter and starch contents of seedlings were comparable to those of the clones (**Figure 2**). The cyanoglucoside content and culinary quality of seedlings and the first clones were both acceptable.

Crosses made between the male-sterile line Ambakadan and selected male parents resulted in progeny with nearly uniform root yields and starch contents, comparable with those of the popular varieties H-165 and H-226 when field trials were conducted in cassava areas of Salem and Peddapuram districts of Tamil Nadu. First clones of Ambakadan hybrid generation were found to be suitable for the starch industry.

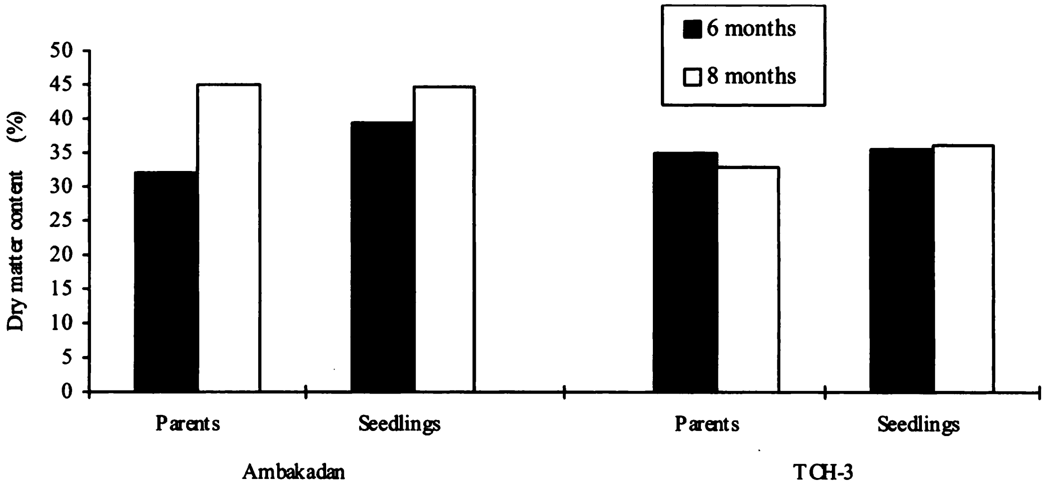

Figure 2. Dry matter content in parents and seedlings of two clones at six and eight months after planting.

IV. All-India Coordinated Research Project on Tuber Crops (AICRP)

The All-India Coordinated Research Project on Tuber Crops has been instrumental in the collection and conservation of cassava germplasm at its various centers in India. Five hundred and fortyfour accessions of cassava are being maintained at 12 different AICRP centers. Coimbatore Center maintains the highest number of 316 accessions of cassava (**Table 9**).

Table 9. Cassava germplasm maintained at different AICRP (All India Coordinated Research Programme) Centers.

Dholi	22	Faizabad	12
Rajendra Nagar	46	Ranchi	14
Coimbatore	316	Jagadalpur	59
Jorhat	26	Shillong	7
Dapoli	22	Navasari	5
Kalyani	9	Port Blair	6
		Total	**544**

Cassava varieties developed at CTCRI and at State Agricultural Universities are being tested in AICRP Centers and based on their performance they may be released in different regions or at the country level. A total of eleven cassava varieties have been released through the AICRP on Tuber Crops (**Table 10**).

Table 10. List of cassava varieties released by CTCRI

Name of Variety	Year of release	Average yield (t/ha)	Duration (months)
H-226[1)]	1971	30-35	10
H-165[1)]	1971	33-38	8-9
H-97	1971	25-35	10
Sree Sahya	1977	35-40	10-11
Sree Visakham	1977	35-38	10
Sree Harsha[2)]	1996	35-40	10
Sree Prakash[3)]	1987	30-35	7
Sree Jaya[3)]	1998	26-30	6-7
Sree Vijaya[3)]	1998	25-28	6-7
Sree Rekha	2000	45-48	10
Sree Prabha	2000	40-45	10

1) Widely cultivated varieties in industrial areas
2) Triploid high starch variety
3) Early maturing variety

FUTURE PROSPECTS

In India, cassava is gaining importance as an industrial crop, from its previous status as a subsistence food crop. The private sector has realized the crop's potential as a starch resource over and above the existing cereals crops, due to the lower production cost and better yield stability. The recent increase in the area of cassava cultivation in Tamil Nadu and Andhra Pradhesh, as well as the involvement of the banking sector in promoting the crop in these states (Project UPTECH by State Bank of India) are all the direct results of this realization. This has led to the high demand for quality planting materials, especially of disease resistant, early-maturing, high-yielding, high-starch varieties. In Kerala, the crop still holds its position as a human dietary ingredient in the native situation, as well as an export item (fresh roots) for over-seas Indian nationals. The culinary quality of roots is an important selection criterion in this market. Hence, efforts to develop good eating varieties that are equal or excel the popular varieties like M4 still continues, though this has been achieved to a great extent with the release of varieties like Sree Jaya, Sree Vijaya and Sree Rekha. In India, cassava has been identified as an important crop in the poverty alleviation program by the Department of Biotechnology (DBT) after realizing its ability to give normal or near-normal yields under marginal conditions. A network research program involving CTCRI has been initiated by the National Centre for Plant Genome Research in New Delhi, for improving the nutritional quality of roots using transgenic technology with DBT funds. Cassava has thus gained importance in the industrial, consumer and social sectors.

The future genetic improvement program is directed to meet the market demands by increasing yield potential, developing disease (ICMD) resistant varieties with high-starch and better nutritional and culinary qualities. The True Seed Program is expected to satisfy the demand for planting materials, especially for extending the crop to remote areas. Developing varieties with reduced post-harvest spoilage, varieties with enhanced starch quality (modified amylose to amylopectin ratio) for industrial use are the future priorities. Collaborative efforts with CIAT-Colombia, EMBRAPA-Brazil and IITA-Nigeria in the past have been helpful in widening the genetic base of the crop. Future interactions with these institutions are expected to strengthen the germplasm conservation, especially in developments of IVAG and IVBG in cassava. Collective efforts to utilize various biotechnological tools in genetic improvement of the crop will be of great help in meeting the market demands for its sustainable production and utilization by industry and the common man of this country.

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CASSAVA BREEDING AND VARIETAL RELEASE IN CHINA

Tian Yinong[1] *and Li Kaimian*[2]

ABSTRACT

Cassava varietal improvement in China started in the beginning of the 1910s in Guangdong province; the main activity at that time was the selecting of varieties, character observation, determination of nutritive value and starch content, and the observation of growth habit. In the beginning of the 1940s some people did research on hydrocyanic acid content, which was published. Real cassava breeding work was started at the end of the 1950s by the Guangdong Agricultural Academy in Guangdong province. Since 1959, the South China Academy of Tropical Crops (now the Chinese Academy of Tropical Agricultural Sciences - CATAS) started cassava breeding and agronomy research in Hainan province. In 1985, a collaborative relationship was established between CIAT and CATAS, and later between CIAT and GSCRI, which started the introduction of cassava genetic resources from abroad. Every year hundreds of cassava hybrid seeds have been introduced from CIAT/Colombia and from Thailand. Now there are two institutes working on cassava breeding research, i.e. CATAS and GSCRI.

In 1980 the first cassava variety (SC6068) was released by CATAS. During the past 20 years cassava breeders in China have made considerable progress in cassava varietal improvement. Seven varieties have been released; they are: SC124, SC8002, SC8013, GR891, GR911, SC5 and SC6. In 1981 CIAT sent seven promising cassava varieties in tissue culture to Dr. Guo Jun Yan of the South China Academy of Botany in Guangzhou. One of these, CM321-188 was later released as Nanzhi-188. This variety spread quickly in Guangdong province, but was later rejected by farmers because of lack of cold-tolerance during stake storage. However, another variety, MPan 19 has recently been released as Nanzhi-199 and this variety seems to be high-yielding and well-adapted to conditions in Guangxi province. These new varieties are now being extended to the cassava growing areas and they will play a very important role in the cassava industry development in China, while at the same time increasing farmers' income from planting cassava. This year, the area of the above varieties is estimated at 30,000 ha, accounting for 8% of the total area. Following this trend the total area of these new varieties will probably reach 50,000 ha next year.

In China, cassava varietal dissemination usually occurs through the following channels: 1. the traditional government channel, i.e. the transfer of technology to the extension station of the Agricultural Bureau; 2. by recommendation of agricultural institutes (pictures and character descriptions) through the Bureau of Science and Technology at the county and city level; 3. propagation by cassava processing factories (in cooperation with institutes); 4. demonstration trials conducted by big farmers. From our experiences over the last ten years, the most successful extension channels are No. 2 and No. 4 (No. 3 is now being tried).

INTRODUCTION

Cassava is the fifth most important crop in the southern part of China, following rice, sweet potato, sugarcane and maize. It is used mainly as animal feed and for starch and alcohol manufacturing. Cassava is mainly concentrated in four provinces, i.e. Guangxi 243,750 ha (65%), Guangdong 60,000 ha (16%), Yunnan 37,500 ha (10%), and Hainan 22,500 ha (6%); the others are Jiangxi, Shichuan, Fujian, etc 11,250 ha (3%). During the mid-1990s, Guangxi became the most important cassava as well as cassava starch

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producing province in China (**Table 1**). The natural conditions of Guangxi gives this province a comparative advantage over other provinces. Moreover, the province already formed an advanced cassava starch processing base, which has been quite successful. During the last five years, at least one new cassava starch factories with a capacity of 20,000 tonnes of starch per year has been built every year. Now there are about 150 cassava starch processing factories in Guangxi with a total capacity of about 700,000 tonnes of starch. Since the market of cassava starch and starch derived products in China is very large (**Table 2**) the cassava industry will have very good prospects. Actually, in 2001, China produced about 350,000 tonnes of modified starch and imported at least 350,000 tonnes of modified starch from other countries.

Table 1. Production capacity and actual production of cassava starch by factories in Guangxi province from 1997 to 2002.

	Production capacity ('000 t)	Actual production ('000 t)	% of national production
1997	300	260	68
1998	350	270	70
1999	430	296	69
2000	450	300	70
2001	470	310	70
2002	500	329	72

***Source:** Estimated by Guangxi Starch Association.*

Table 2. Size of various industries and their potential requirements for modified starch in China.

Industry	Production ('000 t)	Requirement for modified starch ('000 t)	Observation
Paper	36,000	600	mainly cassava mod. starch
Textile	250	175	mainly cassava mod. starch
Food	9,300	100	
Feed	400	100	
Building material		100	mainly cassava mod. starch
Pharmaceutical		50	
Petroleum prospecting		50	
Total		**1,175**	

***Source:** Estimated by Chinese Tuber Crops Starch Association.*

HISTORICAL REVIEW

The history of cassava breeding and varietal improvement can be traced back to the second decade of the twentieth century when cassava varieties were collected, evaluated and the roots analyzed for nutritive value at the Guangdong Agriculture and Sericulture Experimental Farm. Later, these activities were continued by Li You Kai of Xinxing farm in Liuzhou city of Guangxi province. This laid a very good foundation for subsequent cassava breeding research, but it was discontinued during the civil war of 1945-1949. In the early 1950s, cassava varietal improvement research was reinitiated, first in Guangdong province and then in Hainan (a that time a district of Guangdong) and in Guangxi provinces. But systematic and intensive research on cassava cultivation was not conducted until 1959 when the South China Academy of Tropical Crops (SCATC) was founded on Hainan island. Cross breeding began in 1980, and the first variety named "SC6068", selected from hybrid seed of local cassava varieties was released. After that, several agricultural research institutes established their own cassava breeding programs and started the cooperation with CIAT, as well as with other national cassava breeding programs.

PRESENT SITUATION AND PROGRESS

Before the 1990s, the cassava processing industry developed only slowly in China. Cassava research on breeding was not considered of any importance, but only in SCATC a reasonable amount of human and financial resources were spent on cassava research, with limited support from the central government. As such, little progress was made, and average national cassava yields remained low at about 10 t/ha. In the late 1980s and the early 1990s, many new cassava-based products were developed successfully and their utility was recognized by people, which resulted in a great increase in cassava processing output, and the supply of raw material of cassava roots fell short of demand. Being a big country, with a large domestic market, China soon became an importer of cassava. From then on, people became interested in cassava and governments at various levels started to recognize the importance of cassava breeding and the extending of new varieties with high yield and high starch content. As they realized the benefits they received from the cassava processing industry, government funds started to be used for cassava breeding programs and farmers started to increase their input in growing cassava. Many starch factories became very active and initiated their cooperation with the government and research institutes to extend the promising cassava varieties as well as advanced cultivation practices. New cassava varieties with high yield and high starch content were warmly welcomed in the countryside.

During the 1990s, several research institutes, such as CATAS, UCRI and GSCRI, established their own cassava breeding programs. However, at present only CATAS and GSCRI are spending human and financial resources to continue this program because in the agricultural economic development cassava has become relatively important only in Hainan and Guangxi provinces. The Guangdong Academy of Agricultural Science used to be a key cassava breeding center, but since the cassava growing area in the province decreased year by year, they closed the program by the end of the 1990s. Because cassava flowers only in Hainan, we can make crosses and produce hybrid seeds only in that province. Thus, this type of activities is mainly conducted at CATAS, while GSCRI can bring their promising clones (varieties) to CATAS to be used as cross parents to make crosses there in cooperation with CATAS. Presently, the two principal cassava programs in China are capable of annually producing more than 3,000 hybrid seeds from 80-100 cross combinations.

In close cooperation with CIAT and other national cassava breeding programs, from the early 1980s the South China Academy of Botany in Guangzhou, CATAS and GSCRI made considerable progress in cassava varietal improvement. Every year, several thousand cassava hybrid seeds from CIAT/Colombia and the Thai-CIAT program, as well as promising clones in the form of tissue culture were introduced into China. At present, from these hybrid seed recourses from CIAT, three breeding lines were selected and released under the names of "GR891", "GR911" and "SC6" in 1997, 1998 and 2001, respectively. Four other varieties were selected from locally produced hybrid seeds and released under the names of SC124, SC8002, SC8013, and SC5 during 1990-2000 (**Table 3**). In 1981, CIAT sent seven promising cassava varieties in tissue culture to Dr. Guo Jun Yan of the South China Academy of Botany; one of these, CM321-188 was later released as "Nanzhi 188". This variety spread quickly, first in Guangdong province, then to Guangxi and Yunnan provinces from the mid-1980s to the mid-1990s. With this variety, farmers can obtain good yields in fertile soils, but usually get low yields in poor soils. Moreover, the cold-tolerance of this variety during stake storage in winter is rather poor, so finally the variety was rejected by farmers. However, another variety introduced by tissue culture from CIAT/Colombia, MPan 19, has only recently been released as "Nanzhi 199" and is now grown on a large scale. This variety seems to be not only high-yielding but also has a high starch content in the root, and is well-adapted to conditions in Guangxi province. The above-mentioned varieties have been widely tested in regional trials (**Table 4**) and are now being extended to the cassava growing areas in Guangxi, Guangdong, Hainan and Yunnan provinces. They will play a very important role in the development of the cassava industry in China, while at the same time increasing farmers' income from planting cassava. In 2002, the area of these varieties is estimated at about 30,000 ha (**Table 5**), accounting for 8% of the total cassava area in the country. Following this trend the total area of these new varieties will probably reach 50,000 ha next year. Materials from CIAT/Colombia or the Thai-CIAT program have not only played an important role in cassava breeding but are also a useful genetic resource in China. Now, a cassava germplasm bank has been established at CATAS with presently more than 120 accessions, and at GSCRI with more than 40 accessions.

Table 3. Origin and principal characteristics of released varieties in China.

Variety	Parents	Year released	Origin	Principal characteristics
SC6068	SC201	1980	Local seed	high starch content
SC124	SC205	1990	Local seed	high yield, low starch content
Nanzhi 188	=CM321-188	1992	CIAT/Colombia tissue culture	high yield, low starch content, poor cold tolerance
SC8002	SC124×SC205	1994	Local cross	high yield
SC8013	SC124×SC205	1995	Local cross	high starch content
GR891	MCol 2215	1997	CIAT/Colombia seed	high yield, high starch content, early harvestability
GR911	MBra 35×CM523-7	1998	CIAT/Colombia seed	high yield
Nanzhi 199	=MPan 19	1999	CIAT/Colombia tissue culture	high yield, high starch content, good cold tolerance
SC5	ZM 8625xSC8013	2000	local cross	high yield, high starch content
SC6	OMR33-10-4	2001	Thai-CIAT seed	high starch content, typhoon resistance, good germination

Table 4. Root yield and starch content of 12 cassava varieties evaluated in China in 2002[1].

Variety	Evaluated area (ha)	Yield (t/ha)	Starch content (%)
SC124	2	30.0	24.5
SC8002	few	27.8	27.0
SC8013	few	25.3	28.9
GR891	2	26.5	30.9
GR911	15	33.0	26.4
Nanzhi-199	4	28.9	28.7
SC5	4	33.0	28.5
SC6	few	25.2	28.5
KU50	very few	32.0	28.5
Rayong 72	very few	33.4	28.9
SC201 (local check)		24.5	27.0
SC205 (local check)		29.0	28.5

[1]Average of five regional trials conducted in Guangxi, Hainan and Yunnan provinces.

Table 5. Estimated areas planted with new cassava varieties in China in 2002.

Variety	Estimated planted area (ha)	
SC124	2,000	mainly in Guangxi, Yunnan and Fujian provinces
Nanzhi-188	100	mainly in Fujian province
SC8002	8,000	mainly in Guangdong province
SC8013	2,000	mainly in coastal areas of Guangdong province
GR891	400	mainly in Guangxi province
GR911	8,000	mainly in Guangxi province
Nanzhi-199	4,000	mainly in Guangxi province
SC5	4,000	mainly in Hainan province
SC6	200	mainly in Hainan province
Others	1,000	
Total	**29,700**	

Cassava Varietal Release

Since the economic value of cassava is still low, and the crop is planted in relatively small areas as compared to other crops, the extending of high-yield or high-starch varieties still meets many difficulties. But, contrary to the factories' requirements, farmers are more interested in high yield than in high starch content varieties. This is due to a lack of communication between farmers and processing factories, and due to the fact that factories do not pay a differencial price for cassava roots according to their starch content. But, in areas where the cassava processing industry is well developed, it is much easier to extend new cassava varieties, and there are many "big farmers" in such areas.

Cassava release of new varieties in China is still mainly through traditional channels, which means the need for the local governments to join in. We have different levels of agricultural extension stations at the provincial, district, county, and town levels. Their main job is to disseminate new technologies and information from the research institutes to the farmers by the introduction of materials or posters or through wall newspapers. They have some special extension activities, sometimes held in villages (we call it "technologies service in countryside") and sometimes held in town-centers during the market days (once every three days). During the 1990s, the economic situation of China has changed a lot. Many farmers benefited by adopting new technologies, and once they realized how important a role the new technologies are playing in their farming enterprise, some of these farmers buy new agricultural technologies directly from the agricultural institutes. The characteristics of this kind of farmers are: 1. works very hard and is smart; 2. farms at a large scale; 3. they do mostly before the others do, and obtain benefits. These are the ones we now call "big farmers" even though in the past they were also small farmers. Although they are few, these "big farmers" are playing a very important role in the course of rural economic development, and they also play a positive role in extending modern agricultural technologies in rural areas.

The great economic achievement of China is not only due to the reform of the economic system, but also from the reform of the management system. In the past, the only function of the institute was research, and again research, while people did not need to pay attention to other things. It had no influence on your future development whether you made progress or not in your research, and oftentimes many of the results obtained at the research institutes were laid aside and neglected. Now it is very different. The government's policy encourages research institutes to join in the development of "new markets", so most research institutes are now also doing extension work based on the results of their research on the one hand, and to speed up the transfer of technologies to increase productivity and to promote the development of the local agricultural economy. On the other hand, the institutes or the researchers themselves can benefit from their own activities. CATAS and GSCRI have greatly benefited from the expansion of their new cassava varieties.

In the southern part of China, cassava, like sugarcane, is a very important raw material for the processing industry. The difference is that due to government intervention, sugarcane was developed very fast and is now in a situation of over-production. The opposite is true for cassava. Every year there are not enough cassava roots to be used as raw material for the starch processing factories. In the past, the owners of cassava starch factories (private or state) paid very little attention to the development of cassava cultivation. There were many reasons for this; for instance, they could always get some benefit from their processing, while the market demand for cassava starch was small and they could not have predicted that it would develop so fast during the 1990s. Presently, most owners of starch factories (private and state), especially the bigger factories, are recognizing the importance of raw materials' supply. They start to support cassava cultivation by signing buying contracts with farmers and by introducing new cassava varieties with high yield or high starch content to farmers. Although this practice has not yet produced such good results, it seems to be an effective way and which could be further improved to be more satisfactory.

The above description indicates that in China there are presently four channels for the release of cassava varieties, the first one is a traditional government channel, i.e. the transfer of technology to the extension station of the Agricultural Bureau or the Bureau of Science and Technology; the second one is by recommendation of the agricultural research institutes (with pictures and varietal character descriptions) through the Bureau of Science and Technology at the county and city level; the third one is by cassava processing factories (in cooperation with the institute) to disseminate new technologies of cassava to farmers and then help farmers to cultivate cassava; the fourth one is to conduct demonstration trials with big farmers, who then contribute their experiences to others in the area.

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CASSAVA BREEDING AND VARIETAL RELEASE IN THE PHILIPPINES

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ABSTRACT

The cassava breeding program in the Philippines has achieved modest progress since the time CIAT provided support in terms of human resource development and the introduction of elite cassava germplasm as a source of genetic variability.

Through the years cassava breeding in the Philippines has aimed to satisfy both the needs of farmers who grow cassava in diverse agro-climatic conditions, and those of processors who utilize the storage roots for food, feed and industrial purposes.

Using local and introduced materials, hybrids were evaluated and selected in various phases of selection, such as: Observational Trials (single seed evaluation), Single-row Trials, Preliminary Trials, General Yield Trials, Advanced Yield Trials, and finally, Multi-location testing (Regional Trials). All introduced hybrid populations and locally developed hybrids undergo these phases of evaluation and selection. It takes 7 to 8 years of testing before a variety is released as a registered variety by the National Seed Industry Council of the Philippines (NSIC).

Progress in breeding and selection has resulted in the identification of several elite materials possessing high dry matter and starch contents with low to moderate levels of HCN. From 1999 to 2002 four new cassava varieties were recommended for nationwide cultivation in the Philippines. These are: PSB Cv-17 (CG87-03-01), PSB Cv-18 (CG87-02-13), PSB Cv-19 (SM808-1) and PSB Cv-20 (CG91-13-01). These new varieties have high yield potential, high dry matter and starch contents, and are suitable for production of food, feed and starch. Todate there are already 20 registered cassava varieties in the Philippines to provide growers a wide range of choices. In addition, just recently, two new selections were recommended by the Technical Working Group to the NSIC for release. These varieties are KU 50 (from Thailand) and SM818-1. These two have superior dry matter and starch contents as compared to the previously released varieties.

Utilization of these new cassava varieties is being enhanced by the expansion of the cassava area for production of feed and alcohol. The private sector (San Miguel Corporation) expansion of cassava to about 30,000 ha is gaining ground.

Breeding work will continue to focus on the identification of superior varieties that will address the requirement of the cassava-based industry in the country.

INTRODUCTION

Cassava varietal improvement in the Philippines started in the 1960s at the Institute of Plant Breeding (IPB) in Los Banos, Laguna (Bacusmo and Bader, 1992). The original focus of this improvement program, however, was mainly on varietal trials of a few local and introduced varieties (Mariscal, 1987). It was only when the Philippine Root Crops Research and Training Center (PhilRootcrops) was established in 1977 at Leyte State University (LSU), formerly the Visayas State College of Agriculture (ViSCA), Baybay, Leyte, Philippines, by virtue of Presidential Degree No. 1107, that a more organized and relatively well-supported cassava breeding program started. This resulted in the assemblage of a cassava germplasm collection, subsequent screening, and the identification and release of superior local and introduced varieties. The breeding program was further enhanced when PhilRootcrops established a strong linkage with the Centro Internacional de Agricultura Tropical (CIAT) Cassava Program in 1982 through the leadership of Dr. Kazuo Kawano, CIAT's cassava breeder, who initiated the CIAT Regional Cassava Program in

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Asia in 1983, based in Thailand. CIAT provided the national program with improved cassava populations. This resulted in the release of several cassava varieties with parental origin from CIAT and Thailand. More than that, CIAT has helped the Center in strengthening the capability of its breeders to spearhead the systematic evaluation and selection of the improved materials, and their subsequent utilization in the breeding program.

During the more than 20 years of existence of the Center, a modest increase of the national average yield of cassava from 6.0 t/ha in 1977 to 9.8 t/ha in 2002 was attained. This reported yield, however, is the lowest in Southeast Asia. The modest yield increase is attributed to the gradual adoption of high-yielding cassava varieties and improved cultural management practices (Root Crops National RDE Agenda, 1999).

In the Philippines, cassava is one of the important crops that cater to the food, feed and industrial sectors. Walters (1983), Lynam (1986), and Singh (1986) emphasized that cassava will play a major role in satisfying the domestic needs of the country, and that any future increase in output by the cassava producing countries in Asia should be aimed primarily at their domestic markets, such as for animal feed and starch production (food processing, textiles, paper and board, sweeteners and ethanol). Recently the Philippines has experienced a significant increase in production of cassava in order to meet the demand for animal feed and for production of ethanol to be used as an alternative to molasses for the production of liquor. The existing high demand for cassava, therefore, needs a strong backstopping with respect to new improved cassava varieties from the cassava breeding program.

CASSAVA BREEDING

1. Objectives

Cassava breeding in the Philippines aims to satisfy the needs of farmers who grow cassava in diverse agro-climatic conditions, as well as those processors who utilize the storage roots in a variety of ways. The breeding objectives are as follows:

1. High yield
2. High dry matter and starch content
3. Resistance to pests and diseases
4. Tolerance to environmental stresses
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 staple food. High HCN varieties, on the other hand, are used by starch factories because they tend to produce high yields and have a higher starch content, 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 type).

2. Breeding and Selection Methodology

The breeding and selection scheme of the Center is patterned after the CIAT cassava germplasm improvement scheme **(Figure 1)** (Mariscal, 1987). From the improved cassava populations introduced from CIAT/Colombia or the Thai-CIAT program, as well as those locally developed from the Center pass through the following scheme:

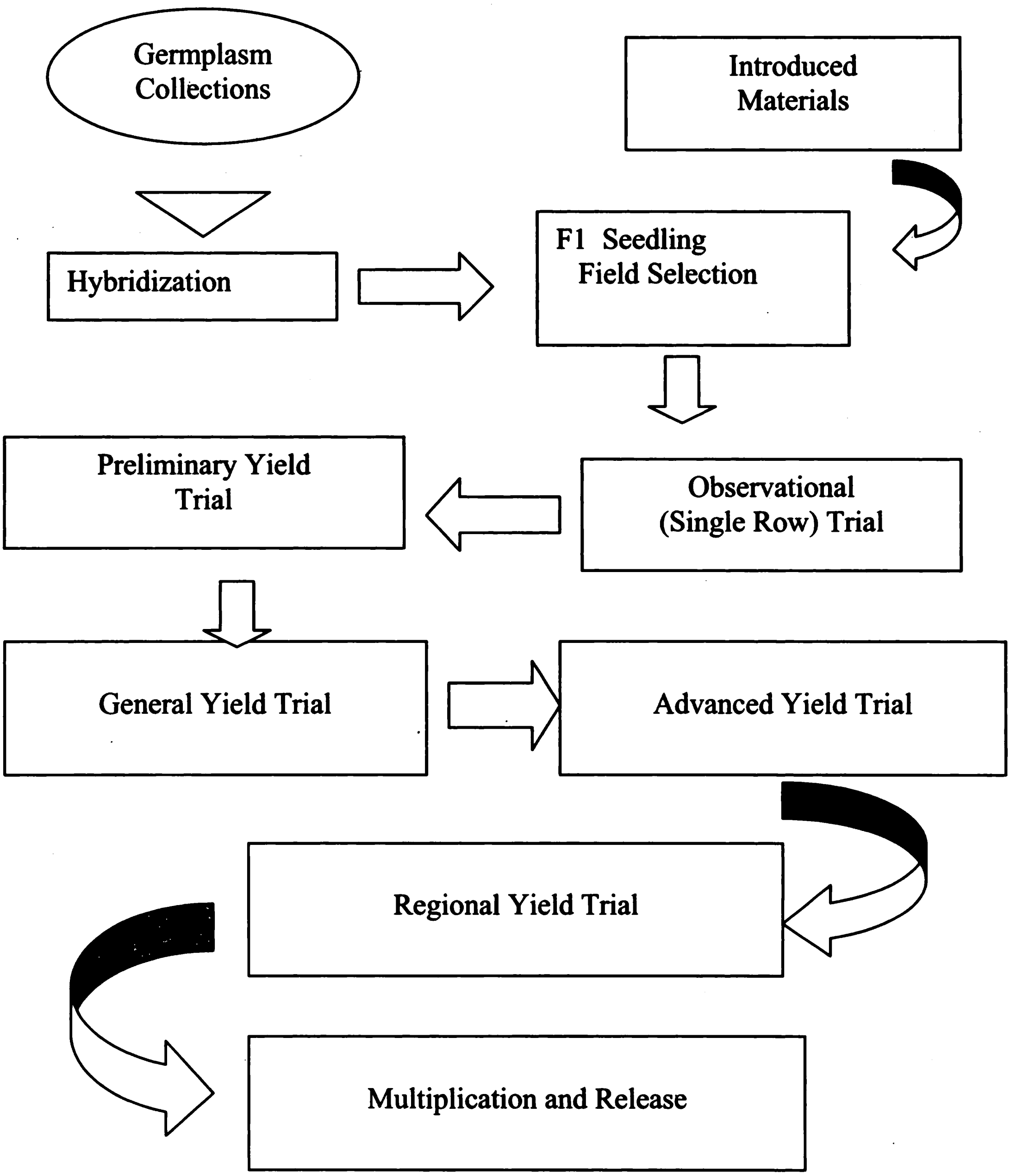

Figure 1. PhilRootcrops breeding and selection methodology.

F_1 Field Selection. Seedlings produced from sexual seed, including those introduced from CIAT/Colombia and the Thai-CIAT program, are subjected to individual plant selection in the F_1 stage. Entries are planted at 2 meters between rows and 1 meter between hills. The harvest is at 10 months after planting and selection criteria are limited to harvest index, plant type, and general appearance of the crop.

Observational Trial. Selections from the F_1 field screening are further tested in the Observational Trial, also known as Single-Row Trial. Normally, five to seven stakes are prepared for each selected clone and planted in a 1 x 1 m planting pattern without replication. A check variety is planted every 10^{th} row. Selection criteria include yield per plant, harvest index, dry matter content, and reaction to pests.

Preliminary Yield Trial. Entries selected from the Observational Trial, as well as local and exotic accessions, enter this phase of screening. Test entries are planted in four to five rows per plot without replication, following the same planting pattern as in the Observational Trial. Selection is based on yield per plot, dry matter, harvest index, hydrogen cyanide (HCN) content, and general appearance of the crop.

General Yield Trial. Selections from the Preliminary Yield Trial are entered in this trial. Test clones are planted in four to five rows per plot replicated three to four times. Distance of planting is 1.0 x 0.75 m. Harvesting is done at 10 months after planting. Important economic characters are closely monitored at this stage and yield per hectare is computed.

Advanced Yield Trial. This is the last stage of selection before clones are included in the Regional Yield Trial of the National Cooperative Testing for Root Crops. A plot measuring 5 x 6 meters is used for each entry and replicated three to four times. A minimum of three different testing sites is required for each selected clone before it is included in the next cycle of evaluation. Harvesting is done 10 months after planting and parameters considered are yield per hectare, dry matter content, HCN content, plant architecture, and general reaction to pests.

Regional Yield Trial. The number of entries at this stage of evaluation is determined by the Root Crop Technical Working Group of the National Seed Industry Council. Agencies involved in variety development submit lists of entries to the group for inclusion in this trial. Potential entries should have passed the Advanced Yield Trial stage of evaluation. Entries determined by the working group are tested in at least ten locations throughout the country following the standard format set by the Technical Working Group. Harvesting is done at 10 months after planting. Parameters gathered in this stage of evaluation include yield, dry matter and starch content, harvest index, HCN content, root shape, ease of harvest and reaction to pest and diseases. Two croppings are required per set of entries before a variety is recommended for registration and release.

Varietal release and recommendation. Results of the two croppings of the Regional trial in all testing sites are summarized and reported during the annual meeting of the Root Crop Technical Working Group. The candidate variety should possess some unique traits and qualities in comparison to the standard check. Entries that qualify for nomination for recommendation are then submitted to the National Seed Industry Council (NSIC) for final approval and release to the farmers for utilization and adaptation.

3. Genetic Gain in Selection

Gains in selection in cassava varietal improvement are enhanced by the wide genetic base of our germplasm collection. PhilRootcrops has maintained and upgraded the genetic stocks of cassava. To date, 322 cassava accessions are maintained in the field genebank. These include both local and foreign collections, as well as elite materials from Advanced Yield Trials **(Table 1).**

Table 1. Germplasm collections of cassava maintained at PhilRootcrops in 2002.

Source	Number of accessions
Local	68
Foreign	92
Tissue culture	25
Elite clones	117
Released varieties	20
Total	**322**

From 1999 to 2002, 5,044 hybrid seedlings have been evaluated **(Table 2).** The sexual seed came from the Thai-CIAT program as well as from crosses made by PhilRootcrops. Summaries of the number of genotypes at different stages of selection are shown in **Table 3.**

Table 2. Total number of cassava hybrid seeds evaluated at PhilRootcrops from 1999 to 2001.

Source	Year	Number of seeds	No. of crosses
Thai-CIAT Program	1999/00	2,400	38
PhilRootcrops	2000/01	2,644	17
Total		**5,044**	**55**

Performance of selected breeding lines from the Thai-CIAT program in the Preliminary Yield Trial generally show exceptional improvement over that of the standard check variety Lakan **(Table 4).** The highest yield of 45 t/ha was obtained from entry OMR40-09-31 which had a dry matter content of 32.2% compared to the check with only 22.4 t/ha and 30.2% dry matter Generally, all the selections outperformed the check variety. This goes to show that these hybrid populations contain superior characteristics.

Table 3. Number of cassava hybrids evaluated at different stages of selection at PhilRootcrops from 1999 to 2002.

Selection stages	1999/00	2000/01	2001/02	Total
Single Plant Trial	1,216	610	-	1,826
Observational Trial	-	180	59	239
Preliminary Yield Trial	30	-	56	86
General Yield Trial	21	21	29	71
Advanced Yield Trial	18	15	11	44
Regional Yield Trial	10	10	12	32
Varietal release	1	2	1	4

Table 4. Performance of selected Thai-CIAT cassava hybrids evaluated in the Preliminary Yield Trial 2001/02.

Entry	Fresh root yield (t/ha)	Dry matter content (%)	Harvest index	HCN content[1)]
1. OMR39-35-22	41.1	32.8	0.61	5
2. OMR39-43-04	42.2	33.6	0.68	3
3. OMR39-48-02	34.2	34.6	0.56	6
4. OMR40-09-34	45.0	32.2	0.55	3
5. CMR39-07-02	38.1	33.2	0.64	4
6. CMR39-07-03	40.8	30.8	0.63	5
7. CMR39-07-04	42.2	31.3	0.56	2
8. CMR39-50-23	40.6	32.4	0.75	3
9. Lakan 1 (Check)	22.4	30.2	0.41	5
10. Lakan 2 (Check)	29.5	32.2	0.50	3

[1)] Sodium picrate method: 6 = high, 1 = low

In the General Yield Trial phase of evaluation, cassava breeding lines selected from seed sent from CIAT/Colombia also showed good performance compared to the check cultivars. Yield of these selections are presented in **Table 5.** An outstanding selection is CM9222-3 which produced an average yield of 37.0 t/ha with a dry matter content of 32.7% and a low level of HCN, making it suitable as a table type variety. Other selections have also shown promising results.

From the series of Advanced Yield Trials conducted during the period covered by this report, some promising genotypes were identified for possible inclusion in the Regional Yield Trials conducted throughout the country. These materials came from CIAT/ Colombia. The results presented in **Tables 6, 7 and 8** show that there are marked improvements in terms of yield, dry matter content and even reaction to scale insects and mites, as compared to the check varieties. It is interesting to note that in **Table 7,** entries SM235-39 and SM2359-7 have shown a high resistance to both scale insects and mites, aside from having high yields and dry matter contents. These two insect pests are the most destructive pests of cassava in the country.

It seems that at this point in time of breeding and selection of new cassava varieties, remarkable improvements have been attained. Progress in selection in all phases of the selection process has been very positive, thanks to the superior germplasm materials contributed by CIAT headquarters and the Thai-CIAT breeding program.

Table 5. Performance of selected cassava hybrids from CIAT/Colombia evaluated in the General Yield Trial of 2000/01.

Entry	Fresh root yield (t/ha)	Dry matter content %	Harvest index	HCN content[1)]
1. SM2454-23	22.1	33.6	0.46	5
2. CM9222-3	37.0	32.7	0.65	4
3. CM9165-9	22.6	34.2	0.52	6
4. CM9165-17	33.3	31.7	0.55	3
5. CM9165-20	24.5	34.5	0.47	5
6. CM9165-25	26.2	35.1	0.51	5
7. Lakan 1 (Check)	32.4	32.6	0.59	3
8. VC-5 (Check)	26.3	31.0	0.52	6

[1)] Sodium picrate method: 6 = high, 1 = low

Table 6. Performance of selected cassava hybrids from CIAT/Colombia evaluated in the Advanced Yield Trial of 2000/01.

Entry	Fresh root yield (t/ha)	Dry matter content (%)	Starch content (%)	Harvest index	HCN content[1)]
1. SM1971-7	22.5	31.3	17.9	0.48	3
2. SM2065-1	25.1	33.3	20.6	0.44	5
3. SM2117-8	30.8	31.4	18.1	0.57	4
4. SM2196-4	27.7	32.1	19.0	0.58	5
5. SM2200-27	21.1	30.4	16.7	0.49	5
6. SM2225-36	41.9	30.2	16.4	0.62	4
7. Lakan 1 (Check)	29.6	30.8	17.3	0.51	5
8. VC-5 (Check)	26.0	28.3	13.7	0.54	7

[1)] Sodium picrate method: 7 = high, 1 = low

Table 7. Performance of selected cassava hybrids from CIAT/Colombia evaluated in the Advanced Yield Trial of 2000/01.

Entry	Fresh root yield (t/ha)	Dry matter content (%)	Starch content (%)	Harvest index	HCN content[1)]	Scale insects rating[2)]	Mites rating[2)]
1. SM2353-17	26.2	34.9	22.9	0.61	5	6.0	1.0
2. SM2353-25	20.4	31.0	17.5	0.64	3	1.0	3.0
3. SM2353-39	21.1	34.0	21.7	0.56	2	1.0	4.0
4. SM2359-4	22.1	34.0	21.7	0.49	4	3.0	2.0
5. SM2359-7	22.2	32.9	20.1	0.56	2	1.0	1.0
6. Lakan 1 (Check)	24.0	33.9	21.5	0.59	4	5.0	1.0
7. VC-5 (Check)	18.7	30.9	17.4	0.61	6	3.0	7.0
8. Lakan 2 (Check)	16.9	34.3	22.1	0.58	3	2.0	3.0

[1)] sodium picrate method: 6 = high, 1 = low

[2)] rating based on 1 to 9 scale with increasing order of pest severity

Table 8. Performance of selected cassava hybrids from CIAT/Colombia evaluated in the Advanced Yield Trial of 2001/02.

Entry	Fresh root yield (t/ha)	Dry matter content (%)	Harvest index	HCN content[1)]	Scale insects rating[2)]	Mites rating[2)]
1. CM9175-25	23.9	48.6	0.60	6	2.0	2.0
2. CM9165-20	22.4	37.0	0.60	7	2.0	3.0
3. CM9165-9	21.6	37.1	0.50	5	2.0	3.0
4. SM2440-6	23.0	32.9	0.70	5	2.0	6.0
5. CM9165-17	31.0	35.6	0.60	6	4.0	3.0
6. CM9222-3	24.9	37.4	0.60	4	4.0	4.0
7. Lakan 1 (Check)	23.7	35.1	0.60	4	3.0	4.0
8. VC-5 (Check)	16.4	31.5	0.60	7	2.0	4.0

[1)]sodium picrate test: 7= high, 1 = low
[2)]rating based on scale of 1 to 9 with increasing order of pest severity

4. Varietal Release and Dissemination

Close collaboration with CIAT in the introduction of improved hybrid populations has resulted in the release of eight cassava varieties of CIAT origin (Mariscal *et al.,* 2001). These varieties produce yields in the range of 24 to 40 t/ha and with dry matter contents in the range of 32 to 34%. The major use of these varieties is for starch processing and animal feed. Recently, four new cassava varieties were released by the National Seed Industry Council for general utilization among farmers. Among these four varieties, one came from CIAT/Colombia and the other three came from the local breeding program of the Institute of Plant Breeding of the University of Los Banos, College, Laguna, Philippines **(Table 9).** Variety PSB Cv-19 (SM808-1) is a selection from an improved population introduced as sexual seed from CIAT/Colombia in 1994. It has an average yield of 32.3 t/ha with 35% dry matter and 22% starch. It has a medium HCN content and was found to be resistant to scale insects and spider mites. This variety is recommended for starch and animal feed production. The other three varieties are recommended for starch, flour and animal feed. From the remaining genotypes selected for testing in Regional Trials, some superior varieties are expected to be released soon. These prospective varieties produced yields of more than 30 t/ha, with a dry matter content of 38 to 40%.

Table 9. New cassava varieties released in the Philippines between 1999 and 2001.

Varietal characteristics	PSB Cv-17 (CG87-3-1)	PSB Cv-18 (CG87-2-13)	PSB Cv-19 (SM808-1)	PSB Cv-20 (CG91-13-1)
Fresh root yield (t/ha)	39.2	39.0	32.3	35.8
Dry matter content (%)	32.0	32.5	35.0	35.3
Starch content (%)	18.9	19.6	22.9	23.4
HCN level	Medium	Medium	Medium	Medium
Root flesh color	White	White	White	White
Reaction to pests				
-Scale insects	R	R	R	R
-Spider mites	MR	R	R	R
Intended use	Starch, feed	Flour, starch	Starch, feed	Starch, feed
Year released	1999	2000	2000	2001

To date, there are already several varieties of cassava for use in the food, feed and starch industry; however, there is a need to have a strong extension program to disseminate and make these new improved varieties available to farmers.

The Philippine Root Crops Research and Training Center (PhilRootcrops) has initiated the following strategy of varietal dissemination among farmers and entrepreneurs:

1. An information drive among farmers through training, field days and the mass media

Short training courses for farmers through NGOs and farmer cooperatives are conducted at the Center or at the sites where farmers intend to plant cassava. Each year during the Center's Anniversary Celebration a farmers' field day is held to show-case the information about the new cassava varieties. This is done through an exhibit and actual plant demonstrations during the field day. Dissemination through radio is also done in order to reach those in far away places who cannot physically be present during the field day.

2. Private entrepreneur contact

The Center also provides information directly to private corporations and individual entrepreneurs who intend to grow cassava at a large-scale.

3. Adaptability trials in specific areas of cultivation

Adaptation trials of recommended cassava varieties is an activity to evaluate cassava varieties for their adaptation to specific growing environments. This serves as a venue for farmers to select the best varieties that can be grown in their locality. Results so far indicate that those varieties that perform best in the adaptability trial are those selected by farmers for planting.

4. Establishment of a system to produce planting material

Using the testing sites of the Regional Trials, each location establishes a seed nursery to multiply the outstanding recommended varieties for distribution in the area. At least a one ha nursery per site is devoted to the production of planting material. Stems produced will be sold at cost to the clientele.

These strategies are designed to meet the increasing demand for cassava in the animal feed and the industrial sector. The San Miguel Corporation, the giant company that produce beverages and drinks has launched a massive campaign for cassava production to support their liquor industry. The company needs at least 30,000 ha of cassava to supply the feed and alcohol industry.

FUTURE DIRECTION

The demand for food to feed our increasing population calls for a vigorous effort to increase food production per unit time per unit area. The national government has focused their policies on food security, poverty alleviation, productivity improvement, global competitiveness, environmental protection and sustainability.

In the Philippines, root crops have been identified as one of the important energy crops that will play a vital role in feeding millions of people; as such, the research and development agenda will focus on the following:

1. Strengthening cassava hybridization work using elite clones and local varieties by way of conventional and unconventional methods of improvement.
2. Aggressively promoting adoption of new recommended cassava varieties.
3. Monitoring the performance of released varieties planted in large-scale production.
4. Continuing the selection of superior varieties that will suit the needs for the food, feed and starch industries.
5. Initiate linkages with the private sector, local government units and non-government organizations in the promotion of cassava for food, feed and industrial uses.

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GENETIC IMPROVEMENT OF CASSAVA IN VIETNAM: CURRENT STATUS AND FUTURE APPROACHES

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ABSTRACT

Cassava breeding and varietal dissemination in Vietnam has made continuous progress. During the past decade (1991-2000) the Vietnam Cassava Program (VNCP), in cooperation with CIAT, Vedan and other cassava processing factories, has developed and disseminated six new high-yielding varieties: KM60, KM94, SM937-26, KM95, KM95-3 and KM98-1. In the crop year 2001/02, the area planted to KM94 and other new improved varieties reached about 94,500 ha or close to 33% of the total cassava area in Vietnam. Cassava yield and production in several provinces has doubled, brought about by the construction of new large-scale cassava processing factories, especially in the south of Vietnam.

Currently, the cassava breeding program in Vietnam is evaluating annually about 12,000 hybrid seeds introduced from CIAT/Colombia, and is producing itself more than 3,000 hybrid seeds from 9-15 cross combinations. At Hung Loc Agricultural Research Center there are ten cassava breeding experiments conducted every year, and 18-24 Regional Trials are conducted in different cassava producing regions in collaboration with various institutions, universities and provincial extension offices. New clones, like KM98-5 (early harvestability, high-starch content, high fresh root yield) and KM98-1 (early harvestability, high fresh yield, low cyanogenic potential) are rapidly being multiplied to provide planting material for various purposes. More than 780 promising new clones have been selected, of which KM140, KM146 and KM163 will be further tested and possibly selected for release. The objectives of further genetic improvement of cassava varieties in Vietnam are: 1) to increase the yield potential and starch content, and obtain early harvestability; 2) to improve quality and the nutritional value, especially the carotene and micronutrient content of cassava, in order to reduce blindness and Fe and Zn deficiency in people living in marginal environments.

INTRODUCTION

In Vietnam, cassava is the third most important food crop, following rice and maize. It is planted in about 263,700 ha of agricultural land in Vietnam, producing about 2.8 million tonnes in 2001 (**Table 1**). Cassava plays an important role in the strategy of national food security (**Figure 1**).

Vietnam is an agricultural country with a population of 80 million. About 20% of farmer households are poor and 5% suffer from hunger. During the past decade of economic renovation, Vietnam has successfully escaped lingering food deficiency. Cassava is also an important source of cash income to small farmers, who either use it for animal feeding or for sale to starch factories.

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Table 1. Area, yield and production of principle food crops in Vietnam from 1999 to 2002.

Crop		1999	2000	2001 prelim.	2002 forecast
Rice	Area ('000 ha)	7,653.5	7,666.3	7,484.3	7,320.0
	Yield (t/ha)	4.10	4.24	4.27	4.34
	Production ('000 t)	31,393.8	32,529.5	31,970.1	31,756.0
Maize	Area ('000 ha)	691.7	730.2	727.3	800.0
	Yield (t/ha)	2.53	2.75	2.92	2.90
	Production ('000 t)	1,753.1	2,005.9	2,122.8	2,320.0
Cassava	Area ('000 ha)	225.5	237.6	263.7	288.4
	Yield (t/ha)	7.98	8.36	10.64	10.90
	Production ('000 t)	1,800.5	1,986.3	2,806.4	3.114.7
Sweet potato	Area ('000 ha)	270.2	254.4	244.7	220.0
	Yield (t/ha)	6.46	6.33	6.76	7.50
	Production ('000 t)	1,744.6	1,611.3	1,655.1	1,650.0

Source: *Adapted from MARD, 2002.*

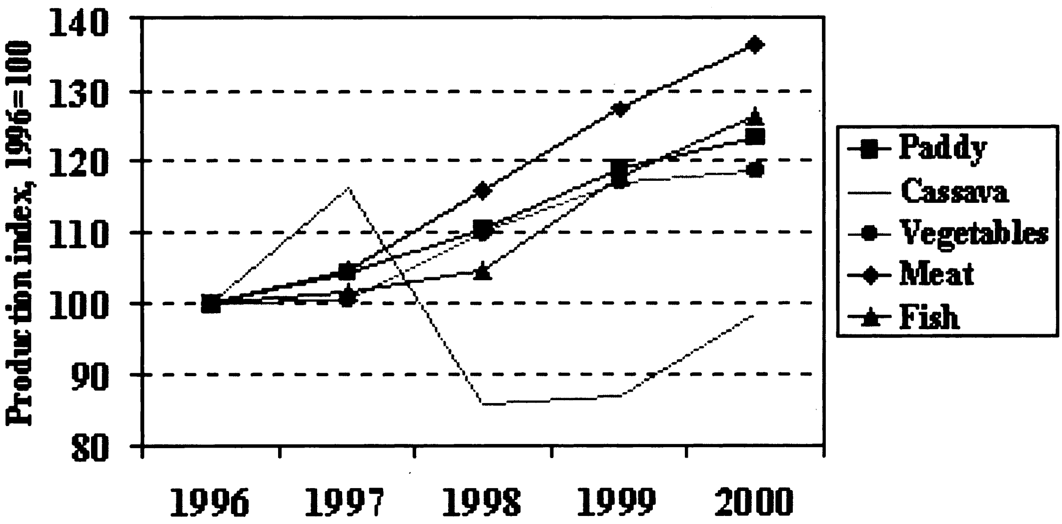

Figure 1. Food production in Vietnam from 1996 to 2000.
Source: *Food Security Programme, MARD, 2002.*

Cassava in Vietnam has been changing its role from a food crop to an industrial crop for starch production and animal feed. In 2001, total cassava starch production in Vietnam was about 500,000 tonnes of which 70% was for export and 30% for domestic use.

In the period of 2001-2005, the Institute of Agricultural Sciences of South Vietnam (IAS) was appointed to be the leader of the Vietnam Cassava Varietal Improvement Project (VNCP) by the Ministry of Agriculture and Rural Development (MARD). This is one of the 42 most important projects of the National Program of Crops and Animal Breeding Improvement in Agriculture.

Based on the target for cassava production and utilization in the country, the objectives of further genetic improvement of cassava varieties in Vietnam from 2001 to 2010 are: 1) to increase the yield potential and starch content, and enhance early harvestability; 2) to improve eating quality and the nutritional value, especially the carotene and micronutrient content of cassava, in order to reduce blindness and Fe and Zn deficiency in people living in marginal environments. This can be achieved through an effective integration of advanced biotechnology techniques and conventional breeding methods.

RECENT PROGRESS IN CASSAVA VARIETAL IMPROVEMENT

Cassava Varietal Dissemination

Cassava breeding and varietal dissemination in Vietnam have made stable and reliable progress. During the past decade (1991-2000) the Vietnam Cassava Program (VNCP), in cooperation with CIAT, Vedan and other cassava processing factories, has developed and disseminated six new high-yielding varieties: KM60, KM94, SM937-26, KM95, KM95-3 and KM98-1 (Hoang Kim *et al.*, 2001b).

New clones, like KM98-5 (selected from F_1 hybrid seeds introduced from the Thai-CIAT program in 1996; pedigree Rayong 1 x Rayong 5; high fresh yield, high starch content, early harvestability) and KM98-1 (selected from F_1 hybrid seeds introduced from the Thai-CIAT program in 1995; pedigree Rayong 1 x Rayong 5; early harvestability, high fresh yield, low cyanogenic potential) are rapidly being multiplied to provide planting material for various purposes (**Table 2**).

Table 2. Results of Regional Yield Trials conducted by Hung Loc Agricultural Research Center in central and south Vietnam (1999-2001).

No. of trials	Variety	Growing period (months)	Fresh root yield (t/ha)	Dry matter content (%)	Starch content (%)	Starch yield (t/ha)	Harvest index (%)
31	KM98-5	8-10	34.5	40.5	28.5	9.8	63
35	KM94	9-11	33.0	40.2	28.7	9.5	58
30	KM98-1	8-10	32.2	38.8	27.6	8.9	66
19	KM60	8-10	24.5	38.7	27.4	6.7	56
35	Local check	9-12	16.5	36.3	25.3	4.2	53

***Source:** Hoang Kim et al., 2000; 2001b.*

In the crop year 2001/02, the area planted to KM94 and other new improved varieties reached about 94,500 ha or close to 33 % of the total cassava area in the country. Cassava yield and production in several provinces has doubled, partially brought about by the construction of new large-scale cassava processing factories, especially in the south of Vietnam (Hoang Kim *et al.*, 2001a).

Collection, Breeding and Selection of Cassava Germplasm

Currently, the cassava breeding program in Vietnam is evaluating annually about 12,000 hybrid seeds introduced from CIAT/Colombia, and is producing itself more than 3,000 hybrid seeds from 9-15 cross combinations. At Hung Loc Agricultural Research Center there are ten cassava breeding experiments conducted every year, and 18-24 regional trials are conducted in different cassava producing regions in collaboration with various institutions, universities and provincial extension offices.

More than 780 promising new clones have been selected, of which KM140, KM146, KM163 will be further tested and possibly selected for release. KM140 is a hybrid between an advanced cultivar and a CIAT-Thai introduction. The fresh root yield is 33-38 t/ha, while it has a high dry matter content. Crop duration is 8-10 months. It has good plant type and good stake quality (**Table 3**).

Table 3. Agronomic traits of KM140 compared to three recommended varieties in the Southeastern Region of Vietnam (data from 7 trials conducted in 2001, harvested 10 months after planting).

Variety	Growing period (months)	Fresh root yield (t/ha)	Root starch content (%)	Starch yield (t/ha)	Plant type & stake quality (1-10)	Root shape & uniformity (1-10)
KM140	8-10	36.0	25.6	9.23	10	9
KM98-5	8-10	34.2	25.8	8.82	9	9
KM98-1	8-10	32.3	24.2	7.81	8	9
KM94	9-11	30.6	25.3	7.74	8	9

Source: *Hoang Kim et al., 2001b.*

KM146 was selected from F_1 hybrid seeds introduced from the Thai–CIAT program in 1997. It has a high fresh root yield and very early harvestability, good root shape and white flesh. KM163 was selected from F_1 hybrid seeds introduced from the Thai–CIAT program in 1998. It has high fresh root yield and a crop duration of 9-11 months (**Table 4**).

Table 4. Results of three Advanced Yield Trials at Hung Loc Center in 1999-2001, based on selections from hybrid seeds introduced from the Thai-CIAT program.

Variety	Growing period (months)	Fresh root yield (t/ha)	Root starch content (%)	Starch yield (t/ha)	Plant type & stake quality (1-10)	Root shape & uniformity (1-10)
KM163	9-11	33.4	27.0	9.02	9	9
KM146	7-10	31.3	25.6	8.02	8	10
KM123	8-10	24.5	26.8	6.56	8	9
KM134	8-10	22.3	27.8	6.20	7	9
KM94	9-11	27.6	28.1	7.75	8	9

Source: *Hoang Kim et al., 2001b.*

Tissue Culture and Mutation in Cassava Breeding

Plant breeders in Brazil and Mexico have developed new cassava varieties by using inter-specific hybridization (Nassar, 1986; 2001; Nassar *et al.*, 2001). We are studying this method in Vietnam by developing an *in vitro* grafting method (Phan Ngo Hoang and Bui Trang Viet, 2001), crossing and applying biotechnology in breeding.

Cultures of *Manihot esculenta* and *Manihot glaziovii* were established from the shoot tips or lateral buds collected from two-month old *in vitro* plants. The shoot multiplication was achieved from shoot tips, on the MS medium supplemented with 0.2 mg/l BA, 0.1mg/l NAA and 0.05 mg/l GA_3. The growth of shoot tips or axillary buds occurred on the hormone-free MS medium, from the explants containing shoot apical meristem or 1-2 axillary buds. The role of the plant growth regulators have been studied (Nguyen Xuan Dung *et al.,* 2002).

Mutation breeding is also underway with the specific objectives of developing early harvestability, high starch content and high fresh root yield. Seeds and *in vitro* plants of five cassava varieties have been studied under different doses of Gamma rays of ^{60}Co to create different mutants for selection.

STRENGTHENING FUTURE GENETIC IMPROVEMENT

In the immediate future, research in cassava genetic improvement is very important. The people of Vietnam have an idiom: "Nuoc, Phan, Can, Giong" (Water, Fertilizer, Good Labor, Variety). These are the four main factors affecting field crops production. Cassava breeding and varietal dissemination are among the key solutions for development.

Cassava plays an important role in the processing industry and in livestock production in Vietnam. Especially, cassava starch for food and industry is becoming increasingly important in creating future demand for cassava (Pham Van Bien *et al.*, 2001). The Ministry of Agriculture and Rural Development (MARD) initiated a five-year project, starting in 2001, to rapidly multiply stakes of the improved varieties that have high starch yield and to distribute these to the farmers. CIAT, Vedan and other cassava processing factories have also helped to implement this project.

High Starch Yield and Short Duration of Cassava Variety

Today, cassava varieties with high starch yield have been adopted widely in Vietnam, because these varieties have higher fresh root yields and starch contents. However, varieties with shorter duration need to be developed (Hoang Kim *et al.*, 2001b). Farmers in the Mekong Delta region need very early varieties with a crop duration of less than seven months to escape floods in the rainy season. These varieties also need to have fresh root yields of 26-30 t/ha and starch contents of about 27%. By evaluating the germplasm collection, VNCP is trying to collect and maintain the short duration character and improve other characters by crossing with high starch yielding varieties, mainly from CIAT.

Improvement of Quality and Nutritional Value of Cassava

A long-term objective is to improve the nutritional value of cassava, including low cyanogenic potential, high protein content, high vitamin A and other micronutrients for malnourished human populations (Graham and Rosser, 2000; West, 2001). The methods to achieve these objectives are to introduce new breeding materials, mainly from CIAT (Bedoya *et al.*, 2001; Calle *et al.*, 2001), crossing and applying biotechnology in breeding, to multiply planting material of new varieties, and to enhance the adoption of sustainable cassava production practices. We participate in a collaborative program with Dr. Hernan Ceballos in evaluating new breeding varieties in Vietnam. It is hoped that within the next few years, the new high quality varieties will be released to farmers.

Efficient Utilization of Recombination Breeding and Biotechnology

The method of recombination breeding was most effective in developing stable high yielding varieties. The pre-requisite for this breeding program is the maintenance and screening of a large cassava germplasm collection to identify donors with desirable features, such as short duration, high dry matter content, low HCN, high protein, high yield and carotene and vitamin A content, tolerance to abiotic stresses and problem soils etc. The method of recombination breeding is being studied in Vietnam.

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A NEW EVALUATION SCHEME FOR CASSAVA BREEDING AT CIAT

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ABSTRACT

One of the most important questions to be answered in plant breeding relates to the parents to be used in the generation of new germplasm. This is particularly true for cassava, given the time required to evaluate segregating progenies and the large genetic variation generated with each cross due to the highly heterozygous nature of the crop. In the past, cassava breeding at CIAT focused on properly identifying the best clones, from large, segregating progenies. However, the process was not designed to take advantage of all the potential information that could be generated. Significant steps have recently been taken at CIAT to modify the evaluation scheme, particularly during the first clonal evaluation stage, with the following objectives: a) obtain information that allows an approximation to the general combining ability of progenitors; b) shorten the length of the evaluation process; c) improve the probabilities of identifying superior germplasm; and d) detect new potential traits that can be incorporated into the selection criteria. The modifications have been implemented and improved during the past three years. The new breeding scheme has already produced important benefits. Parents are currently selected based on the quality of progenies they produce. Leaf retention at five month of age and in the absence of biotic or abiotic stresses, has proven to have a large effect on root yield. The evaluation cycle has been shortened by 16 months, and it is expected that the new scheme is more efficient in identifying superior germplasm.

INTRODUCTION

Cassava germplasm development at CIAT is centered on the development of improved gene pools for specific edapho-climatic zones with importance for cassava production. The most relevant ecosystems are the semi-arid and sub-humid tropics, for which the majority of efforts are devoted. The main selection activity is conducted in sites selected to represent the conditions of the target ecosystem. For each zone, a recurrent selection program with a progressive set of stages is followed. As the stages progress, more emphasis is given to traits of lower heritability, because more planting material for each genotype is available, and the evaluation can be conducted in bigger plots with replications. Certain selection criteria are of general importance across ecosystems (i.e. yield potential, dry matter content), while others are specific for each ecosystem (i.e. specific pests and/or diseases).

The traditional evaluation and selection procedure has a few important drawbacks: a) breeding cycles were long; b) no data was taken at the early stages to allow estimates of general combining ability effects of the progenitors employed; and c) it took several steps in the selection process until replicated evaluations could be performed. Cassava has unique opportunities to increase its relevance in tropical agriculture and agro-industries. To take advantage of these opportunities a more dynamic and efficient breeding scheme is required to meet the new demands on this crop. This article describes the modifications introduced into the cassava breeding scheme at CIAT and some of the initial observations made upon their implementation.

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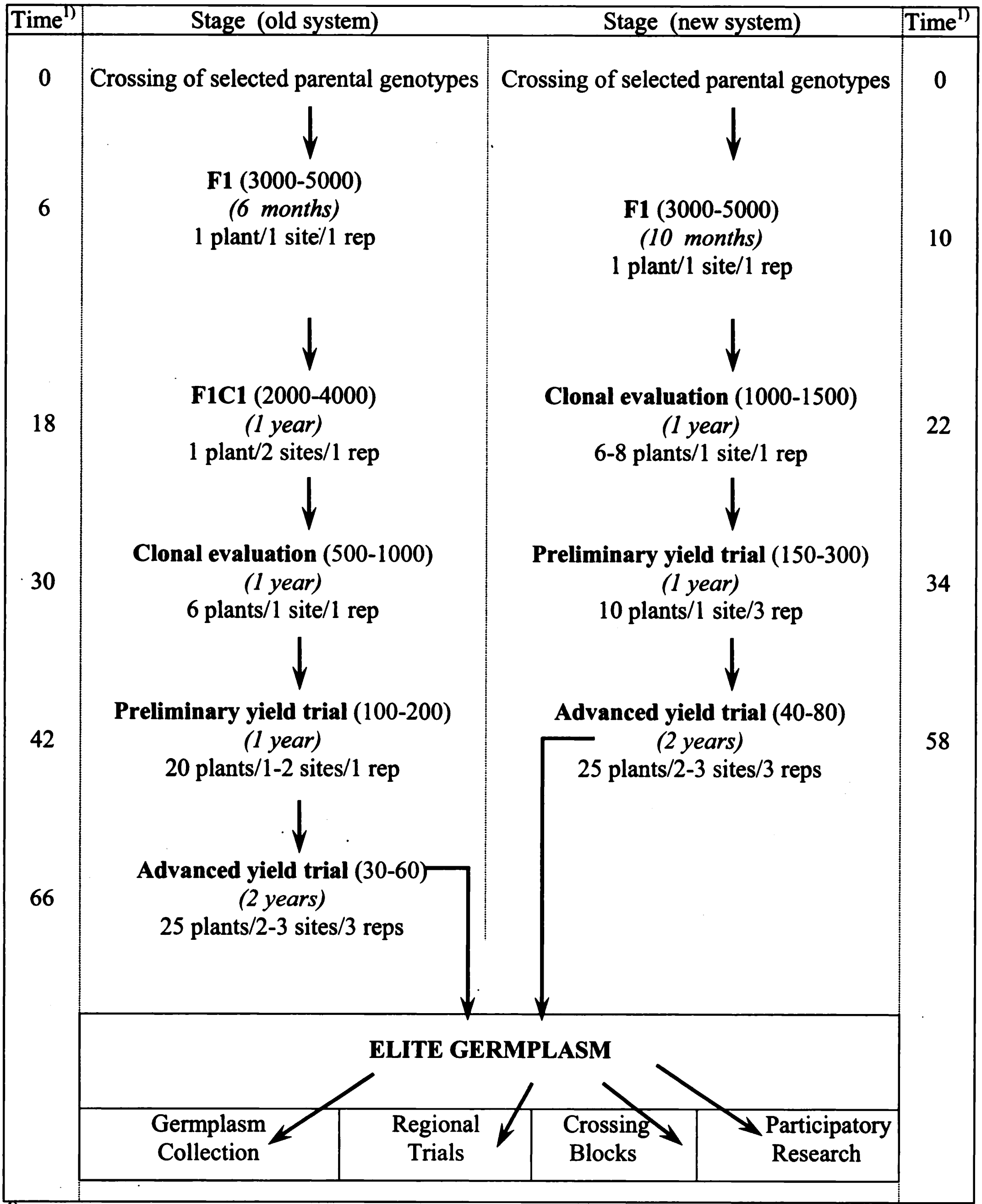
MATERIALS AND METHODS

1. Modifications in the evaluation scheme

Traditionally in CIAT headquartes at Palmira, the progenies generated from the crossing blocks (*F1*) were planted in screenhouses and the seedlings transplanted to the field after two months **(Figure 1).** At six months after planting, two stakes were harvested from each plant and given a consecutive number according to the plant. One of the stakes was planted at CIAT-Palmira, the other was planted at the main selection site (*F1C1*). Selection was conducted at harvest on individual plants at the main selection site. Planting material taken from the selected genotypes, but using the replicated source at CIAT-Palmira, was used subsequently to establish a non-replicated, 6-plant plot, at the main selection site (*Clonal Evaluation*). Evaluation was done using three central plants. The remaining three plants were used as source of planting material which now started to originate at the selection site. The following stage (*Preliminary Yield Trial)* was planted in non-replicated 20-plant plots. Evaluation was done on the central six plants, and the remaining 14 outside plants were left as source of stakes. Selected genotypes were then passed to the *Advanced Yield Trials* at one or two sites, with three replications of 25-plant plots. Genotypes selected over 2 consecutive years at the *Advanced Yield Trial* level were considered as "*elite genotypes*" and incorporated in the germplasm collection and the crossing blocks. Since each year a new breeding cycle was initiated, all the stages were simultaneously being conducted in each site **(Figure 1).**

Some modifications to the traditional scheme have now been introduced. A major constraint of the traditional evaluation methodology was that the first three stages of selection (*F1C1*, *Clonal Evaluation,* and *Preliminary Yield Trial*) were based on non-replicated plots. In addition, large amounts of material was maintained at headquarters just to have duplicates of the very few materials that would eventually reach the status of *"elite genotype"* in each selection cycle. The changes introduced will speed up the selection process, allow for the evaluation of larger number of progenies and, hopefully, will increase the efficiency of the selection process. The main changes are as follows:

1) The *F1* plants are grown for ten months rather than six. At that age they produce up to 8-10 stakes. The stakes are then sent to the proper evaluation site for the *Clonal Evaluation*. This implies that the *F1C1* stage is eliminated and that no duplicate of each genotype is maintained at CIAT headquarters.
2) The *Clonal Evaluations* are based on up to eight plants, rather than six as before. An important modification for the sub-humid environment is that most measurements in the *Clonal Evaluation* are carried out in two stages: at the normal harvest time only two plants are harvested to measure % of dry matter in the roots. This trait varies considerably with the time of harvest and age of the plant. Therefore, to estimate it correctly, the plants need to be harvested at the proper time. The remaining six plants of each plot are harvested just prior to normal planting time (one week before) and yield potential is measured again. A few other traits are also measured or estimated (using visual scores): plant architecture, foliar health (for insects and diseases separately), above-ground biomass (for measuring harvest index), and root aspect. A



[1)]Time in months after germination of botanical seed.

Figure 1. Basic cassava breeding schemes applied for each of the priority ecosystems. On the right is the new scheme currently under implementation. Later stages of selection are made following the old system.

selection index was used to make an efficient and fast selection of the approximately 1000-2000 genotypes evaluated at this stage, for each ecosystem.

3) The changes described above allows taking stakes from no less than six plants (except for those cases where stakes did not germinate or plants died), rather than three, as in the past. For eco-regions different from the sub-humid environment, only one harvesting is carried out using all the available plants (seven).

   The six plants harvested at the second harvest time, produced no less than 30 cuttings, which were used for the first replicated trial based on three replications and two row plots with ten plants per plot. It is recognized that this evaluation results in some competition effect among neighboring plots. However, it is hoped that the number of replications will neutralize most of these effects. Also, row spacing between plots was increased and the plant to plant distance within the plot reduced. This maintained the density unchanged, while favoring competition among plants from the same genotype.

4) A final important modification to the evaluation process is that data was taken and analyzed for all the progenies evaluated. In the past, data was taken only for those families that went beyond the *Clonal Evaluation* stage. Therefore it was difficult to estimate *combining ability effects* of parental materials, because most of the crosses did not produce balanced data (many progenies had been discarded in the field before any data was taken). The changes introduced allows us to base the selection of the parental materials on its breeding value (related to *general combining ability*) rather that its performance *per se*, or empirical appreciation of their potential as progenitor.

2. Description of the selection index used to facilitate the selection process

A selection index (**SI**) is just a way to simplify the selection process. Once all data from an evaluation is taken and downloaded into a computer file, the **SI** summarizes all the relevant information in a single number. The data set can then be ranked from the highest **SI** to the lowest. In this way, the best germplasm concentrate in the top of the file. Having the best materials grouped together facilitates the analysis of each individual genotype for a final selection. It should be emphasized that **SI** does not provide any new information and does not improve the quality of the data either. So, cassava breeding remains hard work and a demanding activity in the field. What the **SI** does is to facilitate the analysis of the data obtained.

The **SI** integrates, in a single number, the information from several variables that the breeder renders as important. Generally, three to five variables are included. Too many variables in the **SI** should be avoided, because the progress for each individual trait decreases when the simultaneous improvement of numerous traits is expected. So, the first element that defines the **SI** is the variables to be included:

$$\mathbf{SI_{.}: X_{1.} + X_{2.} + X_{3.} + \ldots + X_{n.}}$$

where $X_{1.}$ refers to the first variable in the **SI** (for example fresh root yield), $X_{2.}$ refers to the second variable (for example dry matter content), and so on. For each case, there is a dot as a reminder that each genotype has its own **SI** value.

The procedure to define a **SI** requires some weights for each variable to be included (Baker, 1986). Some variables are more important than others: the higher the relevance of the variable, the higher the weight it will have in the index. The relative importance of each variable depends on each breeder's criteria. The **SI** used at CIAT in Colombia does not necessarily have to be used by other cassava breeders. A particular **SI** can be defined for each region, particular end use, or breeder's preferences and/or priorities.

A second element in the **SI** is the relative weight that each variable will have in the **SI**. There are numerous criteria to define weights (Baker, 1986). In some cases an economic value for each trait is used. In other cases the heritability of the trait contributes to the definition of its weight in the **SI**. Furthermore, genetic correlations among variables can also be considered. In the example below, a weight based on the breeder's judgement is used. It is assume that the simplicity of the proposed method, although not scientifically precise or sophisticated, is very appealing. The formula for the **SI**, therefore, evolves to be as follows:

$$SI_{.}: (X_{1.} \times W_1) + (X_{2.} \times W_2) + (X_{3.} \times W_3) + \ldots + (X_{n.} \times W_n)$$

Where W_1, W_2, W_3, ... W_n are the respective weights for each variable.

The **SI**, as developed, is already complete. There is, however, an additional point to explain before applying the procedure. In the last equation, it should be clear, **SI** is a linear function of the **n** variables included in the formula. One problem that this **SI** presents is the issue of units. Different variables are measured in different units: fresh root yield will be around **30** t/ha, number of commercial roots may be around **6** per plant, and harvest index is around **0.60**. The fact that each variable is measured in different units, with large differences in their magnitude creates a problem because those variables measured in higher magnitude would have a higher weight in the definition of the **SI**. This problem can be solved if the variables are standardized, using the classical statistical formula (Steel and Torrie, 1960):

$$X_{i.}' = (X_{i.} - \mu) / \text{St. Dev.}$$

where $X_{i.}'$ is the standardized value, $X_{i.}$ is the original value, μ is the mean of the population, and **St. Dev.** is the standard deviation for the variable analyzed. The standardization procedure changes the units of a given variable (t/ha, %, etc.) into units of standard deviation. After the variables are standarized they should have a mean of zero and a standard deviation of one.

After the **SIs** are calculated, the results are analyzed and eventually some adjustment on the weights are made. In other words, the results of a given **SI** may give too much emphasis to dry matter content and not enough to plant type, for example. So the analysis is a dynamic process involving a few iterations until the desirable results are obtained. The selection index used at CIAT for the sub-humid environment is:

$$SI = (FRY \times 10) + (DMC \times 8) - (PTS \times 5) + (HI \times 5)$$

where **FRY** means Fresh Root Yield, **DMC** is Dry Matter Content, **PTS** stands for Plant Type Score, and **HI** represents Harvest Index. The weights used for each variable were 10, 8, 5, and 5, respectively. These weights are the result of a subjective process by the breeder. As said above, each breeding program will have its own weights, addressing its own priorities.

It should be clarified why in the formula, the value for **PTS** (plant type score) is negative. The reason is simple: the best plant type is rated 1, and the worst is rated as 5. In this case, the index should "reduce the expression" of the variable, because the best material are those with a low score. By utilizing the negative sign the formula will automatically give preference to those materials having negative standardized values, which are those with a low score.

Once the **SI** value for each genotype has been obtained the entire data set can be ordered by the **SI** variable. Most of the superior clones will be on top (or the bottom, depending on how the ranking is made) of the file. It is then **highly** advisable for the breeder to carefully analyze the results, because it is frequent to still find a few undesirable clones among the ones favored by the index.

3. The capacity to maintain high dry matter content at the onset of the rainy season

In the North Coast of Colombia, the *Clonal Evaluation Trial* was handled in a particular fashion. Because of the bimodal distribution of rainfall, with the rainy season starting towards the end of April to early May, cassava is traditionally harvested in February or March. Plants harvested at this time cannot be used as seed source because the stakes deteriorate by the time the rains arrive in May. Consequently, the *Clonal Evaluation Trial* used to be evaluated during the dry season, using three plants. The remaining three plants were left as seed source, being cut in May. When the rains arrive, the cassava plant reinitiates its growth, thus extracting energy that had been accumulated in the roots. As a consequence, dry matter content drops to the extent that starch and chip-drying industries usually either reject the roots or pay low prices for them.

The *Clonal Evaluation Trial* was modified by increasing the number of plants representing each clone to eight. Of these eight plants, two were harvested in March, to measure dry matter content during the optimal time for taking this measure. The remaining six plants stayed in the field until the rains arrived and were finally harvested in mid-May, when root yield and dry matter content were measured again. Despite the duplication of work, it was hoped that this procedure would allow for the identification of clones with capacity to maintain high dry matter content even after the arrival of the rainy season. It should be pointed out that an important modification introduced in the new selection system is that the *F1C1* stage has been eliminated and the first stage of selection is now the *Clonal Evaluation Trial*. In addition to the modifications introduced into these trials mentioned above, there is another major change: since no selection has been made previously, the new *Clonal Evaluations* are much richer regarding genetic variability.

In this paper the results of the *Clonal Evaluations* conducted in the Sub-humid environment of Colombia's north coast and harvested in 2001 and 2002 are presented to illustrate the advantages of the new evaluation scheme.

RESULTS

1. The use of the selection index and availability of data from all clones evaluated

Table 1 presents the results from the *Clonal Evaluation Trial* harvested early in 2002. The trial included the evaluation of 1967 clones from a total of about 52 full-sib families. The codes for identifying full-sib families changed this year from CM to GM, because the CM code already reached the number 10,000. The information provided in this table is very valuable because it offers balanced data about the general performance of each family. This data, in turn, is useful for identifying parents that tend to produce superior performing progenies (≈ breeding value).

For instance, family CM9923 was composed of 34 clones of which 24 were selected (70.6%). The average of selected clones across the evaluation was 16%. It is obvious therefore that this family showed an outstanding performance. In contrast, full-sib family GM281 had 39 clones of which none were selected. Furthermore, it is clear that family GM281 has very low dry matter content (23.0%) and low root yield (14.0 t/ha). On the other hand CM9923 had much higher root yield (32.2 t/ha) and dry matter content (31.2%), as well as excellent plant type (2.03).

Once the information of each family is consolidated, some conclusions can be drawn from their respective progenitors. Moreover, because a given clone participates as progenitor in more than one family, very reliable information about the progeny of each progenitor can be produced to feed back into the breeding process **(Table 2)**. Those clones with superior progenies are maintained and those with mediocre ones are eliminated.

2. Improving dry matter content upon the arrival of the rains

The new procedure for the *Clonal Evaluation* permits measuring dry matter content in each clone on two occasions: during the dry season (March) and after the rains arrive (May). **Figure 2** illustrates the relationship between dry matter content in March and that in May for the 1,350 genotypes harvested during 2001.

From the information provided in **Figure 2**, it can be concluded that a relationship exists between the two sets of dry matter contents, corroborated by a correlation coefficient of 0.689. However, observations made in March do not allow to predict with precision those materials that will present high dry matter content in May. For example, clone "A" in **Figure 2** had high dry matter content in March (> 40%), but very low content in May (< 25%). In contrast, clone "B" showed a mediocre performance in March (< 35%), but it was outstanding (about 37.5%) after the rains arrived in May.

Table 1. Results (averages for each full-sib family) from the Clonal Evaluation Trial harvested in 2002 in Santo Tomás, Atlántico Colombia, with 1967 clones.

Family	Size[1)]	Selec. clones (%)	Clones w/fol. retent. (%)	Fresh root yield (t/ha)	Dry matter content (%)	Plant type (1-5)	HI (0-1)	Select. Index	Family	Size[1)]	Selec. clones (%)	Clones w/fol. retent. (%)	Fresh root yield (t/ha)	Dry matter content (%)	Plant type (1-5)	HI (0-1)	Select. Index
CM 8209	70	11.0	8.6	22.2	29.8	2.69	0.51	-3.0	GM 236	36	11.0	30.6	24.2	29.6	2.65	0.65	5.9
CM 9106	5	20.0	40.0	21.4	28.0	2.90	0.65	-2.2	GM 237	2	0.0	0.0	3.4	21.1	4.75	0.36	-61.9
CM 9148	31	3.0	9.7	20.8	28.9	3.24	0.53	-9.0	GM 238	52	17.3	23.1	30.0	28.1	3.21	0.66	5.3
CM 9178	40	4.9	27.5	20.8	28.9	3.01	0.57	-5.6	GM 239	16	37.5	50.0	28.0	31.1	2.34	0.57	11.3
CM 9703	18	0.0	11.1	21.4	29.6	3.03	0.56	-4.2	GM 246	42	14.3	16.7	25.5	29.9	2.61	0.61	6.3
CM 9907	50	28.0	18.0	28.4	28.9	2.58	0.64	9.1	GM 247	16	37.5	37.5	22.2	29.6	2.81	0.67	3.2
CM 9921	15	40.0	33.3	26.5	31.8	3.03	0.65	9.76	GM 248	27	18.5	25.9	23.6	28.3	2.91	0.69	2.5
CM 9923	34	70.6	17.3	32.2	31.2	2.03	0.59	19.2	GM 249	43	16.8	46.5	22.1	30.7	2.81	0.54	-0.5
CM 9926	21	19.0	19.1	30.9	28.5	3.00	0.67	9.2	GM 250	29	10.3	10.3	25.7	29.6	2.78	0.58	3.2
CM 9945	25	4.0	28.0	19.7	29.5	3.46	0.64	-5.4	GM 252	21	4.8	19.5	21.9	27.4	3.12	0.63	-5.7
CM 9946	8	42.9	37.5	23.1	30.8	2.31	0.54	4.5	GM 253	57	3.5	52.6	22.0	30.2	2.90	0.56	-1.4
CM 9949	35	11.0	28.6	22.6	28.4	2.71	0.54	-4.1	GM 255	31	9.7	0.0	24.8	28.1	2.77	0.52	-3.6
CM 9952	41	17.0	7.3	29.7	26.3	2.88	0.64	3.7	GM 258	29	17.2	44.8	24.9	29.6	2.97	0.60	1.8
CM 9954	15	6.7	26.7	25.5	28.7	1.57	0.51	6.66	GM 259	55	21.8	1.8	26.7	27.7	2.70	0.63	3.4
CM 9957	47	23.4	6.4	26.3	30.8	2.59	0.58	10.0	GM 262	62	16.4	53.2	24.6	28.3	2.62	0.59	0.7
CM 9958	59	35.6	22.0	27.0	30.6	2.28	0.58	9.95	GM 266	61	6.6	32.8	23.4	28.3	2.75	0.58	-1.5
CM 9966	44	16.0	22.7	26.1	28.6	2.69	0.59	2.3	GM 273	28	17.9	0.0	26.6	29.6	2.75	0.62	6.2
GM 210	15	0.0	20.0	18.2	30.1	3.13	0.51	-9.67	GM 274	16	12.5	50.0	27.0	30.3	2.69	0.55	5.2
GM 211	71	11.3	18.3	20.7	31.0	2.87	0.52	-3.1	GM 280	9	0.0	0.0	9.31	25.3	3.33	0.57	-27.3
GM 212	56	1.8	16.1	20.4	31.8	3.05	0.48	-4.7	GM 281	39	0.0	18.0	14.0	23.0	3.04	0.62	-22.7
GM 213	79	7.6	1.3	20.7	28.4	2.51	0.51	-5.7	GM 282	76	2.6	56.6	19.4	27.2	2.82	0.59	-8.4
GM 214	67	12.0	0.0	21.3	31.1	2.63	0.51	-0.71	GM 287	24	8.3	29.2	24.3	27.4	3.08	0.63	-2.5
GM 215	37	5.4	10.8	20.6	28.6	2.82	0.54	-6.62	GM 288	46	26.0	32.6	27.4	29.5	2.63	0.58	6.1
GM 216	29	3.4	27.6	17.0	26.1	2.53	0.42	-18.8	GM 290	66	44.0	40.9	32.7	29.0	2.77	0.65	12.8
GM 217	57	8.8	5.3	20.4	27.9	2.75	0.57	-6.5	GM 291	31	12.9	12.9	26.7	26.6	2.95	0.70	2.4
GM 218	30	6.7	63.3	21.8	31.2	2.93	0.52	-1.8	GM 302	53	26.4	24.4	27.4	29.2	2.75	0.56	3.4

[1)] Size: Number of clones from each full-sib family. **Selec. clones**: Proportion of clones from the family selected using the selection index criteria. **Clones w/fol. retent.:** Proportion of clones from a given family exhibiting foliar retention. **Dry mat. cont.:** Dry matter content (%) in the roots measured after the arrival of the rains. **Plant type:** 1= Excellent and 5= Very Undesirable. **HI:** Harvest Index. **SI**: Selection Index

Based on these data, 20 clones were selected in 2001 not only for their high dry matter content, but also because their DM content decreased little upon the arrival of the rains. These 20 clones were planted again and harvested in May 2002. Dry matter content values in 2001 and 2002 had a good correlation (0.65), confirming that this trait has relatively high heritability, and that the selection scheme as the one implemented is likely to be successful.

Table 2. Progenitors that generated the families listed in Table 1 and general performance of their progenies pooling together data from all the families where they participated.

Progenitor	Number of clones generated	% of clones selected
CM 523-7	511	6.80
CM 6754-8	231	16.45
CM 8027-3	318	23.10
SM 805-15	289	9.24
SM 1219-9	465	13.19
SM 1411-5	305	25.70
SM 1565-17	399	12.24
SM 1657-12	155	13.20
SM 1665-2	400	15.43
SM 2192-6	465	19.24
Rayong 60	394	15.16
Total	**3932**	-
Mean	-	**15.43**

3. Importance of leaf retention

Another significant result obtained from the *Clonal Evaluation* harvested in 2001 was the observation that some genotypes had the capacity to retain leaves for longer periods during plant growth observed by the end of October. At that time, the crop was 5½ months old and a differential capacity to retain leaves was already obvious. Although in most materials (1,225 or 90.7%), leaf abscission had already occurred in the lower 2/3 of the plant, the remaining 125 clones (or 9.3%) had still retained their leaves **(Figure 3).** Leaf retention capacity was recorded at that time.

Table 3 presents the averages of different traits for the 1,225 clones that did not retain their leaves and for the 125 that did. The notable difference observed between the performances of the two groups suggest that the capacity to retain leaves at five months of age (at a time when no marked water stress has yet occurred in the region) has, indeed, a profound effect on overall performance measured at ten months of age. The materials that retained leaves yielded, on average, 26% more fresh roots (24.96 *versus* 19.75 t/ha), which represents an addition of about 2 t/ha of dry matter. Furthermore, leaf retention was also observed to associate with higher dry matter content (between 1% and 2% more, depending on when it was measured) and with a higher harvest index (by about 10%). These results are significant in that a trait has been identified that is most likely to be of high heritability (i.e., easy to select and fix in populations adapted to sub-humid conditions) and has a positive effect on the agronomic performance of cassava in this region.

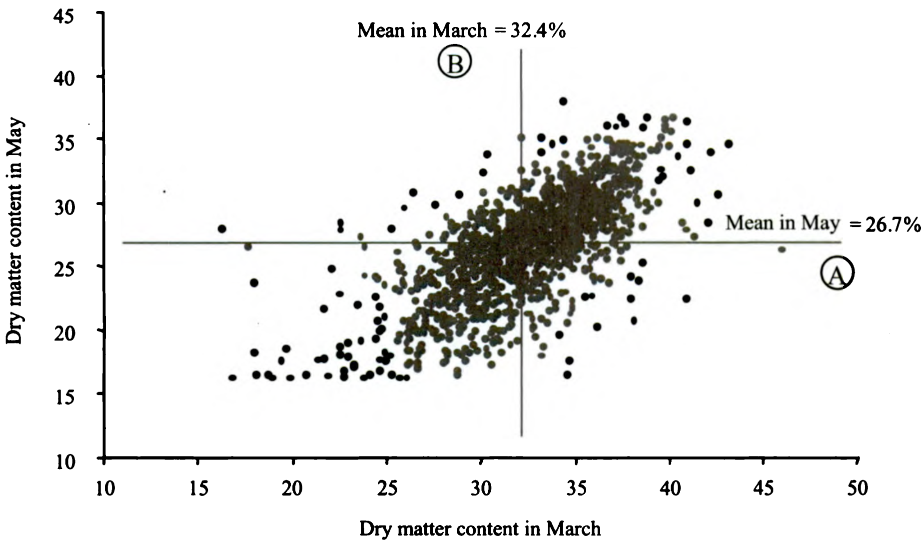


Figure 2. Dry matter content (%) measured for 1,350 genotypes in March and again in May, 2001. Clones A and B are discussed in the text.

Figure 3. Differences in leaf retention as observed in the Clonal Evaluation at Santo Tomás, Department of Atlántico, Colombia. At 5½ months, some families were retaining leaves while others had significant leaf fall.

Table 3. Effect of leaf retention in 5½-month-old cassava on traits measured five months later (at harvest) in the *Clonal Evaluation* in Santo Tomás, Department of Atlántico, Colombia in 2001.

Leaf retention	Dry matter content (%)		Harvest index (0 to 1)		Fresh root yield (t/ha)		Dry matter yield (t/ha)		Fresh root yield[1)] (t/ha)
	March	May	March	May	March	May	March	May	
Yes	32.15	28.51	0.55	0.50	27.05	24.12	9.16	6.95	24.96
No	31.48	26.27	0.48	0.44	21.91	18.89	7.08	5.10	19.75

[1)] Weighted average of fresh root yields taking into account the number of plants harvested in March and May.

The positive effects of leaf retention on the general performance of cassava was predicted earlier by Cock and co-workers (1979). These results confirmed the predictions based on theoretical models and have been further confirmed with other evaluations whose results are not presented here. The distinctive variation for leaf retention was apparent because a large number of clones (new *Clonal Evaluation*) were represented by eigth rather than one plant per genotype (old *F1C1* stage).

CONCLUSIONS

The main advantages of the new evaluation scheme can be summarized as follows:

- The duplication of materials maintained at CIAT headquarters is avoided until they reach status of "elite genotype".
- The selection of a large number of segregating progenies, at the *F1C1* stage, which was based on single plant observations, is avoided.
- The time required to reach the stage of replicated trials is minimized.
- The total length of each cycle of selection is reduced by almost a year.
- Data records will allow for selecting parental material based on *general combining ability*.
- The total cost for each cycle of selection should be reduced.
- Selection will be less subjective by using appropriate selection index specifically developed for that purpose.
- Genetic differences among clones are much more apparent in the *new Clonal Evaluation* than in the old *F1C1* stage.
- For environments with rains concentrated in one season, there is a possibility of selecting clones able to maintain high dry matter upon the arrival of the rains.

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CRYOPRESERVATION OF *IN VITRO*-GROWN SHOOT TIPS OF CASSAVA

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ABSTRACT

An *in vitro* collection of cassava germplasm has been established at the Scientific Equipment Center of Kasetsart University's Research and Development Institute since 1985. Nearly 130 cultivars are presently maintained under slow-growth conditions. Most *in vitro* conservation methods are for short- to medium-term storage; they encounter various problems such as high costs of maintaining the stock, space requirements, risks of contamination and somaclonal variation with increasing time. For long-term conservation of plant germplasm, cryopreservation is a theoretical choice. Cryopreservation is based on the non-injurious reduction and subsequent interruption of metabolic functions of biological materials by reducing the temperature to that of liquid N (-196°C). However, the availability or development of a simple, reliable and cost-effective protocol and the subsequent regeneration of the plants are basic requirements for germplasm conservation. Vitrification is achieved by using a sufficiently high concentration of solutes, and by the use of rapid cooling rates to prevent the cell solution from freezing into ice; this ensures its transition into the amorphous or glassy state.

We first succeeded in the cryopreservation of *in vitro*-grown shoot tips of cassava (*Manihot esculenta* Crantz cv. CM3281-4) by a simple vitrification method. In the protocol, excised shoot tips from *in vitro* plantlets were precultured on solidified culture medium, supplemented with 0.3 M sucrose for 16 h; these were then treated with a mixture of 0.4 M sucrose and 2 M glycerol for 20 min at 25°C. The osmo-protected shoot tips were sufficiently dehydrated with a highly concentrated vitrification solution (designated PVS2) for 45 min prior to plunging into liquid N. Successfully vitrified shoot tips were rewarmed rapidly in water at 45°C and then plated on culture medium. These vitrified shoot tips developed shoots within three weeks after being recultured. The average rate of normal shoot formation was about 75%. Recently, the vitrification protocol was successfully applied to ten other cultivars of cassava. The average recovery rate was about 70%.

Further studies are necessary to develop a method that can be routinely applied to a wide range of lines showing diverse traits in gene banks.

INTRODUCTION

An *in vitro* collection of cassava germplasm has been developed at the Scientific Equipment Center of Kasetsart University's Research and Development Institute since 1985. Nearly 130 cultivars are presently maintained under slow-growth conditions. *In vitro* conservation methods are for short- to medium-term storage; they encounter various problems such as high costs of maintaining the stock, space requirements, risks of contamination and somaclonal variation with increasing time. Cryopreservation in liquid nitrogen appears to be a logical choice for long-term storage of plant germplasm with minimum space and maintenance requirements. Cryopreservation is based on the non-injurious reduction and subsequent interruption of metabolic functions of biological materials by reducing the temperature to that of liquid nitrogen (LN) at -196°C. However,

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the availability and development of a simple, reliable and cost-effective protocol are basic requirements for the long-term conservation techniques.

Cryopreservation of shoot tips of cassava using a conventional slow freezing method was reported by Escobar *et al.* (1997). However, this procedure is very complicated and time consuming and gives generally low rates of growth recovery Almost ten years ago, some new cryogenic procedures (vitrification, and encapsulation-dehydration techniques) were reported by Engelmann (2000) and by Sakai (1997; 2000). These protocols dehydrate a major part of the freezable water of specimens at non-freezing temperatures and enable them to be cryopreserved by being directly plunged into LN. These new protocols simplified the cryogenic procedures and increased the applicability to a wide range of plant materials, especially non-hardy tropical plants. Vitrification refers to a phase transition from a liquid into amorphous glass, while avoiding crystallization. The vitrification protocol requires the use of a highly concentrated vitrification solution, which sufficiently dehydrates explants so that they turn into a stable glass when cooled into LN. We first succeeded in the cryopreservation of cassava (cv. CM3281-4) by vitrification (Charoensub *et al.,* 1999).

However, to be able to apply the vitrification protocol to a wide range of cassava germplasm, it is essential to develop a simple and effective micropropagation method, which can supply a large number of uniform and suitable meristems required for successful cryopreservation. We succeeded in cryopreservation of ten cultivars of cassava (average rate of recovery growth about 70%), using standardized ideal apices, which are produced by mono-nodal cutting culture (Hirai and Sakai, 1999).

MATERIALS AND METHODS

In vitro-grown plantlets of cassava (*Manihot esculenta,* cv. CM3281-4) were maintained on MS inorganic medium (Murashige and Skoog, 1962) containing 100 mg/l inositol, 1 mg/l thiamine HCl, 0.02 mg/l BA, 0.1 mg/l GA, 0.01 mg/l NAA, 3% sucrose and 7.5 g/l agar, pH 5.6 at 25°C under a 12 h photoperiod (50 µmol s^{-1} m^{-2}). They were subcultured every two months. The nodal segments, consisting of one lateral bud and a 0.5 cm long stem, were taken from 2-month-old stock cultures and densely cultured (30 nodal segments) on the same medium as mentioned above in Petri dishes (10 cm diameter, 2 cm height). These segments developed young axillary shoots and leaves after culture under the light conditions **(Photo 1).** The apices (about 1 mm long with two leaf primordia) were excised from the 2-day old axillary shoots (about 1 cm height) for cryopreservation.

The excised apices were precultured on MS inorganic medium supplemented with 0.3 M sucrose for 16 h. They were placed in a 1.8 ml cryo-tube and then osmo-protected with a mixture of 2 M glycerol and 0.4 M sucrose (LS solution) for 20 min at 25°C. After removing the LS solution, a highly concentrated vitrification solution (PVS2, 7.8 M) (Sakai *et al.,* 1990) was added and gently mixed. After being replaced once with fresh PVS2, apices were dehydrated with PVS2 for 45 min at 25°C. The cryo-tubes in which apices were finally suspended in 0.5 ml of PVS2, were plunged into LN (-196°C) and held for at least 2 h. After being rapidly warmed in water at 45°C by vigorously shaking for about 1 min, PVS2 was drained from the cryo-tubes and replaced with MS inorganic medium containing 1.2 M sucrose for 20 min. Then cryopreserved apices were transferred onto sterilized filter paper discs over a solidified culture medium in Petri dishes. After one day, they were transferred again to fresh medium.

Photo 1. The mono-nodal segments developed young axillary shoots after being cultured[1)] for 12 days.

1) The nodal segments, consisting of one lateral bud were densely cultured in a Petri dish containing MS inorganic medium supplemented with 100 mg/l inositol, 1 mg/l thiamine HCl, 0.02 mg/l BA, 0.1 mg/l GA, 0.01 mg/l NAA, 3% sucrose and 7.5 g/l agar.

In this study, ten cassava cultivars (CM3281-4, CM323-52, CM3401-2, Hanatee, MInd 9, AMM22, MKUC, KU50, Rayong 1 and Rayong 90) were tested for their cryopreservation by vitrification.

RESULTS AND DISCUSSION

The key factors for the successful cryopreservation by vitrification are the acquisition of osmo-tolerance to PVS2 solution and the mitigation of injurious effects during the dehydration process. To enhance the osmo-tolerance of excised apices, they were precultured with 0.3 M sucrose for 16 h, followed by the treatment with 2 M glycerol and 0.4 M sucrose for 20 min before being dehydrated with PVS2 solution. To determine the optimal time of exposure to PVS2 solution, osmo-protected apices were treated with PVS2 at 25°C for different lengths of time before being plunged into LN. The optimal time was obtained at 45 min (data not shown).

The recovery rate of apices excised at different ages (10 to 18 days old) of donor plantlets were compared. The apices sampled from the 12-day-old plantlets resumed growth within one week after reculture and developed normal shoots without intermediary callus formation. This simple micropropagation method enabled the production of a large number of relatively homogeneous and adequate apices in terms of size and physiological state and growth response, thereby increasing the chance of positive and uniform responses to subsequent cryogenic treatments and recovery growth. This mono-nodal cutting culture allowed some standardization of the apices used for cryopreservation, as the axillary buds began to develop into terminal ones, though no marked elongation on the stem was noticeable (Bachiri *et al.,* 2001).

The vitrification protocol was tested for ten other cultivars of cassava, six of which produced high rates of recovery growth (70-90%), with an average recovery rate of about 70% **(Table 1).**

Table 1. Rates of recovery growth of ten cultivars of cassava after being cryop reserved by virtification.

	% shoot formation	
Cultivars	–LN[2)]	+ LN[2)]
CM3401-2	90.0	43.3 ± 12.5
Hanatee	80.0	60.0 ± 0.0
MInd 9	90.9	43.3 ± 17
CM323-52	91.7	90.2 ± 7.5
AMM22	90.9	86.7 ± 12.5
CM3281-4	90.9	86.7 ± 4.7
MKUC	90.0	75.6 ± 6.2
Rayong 1	80.0	73.3 ± 4.7
KU50	90.9	70.0 ± 8.2
Rayong 90	90.9	31.9 ± 7.3

[1)] Excised apices were precultured with 0.3 M sucrose for 16 h, and osmo-protected with 2 M glycerol and 0.4 M sucrose for 20 min. Thereafter they were dehydrated with PVS2 for 45 min at 25°C befored being plunged into LN. Ten apices were tested for each of the three replications in every cultivar.

[2)] -LN: without being immersed in liquid nitrogen, + LN: being immersed in liquid nitrogen.

Acknowledgements

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BIOTECHNOLOGY IN CASSAVA GERMPLASM CONSERVATION AND BREEDING IN INDIA

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ABSTRACT

Biotechnological tools such as tissue culture and DNA analysis are increasingly being utilized for germplasm management and breeding in crop plants. Germplasm is the basic material for plant breeding, and as such, management of genetic resources in the most efficient way is pivotal for crop improvement. Realizing the importance of this, the collection of cassava germplasm started in India about 50 years back, and more than 1600 accessions have been collected. These are being maintained in a field gene bank with annual replanting. Part of the germplasm is also being maintained in *in vitro* form.

The large number of accessions is a problem in many old collections, and it is more so in a vegetatively propagated annual crop like cassava. Attempts were made to minimize the number in a scientific way without affecting the genetic variability. Many of the accessions were found to be apparent duplicates. This was confirmed in a systematic way by identifying the duplicates based on standard morphological characters, isozyme patterns and DNA polymorphism.

The existing germplasm has been characterized for the 11 morphological characters suggested by the Cassava Germplasm Network. The data have been analyzed for similarity and about 138 apparent duplicate sets were identified. Morphological duplicates were analyzed for esterase isozyme polymorphism and about 60% were found to be duplicates at the isozyme level. These isozyme duplicates were again analyzed for their similarity at the DNA level using RAPD polymorphism. About 50% were found to be duplicates at the DNA level. Such duplicate accessions could be eliminated from the field germplasm bank and preserved only in *in vitro* or cryo form. This information, along with that on economic characters and passport data was utilized for identification of a tentative core collection consisting of 15% of the accessions. Isozyme and DNA analyses were also used for basic genetic studies, such as assessing the variability and genetic diversity available in the population. Based on this, clusters were identified and crosses were made between distant clusters to produce a wide spectrum of variability.

Attempts were also made to identify molecular markers for economic characters, which will be useful for Marker Assisted Selection (MAS). Duplicates, which differed in one or two economic characters, were found to be good material for marker analysis. Research is under way to use DNA analysis for phylogenetic studies. Future strategies involve the use of proven SSR markers for Marker Assisted Selection of disease resistant varieties, and utilization of commercially available genes for quality improvement in cassava.

INTRODUCTION

Germplasm is the raw material for crop improvement. Realizing the importance of germplasm, cassava breeders in India started the systematic collection of germplasm in the 1940s. Cassava is an introduced crop in India, and it is believed to have reached Indian shore during the 17th century through Portuguese sailors. Even though it was introduced as a botanic specimen in the Calcutta Botanic Garden during 1794 (Tan, 1994), it was not until 1840 that improved varieties were officially introduced for cultivation in southern India, especially in the state of Kerala. Research on cassava started in India about one century later. At the time, breeders could collect as many as 75 different cultivars from Kerala (Joseph et *al.,* 1992). Even though the number of varieties introduced in the beginning was

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limited, a large number of recombinant varieties were selected and cultivated by farmers. These selections were mostly for cooking quality, in contrast to the bitter nature of the introduced varieties. Later exotic varieties were introduced through governmental agencies, as well as through CIAT (Colombia) and IITA (Nigeria).

In addition to the conventional way of conservation, cataloguing and evaluation of germplasm, biotechnological tools such as tissue culture and molecular characterization are increasingly being used for germplasm management and utilization (Taksley and Orton, 1983; Ocampo *et al.,* 1993; Carvalho *et al.,* 1998). A brief account of the biotechnological approaches for management of cassava germplasm, as initiated in India, is given in the paper.

Status of Cassava Germplasm

The Central Tuber Crops Research Institute (CTCRI), in Thiruvananthapuram, Kerala, is the main Center for conservation of cassava germplasm in India. Some of the State Agricultural Universities are maintaining a limited number of accessions as a working collection. At present, CTCRI is holding about 1,635 accessions of cassava (*Manihot esculenta* Crantz), which consists of 785 exotic and 850 indigenous collections. The indigenous collections include land races and breeding lines. The exotic groups include collections from different cassava growing countries like Nigeria, Madagascar, Thailand, Ghana, Colombia, Uganda, Sri Lanka and Malaysia. There are nine other species of cassava namely *Manihot anomala, M. caerulescence, M. epruinosa, M. flabelifolia, M. glaziovii, M. dichotoma, M. maracasensis* and *M. peruviana.*

The available germplasm has been profitably utilized for the selection and release of three short-duration varieties and eight high-yielding hybrids. The wild species are being utilized in interspecific crosses for the incorporation of mosaic resistance to cultivated varieties.

Collection of Germplasm

The National Bureau of Plant Genetic Resources (NBPGR) in New Delhi is the nodal agency for collection of germplasm in India. Land races are mostly collected through germplasm collection trips, jointly organized with NBPGR. Exotic accessions are also procured through NBPGR. Sexual seed of various crosses have been obtained from CIAT/Bangkok.

Conservation of Germplasm

The existing germplasm has been characterized based on International Plant Genetic Resources Institute (IPGRI) descriptors and these are documented in a computerized database. This data has been utilized for identification of genetic stocks for economic characters (Santha Pillai *et al.,* 2000).

Identification of morphological duplicates

Occurrence of duplicate accessions is a problem in large collections of germplasm. This adds to the cost of field maintenance, without contributing to the variability. Scientific means of identification of duplicates, and their elimination have been thought off by several workers. As per the decision taken in the First Meeting of the International Network for Cassava Genetic Resources (Ekanayake, 1992), the existing germplasm was screened for 11 morphological characters (**Table 1**). The data was analyzed to identify those accessions, which were identical in all 11 characters. By this exercise, 138 sets of morphological duplicates were identified (**Table 2**). It was found that the number of duplicates was greater in the indigenous group. It may be due to periodic collection of germplasm from the same area or spreading of good varieties to far off places. It is also observed that the same cultivars are know by different names in different places (Santha Pillai *et al.*, 1999).

Table 1. Key morphological characters of cassava.

Shoot characters	Root characters
Stem epidermis color	Root surface color
Stem periderm color	Root cortex color
Apical leaf color	Root flesh color
Shape of central leaf lobe	Root neck (peduncle length)
Color of petiole	
Apical pubescence	
Flowering	

Table 2. Frequency of morphological duplicates.

	Exotic	Indigenous
No. of accessions screened	727	786
No. of duplicate groups	46	92
Frequency of duplicates in each group	2(45)	2(67)
	3(1)	3(14)
		4(7)
		5(2)
		6(2)
		7(1)
Total no. of duplicates	47	140
Percentage of duplicates	7	18

BIOTECHNOLOGICAL APPROACHES FOR CONFIRMATION OF DUPLICATES

Isozyme Analysis

.Studies at CIAT/Colombia showed that esterase isozyme produced large polymorphism in cassava, and it can be used as a varietal marker for routine identification of cassava cultivars (Ramirez *et al.*, 1987). Accordingly, the morphological duplicates identified in the collection, were analyzed for esterase isozyme polymorphism. Those, which showed 100% similarity in banding pattern, were rated as isozyme duplicates. In addition to visual scoring, it was confirmed by analyzing the molecular weight of the bands using the software 'AAB 1D Advanced'. Out of the 138 sets of morphological duplicates analyzed for esterase enzyme, 85 showed similarity in banding pattern (Sumarani *et al.*, 2002; Harisankar *et al.*, 2002). Details are given in **Table 3**.

Table 3. Morphological duplicates and isozyme duplicates in cassava germplasm.

	Exotic	Indigenous	**Total**
No. of morphological duplicate groups	46	92	**138**
No. of isozyme duplicates	28	57	**85**
Percentage of isozyme duplicates	60	63	**62**

DNA Analysis of Isozyme Duplicates

DNA analysis, based on RAPD (Random Amplified Polymorphic DNA) has been used elsewhere for studies of variability and identification of duplicates in cassava (Marmey *et al.,* 1994; Carvalho *et al.,* 1998). Accordingly, 85 sets of isozyme duplicates were analyzed for RAPD banding pattern following Dellaporta *et al.* (1983). Random primers from OPERON Q- series consisting of 20 primers were used for polymerization. Thirty-six groups including multiple sets were found to be duplicates at the DNA level as well (Santha Pillai *et al.,* 2002). RAPD banding pattern in a sample of five sets based on one primer is shown in **Photo 1** and that for 3 primers is shown in **Photo 2**. In addition to the visual scoring, the genetic relation was analyzed numerically based on base pair and drawing dendrograms using the software "AAB 1D Advanced" (**Figure 1**). The duplicate accessions from each set can be eliminated from the field gene bank and maintained only in tissue culture or under cryopreservation.

IDENTIFICATION OF A CORE COLLECTION

This information on duplicates was used as an additional tool for identification of a core collection of cassava germplasm consisting of about 15% of the total germplasm (**Table 4**). The core collection consists of released varieties, geographic representatives, wild varieties and genetic stocks for various economic characters, after elimination of the duplicates (Santha Pillai *et al.,* 2002). The core collection is being analysed for DNA variability.

STUDIES ON MOLECULAR GENETICS AND BREEDING

Analysis of Genetic Variablility and Genetic Diversity

Molecular markers like isozyme and RAPD can be utilized for studies of genetic variability and genetic diversity in the population. To start with, esterase isozyme markers were used to study the variability in 113 elite breeding lines. The genetic distance between accessions was analysed by constructing dendrograms and identifying clusters (**Figure 2**). The population fell into 12 clusters (Santha Pillai and Sudaresan, 1998). Hybridization involving genetically distant genotypes is expected to show wide variability. Crosses within clusters and between clusters were made and their F1 performance is being studied.

Use of Molecular Markers to Confirm True Hybrids

Confirmation of hybrid nature of the F1 is very important in genetic studies. In heterozygous crops, it is very difficult to get morphological markers and in such cases DNA analysis can be used as an additional tool. RAPD pattern of a male parent, female parent, and the F1 based on 12 primers was analyzed. It was found that all the bands in the hybrid came from either the male or the female parent, and there was no additional band. This was confirmed by comparison of base pairs as well (**Table 5**).

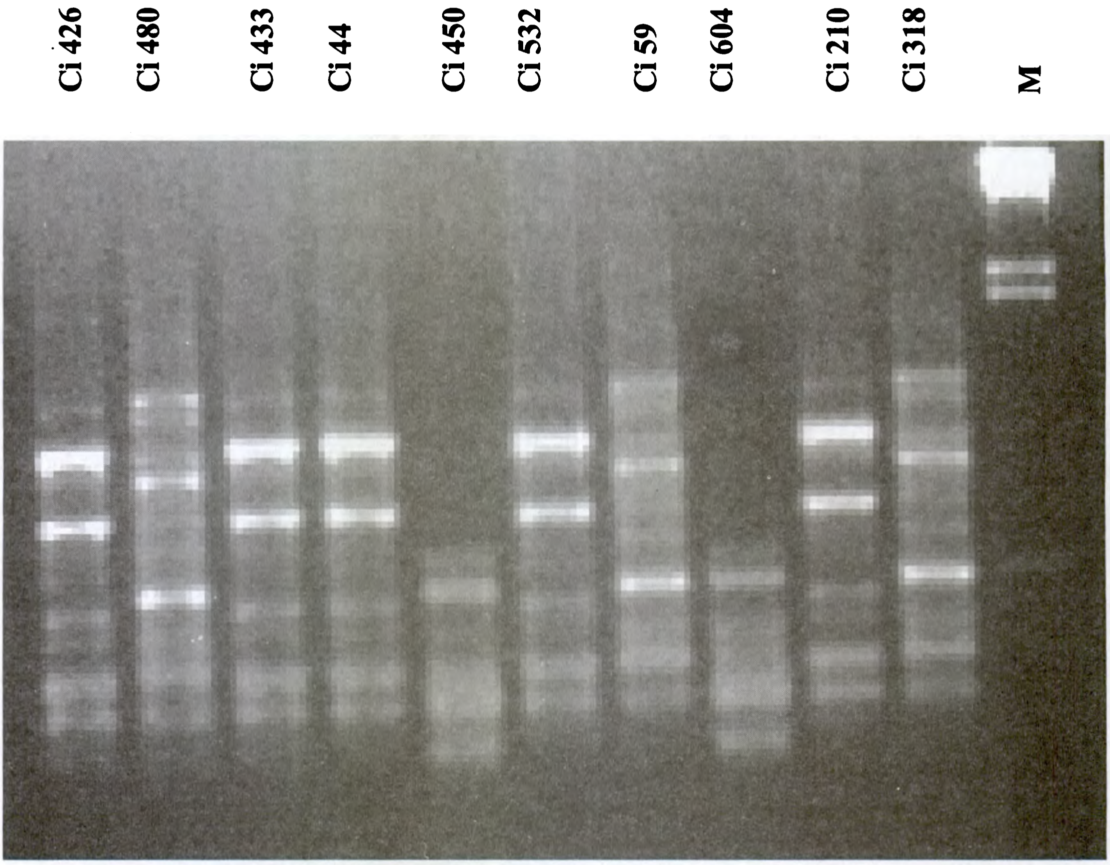

Photo 1. DNA (RAPD) banding pattern in a sample of five duplicate sets based on one primer: OPQ-5.

DNA Fingerprinting of Released Varieties and Elite Breeding Lines

RAPD markers give distinct banding patterns for different varieties, based on one primer or other and it can be used as an additional means for identification. RAPD patterns of 11 released varieties and some of the elite breeding lines based on 10 primers have been produced and documented. RAPD banding pattern of an elite variety based on 10 primers is shown in **Photo 3**.

Molecular Markers for Economic Characters

Identification of molecular markers for economic characters will be useful for Marker Assisted Selection (MAS). Usually this is done in inbreds or 'near isogenic lines'. Duplicate sets which differ in a limited number of DNA bands and a limited number of economic characters can be used to identify tentative markers for the character. By this method a tentative marker for mosaic resistance was identified from a duplicate set. However, this needs confirmation by conventional means. Similarly, a high starch triploid showed intensity of bands for a particular primer and this again can be used as a tentative marker for starch.

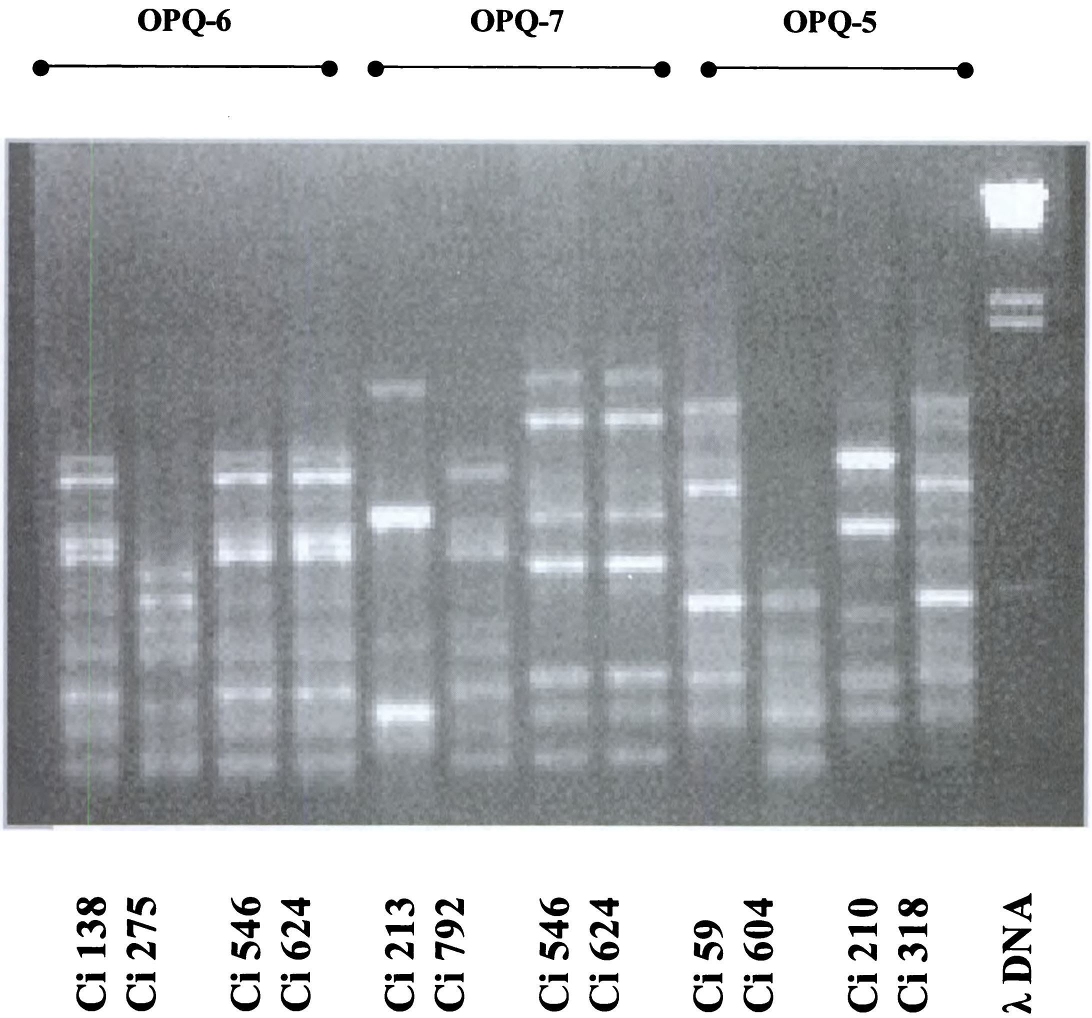

Photo 2. RAPD banding pattern in two duplicate sets based on three primers.

Phylogenetic Studies

The wild species available at the Institute have been analyzed for RAPD patterns and the data is being compared with cultivated varieties to find the genetic relationship and to identify the progenitors.

FUTURE STRATEGIES

Research is being conducted to confirm the tentative markers identified. It is proposed to try the SSR marker, already available for African Cassava Mosaic Disease, for

Marker Assisted Selection. It is also planned to identify molecular markers for drought tolerance using drought tolerant accessions identified from the cassava germplasm collection. The high carotene accessions available in the germplasm will be utilized for identification of gene sequence for β-carotene. Germplasm will be screened for unconventional characters like industrial quality of starch, keeping quality etc., and these again will be utilized for identification of markers and sequencing of the genes. It is also planned to use the 'available genes' for production of transgenics having higher nutritional status, especially protein and iron.

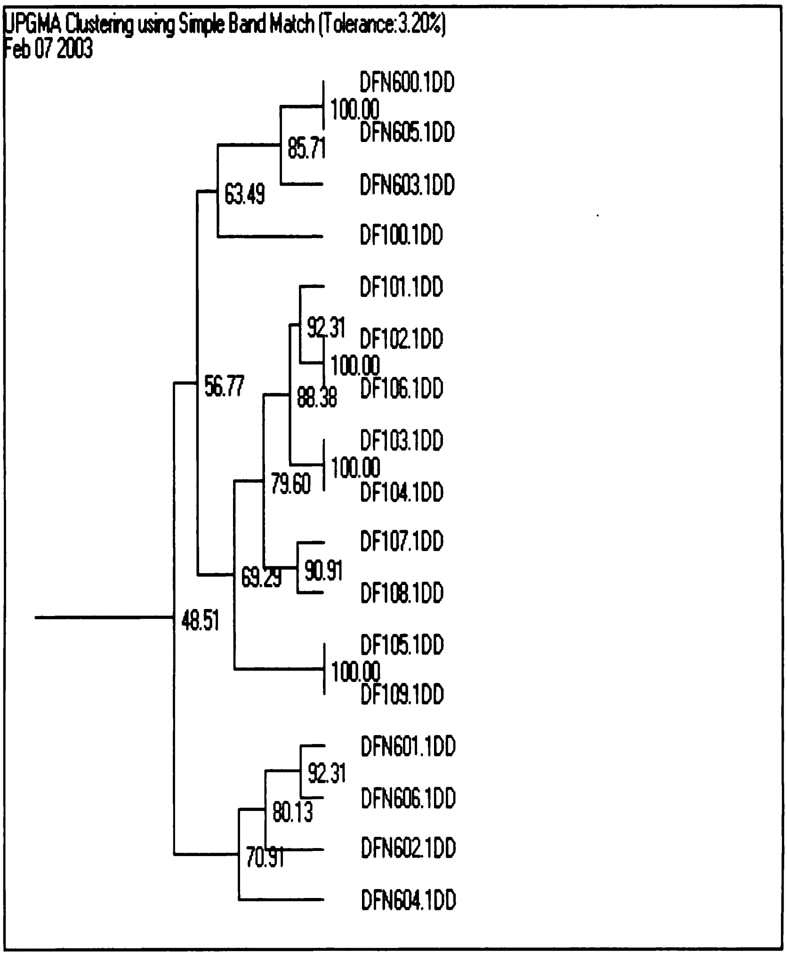

Figure 1. Genetic relation between DNA variants based on dendrogram.

Table 4. Tentative core collection of cassava germplasm at CTCRI, India.

Sl no.	Criteria	No. of accessions
1.	High yield (>5 kg/plant)	30
2.	High starch (>33%)	25
3.	Low cyanogens (<10 ppm)	25
4.	High carotene (>450 ppm)	35
5.	CMD symptom free	75
6.	Popular varieties	20
7.	Released varieties	18
8.	Geographic representatives	4
9.	Wild relatives	9
	Total	**241**

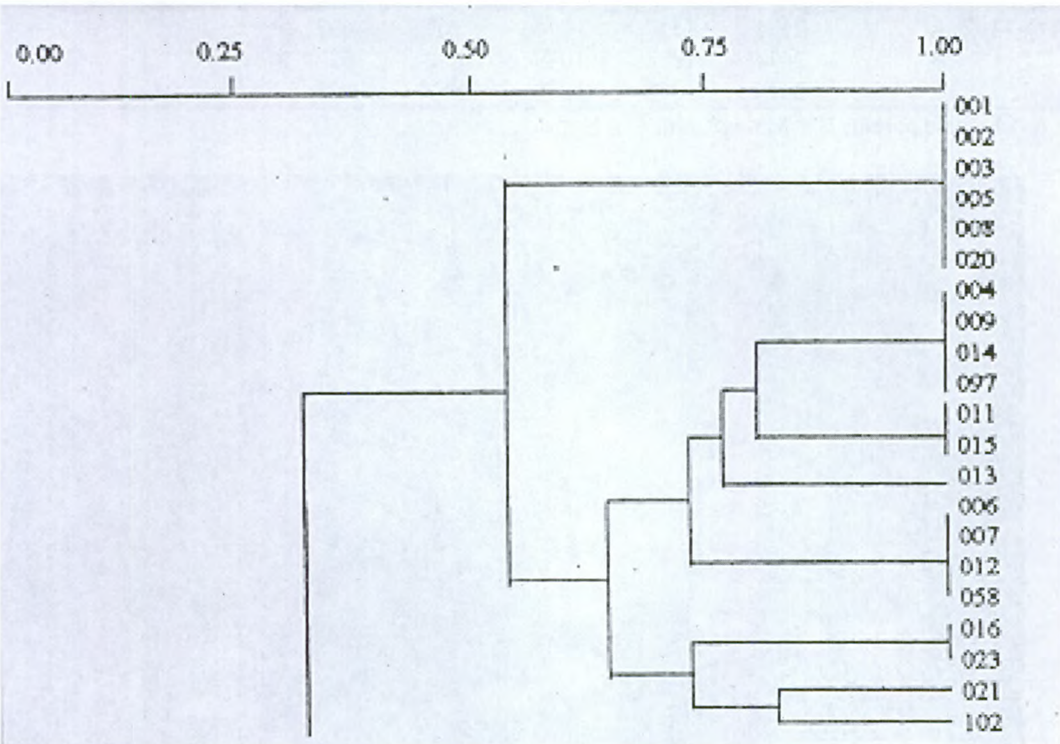

Figure 2. Genetic distance between isozyme variants based on dendrogram.

Table 5. Comparison of DNA base pairs in the hybrid and its parents.

Primer	Genotype	Number and molecular weight of bands							
		1	2	3	4	5	6	7	8
OPQ-10	A[1]	5366	2414	1960	1485	1164	1049	882	716
	B	3300	1893	1591	1248	852			
	C	3300	1893	1591	1248	852			
OPQ-11	A	2252	1537	1248	1013	823	623	472	
	B	4357	2872	1893	1591	1385	1013	716	
	C	4357	2872	1893	1591	1385	1013	716	
OPQ-12	A	2332	1829	1248	1013	913	767	581	
	B	2029	1434	1086	741	581	472		
	C	2029	1434	1086	741	581	472		
OPQ-13	A	2175	1537	1124	767	602			
	B	2414	1338	1049	882	623			
	C	2414	1338	1049	882	623			

[1] A = Female parent; B = Male parent; C = Hybrid

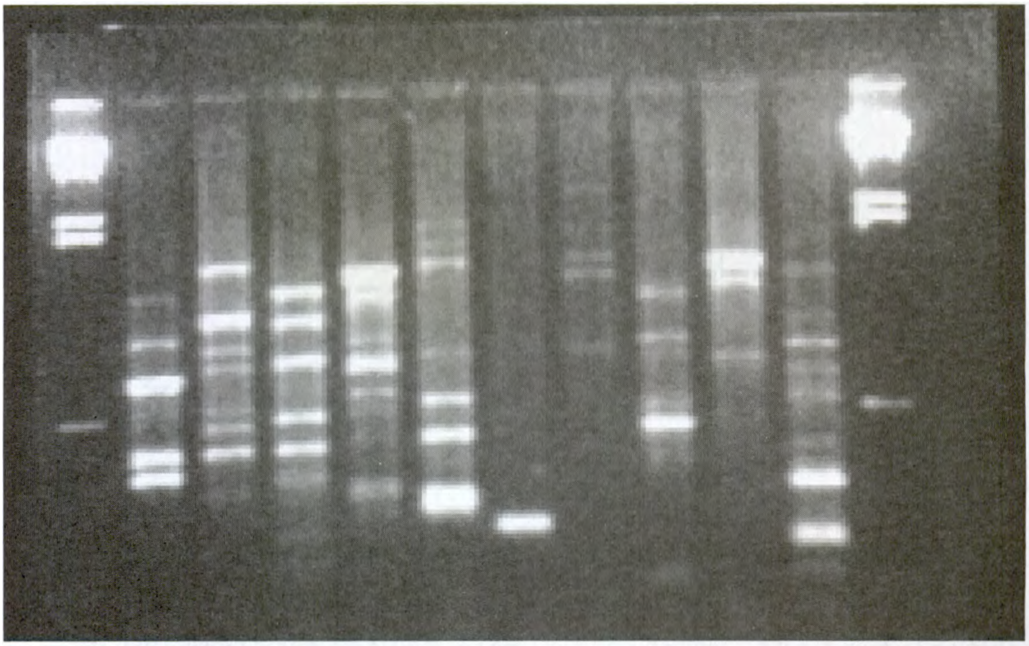

Photo 3. RAPD banding pattern of an elite variety based on 10 primers (Lane no 1 & 12 are DNA markers).

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THE USE OF DOUBLED-HAPLOIDS IN CASSAVA BREEDING

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ABSTRACT

Cassava breeding is difficult and, compared with other crops, inefficient. The problems in cassava breeding relate to the length of the breeding cycle, the large genetic load present in the crop, and the heterozygous nature of the parents and progenies evaluated. The production of doubled haploids, through tissue culture techniques, offers interesting advantages. By definition, any process that involves increased homozygosity will result in a decrease of genetic load. Doubled-haploid lines, therefore, are expected to produce better hybrids. Furthermore, the availability of homozygous lines would allow for a gradual and consolidated breeding to improve parental performance in hybrid combinations. This means that the genetic enhancement will benefit from previous gains, like steps in a staircase. The breeder "*owns*" the genetic superiority of an inbred progenitor but that is not necessarily the case with heterozygous parents. With the introduction of doubled-haploids, the emphasis of cassava breeding shifts from producing large numbers of hybrids (hoping to find a superior one) to improving parents for the production of better hybrids that are *designed*, not just *found*. In addition to these advantages, doubled-haploids will facilitate discovery and exploitation of recessive traits and germplasm conservation. One important additional advantage is that germplasm exchange could be greatly facilitated, thus helping to overcome the relative isolation in which many cassava-breeding projects, in different countries, currently operate.

INTRODUCTION

Cassava improvement has not been as consistent and efficient as in other crops due to many constraints. A typical scheme implies crossing elite clones to produce segregating families **(Figure 1).** Each individual produced is highly heterozygous. Once a superior genotype is identified (a process that requires about six years), it is vegetatively multiplied to take advantage of the reproductive habits of this crop. This system (except for the vegetative multiplication) has similarities with the ones used for autogamous crops (beans, wheat, rice, etc.) as well as for the hybrid maize industry. However, there is a major difference because cassava is never pushed to produce inbred (homozygous) lines from the segregating progenies of a given cross. The system also bears some similarities with recurrent selection used in allogamous crops (maize), but there is a significant difference because in cassava there is not a clearly defined population whose allelic frequencies are modified through evaluation and selection, as in true recurrent selection schemes.

1. Problems and Limitations in Cassava Breeding

From the simplified information provided in **Figure 1**, it is apparent that a major drawback of cassava breeding is also the length of each breeding cycle. For the reasons below, cassava breeding is slow and inefficient:

[1] Cassava Breeding Project, CIAT, Apartado Aereo 67-13, Cali, Colombia.
[2] Former cassava breeder at CIAT. Currently at Weaver Popcorn Company, Indiana, USA.

Pedigree selection[1]	Current system in cassava	Recurrent selection in allogamous crops such as maize	Semester
A x B	A x B	Original cycle (C0) of the population	1
F_1		200 families evaluated	2
F_2		Best 20 families selected and recombined (C1)	3
F_3	A progeny of size "n" is evaluated in successive stages. Simultaneously, the number of plants representing each clone is increased.	200 new families (C1) evaluated	4
F_4		Best 20 families selected and recombined (C2)	5
F_5		200 new families (C2) evaluated	6
F6 ⇒ C		Best 20 families selected and recombined (C3)	7
		200 new families (C3) evaluated	8
C x Y		Best 20 families selected and recombined (C4)	9
F_1		200 new families (C4) evaluated	10
F_2		Best 20 families selected and recombined (C5)	11
F_3		200 new families (C5) evaluated	12
F_4	Best clone selected ⇒ C	Best 20 families selected and recombined (C6)	13
F_5	C x Y	200 new families (C6) evaluated	14

1) Used in autogamous crops and for the production of inbred lines in hybrid crops such as maize.

Figure 1. Illustration (highly simplified) of the differences in breeding systems employed for the genetic improvement of different types of crops.

a. Because no inbreeding is carried out at any stage of cassava breeding, a sizable genetic load (undesirable or deleterious genes) is expected to prevent the crop fully achieving its actual yield potential (Hedrick, 1983).
b. Because there are no clearly defined populations (as defined by quantitative genetics), allelic frequencies cannot be efficiently modified. Cassava breeding in this regard resembles more the selection of segregating progenies from two parental lines in autogamous crops.
c. Because of the highly heterozygous nature of the crop, dominance effects are likely to play a very important role in the performance of materials being selected. The current scheme can exploit dominance effects because, once an elite clone is identified, it can be propagated vegetatively, therefore carrying along the combination of genes responsible for dominance effects (Lamkey and Staub, 1998). However, selection of progenitors for the production of new segregating material is based on their *per se* performance. In that case, the current procedure has a bias because the breeding values of these clones are unlikely to be well correlated with their performance, precisely because of the distorting effects of dominance.

d. Production of recombinant seed is cumbersome in cassava. On average, only 0.6 viable seeds per pollination are produced. It takes about 16-18 months since a given cross is planned until an adequate amount of seed is produced.
e. When a desirable trait is identified, it is very difficult to transfer it from one genotype to another (even if a single gene controlled the trait). The back-cross scheme, one of the most common, successful and powerful breeding schemes for cultivated crops (Allard, 1960) is not feasible in cassava, because of the constant heterozygous state used throughout the breeding process.
f. Maintenance of genetic stocks is expensive and cumbersome. The only proven methods for long term storage of germplasm is through tissue culture procedures (expensive and requires several months to recover plants for planting in the field) or else by maintaining representative plants in the field (expensive when large numbers of genotypes need to be maintained year after year, and also the stocks are vulnerable to gradual contamination by pathogens).
g. The occasional exchange of germplasm among cassava-breeding programs in different countries is restricted to a few plants from few genotypes. Cassava-breeding projects, effectively work in isolated conditions.
h. Lack of inbreeding in cassava implies that there are few opportunities for identifying useful recessive traits, which could have huge beneficial effects on the crop. For instance, acyanogenesis in the roots has been identified as a very desirable trait. It has been postulated that this trait may be recessive. Also worth mentioning are the several starch mutations that are generally recessive in most crops (Neuffer *et al.,* 1997).

These may all be a valid explanation for the limited genetic gains for higher productivity observed in the crop, compared with that of other crops such as maize or rice. It should be emphasized that because the highly heterozygous condition of cassava in every stage of the breeding process, consolidation of genetic gains is difficult, due to the inherent genetic instability of heterozygosity.

From the practical point of view, implementing a traditional recurrent selection method in cassava offers some problems. Pollinations are slow and inefficient. It takes about 16-18 months since a given cross is planned until the recombinant seed is finally obtained (usually field operations have to adjust to the occurrence of the rainy season, and if that is the case, then planting can only be done 24 months after planning the cross). The third year would be used to grow the plant from the botanical seed. During the fourth year, a clonal evaluation could finally be carried out. Therefore a typical recurrent selection method would require no less than six to seven years (**Figure 1**). In this case, however, no self-pollinating for reducing genetic load would have been included.

2. Advantages of Inbreeding

When an elite clone is self-pollinated two important events occur: **a)** the unique, specific combination of genes present in the genotype is broken, therefore losing the agronomic superiority that the clone might have; **b)** self pollination forces an average of half of the loci to become homozygous, thus facilitating the elimination of undesirable, deleterious alleles present in the original clone but hidden because of its predominant heterozygosity. In other words, selfed progenies allow for a reduction of the genetic load originally present in the clone, therefore becoming better progenitors themselves. In a way, selfing allows to "*concentrate*" the desirable genes originally present in the elite clone.

If inbreeding was pursued until near or complete homozygosity, then the transfer of desirable traits through the back-cross scheme becomes feasible. Also, homozygosity "*captures*" genetic superiority because of its inherent genetic stability. Therefore, each cassava improvement cycle would be a consolidated step that could help further progress in a more consistent and predictable way. On the other hand, each time a hybrid is used as parent, the process goes back to the initial step because of the genetic instability of the heterozygous material. In the latter case, progress cannot be easily consolidated or sustained through time, but in a rather inefficient way.

From the quantitative point of view the variability of a given population has traditionally been split into two major components: additive and dominant effects (Bos and Caligari, 1995; Hallauer and Miranda, 1988). Additive effects are very important because they define the breeding value of an individual, that is, its relative merit based on the quality of the progeny they produce. Dominance effects are also very important in plant breeding. They are the main contributors to the heterosis or hybrid vigor observed in hybrid cultivars, including cassava. However, contrary to the additive effects, the dominance cannot be transmitted to the progeny. This means that dominance effects cannot be effectively exploited in a breeding program, unless a sophisticated breeding scheme (reciprocal recurrent selection) is employed (Hallauer and Miranda, 1988).

The current breeding scheme is based on the selection of individual genotypes within half- or full-sib families. **Table 1** illustrates how the total genetic variance and its components (additivity and dominance) are partitioned among and within different types of families. It is clear that all genetic effects will influence the selection of plants from half- or full-sib families. That is, 100% of additive variance and 100% of dominance variance are exploited during the selection process (this is so because the breeder selects the best families, and then, the best genotype within the best family). This is a convenient situation because, once a given clone is selected, both the additive and dominance effects determining its good performance can be perpetuated because of the vegetative reproduction of the crop. The specific combination of genes present in a clone can be maintained unaltered generation after generation, as long as there is only vegetative reproduction.

Table 1. Distribution of additive and dominance genetic variance among and within full-sib and inbred line families

	Among families		Among plants within families	
Type of family	Additive variance	Dominance variance	Additive variance	Dominance variance
Half-sib family	1/4	0	3/4	1
Full-sib family	1/2	1/4	1/2	3/4
Inbred lines	2	0	0	0

***Source:** Hallauer and Miranda, 1988.*

However, only the additive portion of the total genetic variance can effectively be passed on to a next generation when the same clone is used as parent in a breeding project. It is important to recognize that dominance strongly influences the selection of the best clones but has no effect on their breeding value. In other words, dominance effects can be beneficial for the *per se* performance of a clone, but it has a confounding effect of its actual value as progenitor.

Inbreeding is advantageous because it erases the dominance effects from the selection process. The resulting inbred lines do not possess any dominance effects, and therefore, there will be no heterosis or hybrid vigor expressing in their performance. That is precisely why inbred lines are inferior, agronomically speaking, compared with the non-inbred cassava materials. A striking feature of the data presented in **Table 1** is that inbred lines show twice the additive variance originally present. In other words, when selecting among inbred lines the additive variance originally present (among F_2 plants from an F_1-hybrid) has been expanded, thus greatly facilitating the selection process of those additive effects that are precisely the only ones that define a superior progenitor.

Inbred lines are better material for selecting progenitors because, by definition, they carry lower levels of genetic load, no confounding dominance effect influence the selection process and because the additive genetic effects are expanded considerably, making the selection more efficient. Also, if a breeding process is based on the use of inbred lines the transfer of valuable traits is greatly facilitated because the back-cross scheme becomes feasible.

The availability of inbred lines in cassava would also benefit other areas in addition to breeding. Genetic and molecular marker analysis would be facilitated if homozygous lines were produced. The only way to maintain germplasm in cassava is either by growing the plants in the field or by tissue culture. Inbred lines could be maintained and shipped in the form of botanical seed. Phytosanitary problems could be reduced or eliminated if maintenance and/or multiplication of genetic stocks were partially based on botanical seed. Germplasm exchange among the few cassava-breeding projects in the world would be enhanced because it would be based on botanical seed, rather than *in vitro* plants. Finally, clones could be reproduced by sexual means. Although time-consuming, the first stage of evaluation could be based on many plants produced by the crossing of selected inbred lines. Currently, the evaluation process takes three years to reach a stage for selection based in just 30 plants.

3. The Problems of Inbreeding

Cassava, being an out-crossed crop, abhors inbreeding and shows severe depression. As was the case of temperate maize in the early 1900s and tropical maize by the 1970s, cassava will need to be improved for its tolerance to inbreeding depression. A few recurrent selection cycles (selfing each elite clone down to the S_2 level, and recombining the surviving progenies) should prepare elite cassava populations for the trauma of total homozygosity.

A recurrent selection involving the production of inbred lines would be difficult to implement because of the length of each cycle of selection. It is estimated that no less than nine years will be required from the time a group of elite clones are selected until recombinant seed from their inbred lines was obtained. Therefore, if a breeding scheme using inbred lines is to be implemented, a way to reduce the time required for each cycle of selection is urgently needed.

Doubled haploids have been produced and have benefited breeding efforts in many crops (Griffing, 1975). Upon producing an F_1 plant, tissue culture techniques are applied to the reproductive tissue (typically anther culture). This process produces a haploid tissue that, quite frequently, doubles spontaneously to produce the doubled-haploid tissue, which by definition, is homozygous. There are other alternatives for producing similar materials (i.e. using inter-specific crosses). However these methods have seldom been incorporated as a routine tool in breeding projects.

If an efficient protocol for the production of doubled-haploids were available, it could be incorporated into the cassava-breeding process with the advantages that inbred lines offer as explained above. From the practical point of view the protocol for the production of doubled-haploids would allow shortening the time required to produce hybrids from inbred lines down to three years.

4. Expected Responses to Selection with Alternative Breeding Methods.

Breeding projects always search for maximizing the gains from selection. The genetic progress (GP) after one cycle of recurrent selection can be estimated as follows (Hallauer and Miranda, 1988; Simmonds and Smartt, 1999):

$$GP = i\ N^2_A/N_F$$

where ***i*** is a factor related to the intensity of selection (proportion of the population selected to be parent for the next cycle); N^2_A is the additive component of the genetic variance measured in the parental population and N_F is the phenotypic standard deviation of the parental population. These N^2_A and N_F parameters will vary depending on the selection unit used (i.e. individual plant, mean family performance, mean of clones across replicated trials in different locations, etc.).

In turn, the N_F can be defined as:

$$N_F = \sqrt{N^2_A + N^2_D + N^2_E}$$

Where N^2_A and N^2_D are the additive and dominance components of the genetic variance and N^2_E is the environmental effect of the evaluation of the respective selection unit. It should be clear that to increase GP there are only few alternatives: a) increase the value of *i* (that is, increase the selection intensity); b) increase the additive component of the genetic variance exploited by selection; and/or c) reduce one or all components of the phenotypic standard deviation. Changes in the selection intensity do not depend on the breeding scheme employed. On the other hand, the proportion and magnitude of the additive component of the genetic variance exploited and the size of the phenotypic variance depend heavily on the breeding method implemented, as illustrated below.

The phenotypic standard deviation in phenotypic mass selection is very large because of the environmental component associated with single plant evaluations. In the clonal selection used in cassava, although single genotypes are selected (as in mass selection), the environmental variance is reduced because "*n*" plants representing the genotype are used in the evaluation and selection process. However, all the dominance effects remain as component of the denominator of the formula. Therefore, clonal selection would maximize GP when dominance effects are negligible, which is not the case of cassava.

When doubled-haploids are used, two important modifications are introduced into the formula for GP: a) the additive component in the numerator and denominator of the formula is now twice as large as before (but in the denominator the square root of the additive component is used); and b) the dominance component of the phenotypic variance disappears.

$$GP_{(\text{Phenotypic mass selection})} = \frac{i\,N^2_A}{\sqrt{N^2_A + N^2_D + N^2_E}}$$

$$GP_{(\text{Clonal selection})} = \frac{i\,N^2_A}{\sqrt{N^2_A + N^2_D + (N^2_E/n)}}$$

$$GP_{(\text{Doubled-Haploids selection})} = \frac{i\,2\,N^2_A}{\sqrt{2\,N^2_A + (N^2_E/n)}}$$

The information provided illustrates the advantage of clonal evaluation over phenotypic mass selection. It also suggests that selection based on doubled-haploids would be better than the clonal evaluation (based on F_1s) traditionally used for cassava breeding. However, because of the inbreeding depression observed in this crop, doubled-haploids would perform very poorly compared with the full vigor clones (F_1s).

It is difficult to make a fair comparison between the traditional and the new proposed scheme, because the latter introduces an intermediate stage when selection in the homozygous stage is conducted on the *per se* performance of the doubled haploids. This is the point where twice as much additive variance can be exploited. The second stage in the new scheme would be reconstituting the dominance effects in a controllable and predictable way, by crossing specific pairs of doubled haploids lines. Hybrids developed from inbred cassava clones should perform better than current hybrids because: **a)** the elimination of deleterious genes through homozygosity; **b)** easier identification of "complementing parents" for the production of hybrids with maximized heterozygosity or hybrid vigor (dominance effects); and **c)** the possibility of building up, over several recurrent selection cycles, the dominance effects.

5. A Breeding Scheme Based on Inbred Cassava Lines

A drastic change in the way cassava breeding is achieved should be introduced for taking advantage of the benefits of inbreeding. **Figure 2** illustrates the general features of the proposed scheme.

Months	Activity	Action
0	Elite clones are selected and planted	
6-8	Plants from elite clones start to flower	
24	**DH** obtained from selected clones. Ten vitro-plants per **DH**	N^2_A increases and N^2_D disappears from differences among clones
34	**DH** evaluated for many agronomic traits based on *per se* performance	Selection operating in $2N^2_A$
52	Seeds from crosses among selected **DH** obtained (no less than 10 seeds/cross)	A controlled recovery of N^2_D
62	Selection of F_1 crosses based on 10-plants plots in target environments	Selection on high-h^2 traits and multiplication of planting material
68	Planting of nursery for next cycle of recurrent selection	Shortening of the duration of each selection cycle
74	Evaluation and selection of hybrids from **DH** lines based on 100 plants	Selection for dominance effects (heterosis) and low-h^2 traits
74	Best **DH** lines selected and heterotic patterns among them identified	Capture of genetic superiority (including that from dominance)
84	Seed from crosses to further improve **DH** lines obtained	Initiation of a new cycle of (reciprocal) recurrent selection
0	Beginning of a new cycle of selection	

Figure 2. Illustration of a breeding scheme based on the production, evaluation and selection of doubled-haploid (DH) cassava lines to exploit additive and dominance effects in the production of superior hybrid clones.

1. Production of doubled-haploid (DH) lines

The process starts with the selection of elite clones themselves or after improvement for tolerance to inbreeding following the S_2-recurrent selection described above. Once the planted material begins flowering, tissue will be taken for the induction of doubled haploidy through tissue culture protocols developed specifically for that purpose in cassava.

Upon the production of DH tissue or embryos, *in vitro* multiplication of each line will be carried out, to produce at least ten hardened plants ready for transplantation to the field. This would take place at the end of the second year of activities.

2. Selection of doubled-haploid lines

Several DH lines will be produced and the ten plants representing each of them will be planted in a *Clonal Evaluation Trial* in the proper target environment. Hopefully these trials will involve at least 200 DH lines. Selection of these lines will be conducted for relevant characteristics with moderate to high heritability: resistances to diseases and/or insects, plant architecture, root dry matter content, root and parenchyma color, harvest index, etc. The selection at this stage operates with twice the additive genetic variance expected to be found in the original population under random mating conditions. Therefore, it is expected that large contrasts will be apparent at this stage. Lines surviving to this stage will have, by definition, reduced genetic load compared with the elite lines from which they originated.

While the field evaluation is conducted, lab analyses can be simultaneously carried out to obtain the molecular fingerprinting of each line. This will allow for further selection of characteristics difficult or impossible to determine from the field trials. For instance, marker assisted selection for CMD (Cassava Mosaic Disease) could be implemented in Colombia, although the disease is not present in that country. Also genetic distances among the lines could be determined to facilitate the following stage within the recurrent selection cycle.

3. Production of hybrids from selected DH lines

The following stage in the selection process involves the production of hybrids among the surviving DH lines. It is expected that from the 200 or more DH lines at least 30 will reach this stage. Although it is clear from the literature that genetic distances have failed to explain satisfactorily the heterosis among inbred lines in maize (Lamkey and Staub, 1998), genetic distances measured through molecular markers can be used at least to orient the crosses that deserve some priority. This could be justified until an adequate definition of heterotic patterns is eventually reached. Since the parental materials (DH lines) are homozygous just a few seeds per cross are required at this stage. The only justification for obtaining more than one seed would be to accelerate the time required for evaluation with a large number of plants representing each hybrid or clone.

With the production of hybrids from the selected DH lines, dominance effects (heterosis) are generated and, because of the breeding scheme proposed, will be fully exploitable by the cassava-breeding project.

4. Evaluation of DH-derived hybrids

Depending on the number of hybrid seeds produced in the previous stage, the evaluation and selection of hybrids can be conducted in two successive steps or just one growing cycle. In **Figure 2** it is assumed that only ten plants from each cross can be obtained from botanical seed, and therefore that the evaluation and selection is conducted in two consecutive growing cycles.

The *first selection* is performed on all the hybrids produced and based on the 10 plants representing each hybrid clone. Because there is no replication, selection will be based only on high–heritability traits, and in the proper target environment, to allow for the pressure from biotic and abiotic limiting factors. The same evaluation plots are used as seed multiplication plots.

The *second stage* of selection and evaluation is conducted with about 100 plants (i.e. two replications at two locations with 25-plant plots). Only hybrids that survived the selection process the previous year will be included in this evaluation. Low-heritability traits are incorporated as selection criteria at this stage. Only a few clones will survive this selection and they will be included in *Regional Trials* for their eventual release as has been traditionally done up to now.

5. Preparation of nurseries for next cycle of recurrent selection

While the evaluation of hybrids is conducted, their parental **DH** lines will be planted in the field in such a way that they are about six month old when the results of the hybrid trials become available. As soon as the hybrid trials yield results regarding the best **DH** progenitors, they will be crossed to generate new genetic material for the following cycle of selection. The only purpose of these crosses will be to generate F_1 plants from which to extract flower tissues for the production of a new generation of **DH** lines.

Hybrid trials will not only generate elite clones to be included in *Regional Trials* and eventually be released as new varieties, but also provide important information about the **DH** lines that generated the hybrid clones. This information will be used to determine lines with good general combining ability (i.e. that generate progenies with performances that are better than the mean of all the hybrids evaluated) as well as detecting heterotic patterns. This information is fundamental for deciding the kind of crosses that will be made for the next selection cycle.

6. Advantages of the proposed scheme

The capacity to produce inbred lines in cassava through the use of a dynamic process allows to drastically change the breeding process:

a) the emphasis will shift from producing vast numbers of hybrids hoping that one (or few) will be genetically superior, towards the production of parental lines that will allow *'to design'* outstanding hybrids in a gradual, consistent and reliable fashion
b) genetic loads will be quickly reduced in elite cassava populations

c) hybrids produced from inbred lines will be better than hybrids produced from non-inbred progenitors because genetic load is reduced and because the system allows building up dominance effects
d) germplasm exchange will be greatly facilitated (botanical seed of outstanding parents) with obvious advantages for the cassava research community
e) gene exchange will also be greatly facilitated (currently it is very difficult to transfer one valuable gene from its source into an agronomically superior clone: the availability of inbred lines would make the back-cross scheme feasible for cassava)
f) inbred materials are genetically stable, they allow the breeder to capture and efficiently exploit the genetic superiority contained in them, therefore, guaranteeing a sustainable and consistent genetic progress that cannot be observed nowadays
g) once a given combination of inbred lines is found (good performing hybrids) the same genotype could be produced at first using botanical seed, and from there by vegetative means. This implies not only a faster multiplication rate but also cleaner genetic stocks (from the phytosanitary point of view)
h) the system allows for the identification of useful recessive traits.

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MICRO-PROPAGATION OF CASSAVA PLANTS THROUGH THE TEMPORARY IMMERSION SYSTEM AND HARDENING OF MASSIVE NUMBERS OF CASSAVA VITROPLANTS

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ABSTRACT

Tissue culture is a technique widely used for propagation of plant material. This method has been used successfully to propagate species such us cassava, sweet potato, plantain and sugarcane. Recently, the development of techniques such us the Recipient for Automated Temporary Immersion (RATI) and Temporary Immersion System (TIS) have improved significantly the efficiency of tissue culture propagation methods.

The RATI and TIS techniques were originally developed in France and have been tested successfully in countries such us Cuba with cassava and other species. The use of these methods is helping research institutions to advance in the production of massive numbers of plants. However, one of the main limitations for a wider use of these techniques is the hardening period during which the explants have to be adapted to normal conditions, before its final transplanting to the production sites. This change of the conditions in which the plants are growing usually causes high death percentages in the plants produced with the *in vitro* multiplication systems.

CLAYUCA, in collaboration with CIAT, has done some work for the development of a methodology for the hardening phase of massive numbers of vitroplants. The present paper describes these experiences, discussing the different stages of a successful methodology developed for handling large numbers of *in vitro* plants produced with the help of biotechnology-based multiplication systems.

INTRODUCTION

Important advances have been obtained in recent years in the development of improved, higher yielding cassava varieties. This new cassava germplasm is helping farmers to obtain higher incomes and to improve their economic well-being. Despite the advances obtained in breeding efforts, one of the most important constraints for a more widespread use by farmers of the improved cassava varieties is the lack of planting material, in larger quantities, at the right moment and with the desired quality characteristics.

The use of biotechnology-based methods for rapid multiplication of improved varieties is one of the strategies that is helping to solve this limitation. One of the most important biotechnological methods available is the one known as Recipient for Automated Temporary Immersion, more popularly known as the RATI system. With the use of RATI systems for multiplication of cassava planting material, researchers at CIAT have been able to obtain very good multiplication rates, varying between 5 to 10, depending on the variety (**Table 1**).

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Table 1. Cassava multiplication rates with the RATI System.

Clones	Initial no. of explants	Total no. of explants	Multiplication rate
CM 3306	10	101	10.1
CM 523-7	10	106	10.6
MTai 8	10	61	6.1
MCol 1505	10	53	5.3

Source: *Escobar, 2001.*

The importance of these methods is the possibility of producing massive numbers of plants in very short periods of time. **Figure 1** illustrates the potential of these systems for producing millions of plants of a given crop. It can be seen that with a multiplication rate of 4 to 1, using cycles of 4 to 6 weeks, it is possible to produce up to 75,000 plants in one year.

Time (weeks)	0	6	12	18	24	30	36	42	48
Initial no. of plants	10	40	152	580	2,204	8,375	31,826	40,938	35,564
Final no. of plants (assumes 5% losses)		38	.145	551	2,094	7,956	30,234	38,890	33,786

1st exit of 20,000 plants ↓

2nd exit of 30,000 plants ↓

3rd exit of 25,000 plants ↓

——Hardening facilities——

Figure 1. Multiplication rates with in vitro production systems.

The main limitation for a more widely disseminated use of these methodologies is the period of adaptation of the vitroplants after they have been multiplied. This phase, better known, as the "hardening period" is frequently associated with high percentages of losses from death of the vitroplants. The plantlets produced by such systems are like test-tube babies – weak, and fragile – after 6 to 11 months under artificial conditions of light, temperature, moisture, and nutrients in sterilized rooms. Consequently, they need to undergo a stage of acclimatization or hardening before they can be transferred to their final site. In cassava, this process is very delicate, becoming a bottleneck in the mass production of cassava planting materials through tissue culture. This paper describes some recent experiences of CLAYUCA and CIAT for the development of a methodology for post *in vitro* management of cassava planting material.

A. Hardening Process of Cassava Plantlets

Hardening large numbers of cassava plants that have been produced with the use of biotechnology-based methods such us RATI, is a process inevitably associated with losses. Most losses of plantlets occur during the transfer to the soil, that is, when the plantlets are moved from the artificial environment of test tubes to the natural soil, and must adapt to new microclimatic conditions. Where the transfer is not carried out with adequate management and handling, the percentage of losses can be very high (between 50% and 95%), thus limiting the adoption of the improved *in vitro* multiplication methods. It also discourages progressive farmers who may want to produce rapidly and safely disease-free planting materials, or to multiply massively a new promising variety over a short period. Other drawbacks of the hardening process are the cost and size of the installations needed, such as greenhouses and screenhouses.

Stages of the Hardening Process (HP)

A good, efficient hardening process includes at least six different stages:.

Stage 1: Pre-operational activities

The normal development of an HP demands prior planning that includes a detailed timetable of all activities involved, including:

a. Selecting and training personnel
b. Selecting and adapting installations
c. Laboratory tests
d. Acquiring equipment, materials and inputs
e. Requesting the biotechnology laboratory for the number of *in vitro* plants that can be "hardened" per week.

a. Selecting and training personnel

Labor should be qualified; if not, personnel should at least receive training on the basic aspects of HP. The number of workers needed depends on their experience and on the quantity of plants entering the process: a novice worker can handle about 200 plants per day and an expert up to 600.

b. Selecting and adapting installations

Two principal installations are used: the work area and a screenhouse or greenhouse (sometimes both).
The work area comprises the following spaces: a deposit for soil and sand, a mini-store for keeping materials and inputs, a soil surface for mixing, and a cool site for transplanting. This space should be protected from solar rays and strong winds, and should have, in addition, a washing area and a working table **(Photo 1)**.

The screenhouse should have a roof, and be adapted for automatic climate control (**Photo 2**). It should have microsprays , suspended either over the tables or from the roof and installed along the floor to control the temperature and relative humidity, especially in the first days of the hardening process. Although bright lighting is needed to favor plantlet development, the morning, mid-day, or afternoon sun should not be allowed to reach directly the plantlets during the first eight days of acclimatization. Accordingly, a protective screen can be installed. The best option for protective screen according to CIAT experience is the Polypropylene meshing ("Saram"), covered on the outside with several sheets of aluminum paper (each 30 cm wide), and separated at 5-cm intervals. The screen should be highly functional, installed on both sides of the screenhouse (to face sunrise and sunset), and reaching 1 or 2 m above the tops of the bags in which the plantlets sit. It should manually be withdrawn gradually, as the sun traces its path through the sky to let light enter the installation. The aluminum reflects the sun's rays and prevents heating of the area where the plantlets are being hardened. The maximum temperature within a screenhouse fluctuates between 33° and 38°C, and the minimum between 18° and 22°C.

The Greenhouse should have an automatic microspray irrigation system. Both in the greenhouse and screenhouse, the system should be controlled with a solenoid valve and control clock. The system saves 90% of the costs of labor needed to irrigate the plantlets.

Space for acclimatization. In both the screenhouse and greenhouse, the transplanted plantlets should occupy a space that needs to be increased by as much as three times as the plants grow for 2 or 3 months after transplanting, depending on the variety, and its stage of development. For example, to plant one hectare of cassava, using 10,000 plants, the greenhouse or screenhouse space needed initially is an area of 25 to 34 m^2. Two months later, these 10,000 plants will need an area of 50 to 68 m^2.

c. Laboratory tests

The soil, sand, and water to be used in the installations should first be analyzed chemically and biologically to correct potential problems.

d. Acquiring equipment, materials and inputs

To acclimatize the cassava plantlets, the following elements are needed:

- Soil mill, sieve and mixer; sterilizer; fumigator; protective equipment for fumigation of pesticides
- Test tubes, balance, flask washer, scissors, plastic or bamboo trays
- Broad container (e.g., tray) to receive plantlets with agar that have been extracted from their flasks
- Bucket, spade, wheelbarrow, and garden spades; hose and irrigator.
- Black plastic bags (7 × 14 cm) with perforations for drainage, and transparent plastic bags (1 × 1 m)
- Field book, registration forms, indelible marker, pencil; plastic mini-stakes for identification

To prevent possible contamination of plantlets, all implements to be used should be disinfected. For example, if roots or leaves are cut with scissors, these should be disinfected in a soapy solution every time a cut is made.

e. Requesting from the biotechnology laboratory the appropriate number of plants that can be hardened

There needs to be good coordination between the number of plantlets that are requested from the *in vitro* multiplication facility and the space available. The ideal situation is to minimize as much as possible the period of time during which the vitroplants are kept before transplanting them to the soil. Experiences obtained by CLAYUCA and CIAT indicate that it is feasible to acclimatize approximately 302 cassava plantlets per square meter of useful area of greenhouse or screenhouse.

Stage 2: Operational or technical activities

The success of an HP depends on the comprehensive management of a series of operations, starting from the reception of vitroplants up to their transplanting to the field.

a. Receiving in vitro plants

The vitroplants coming from the biotechnology laboratory are usually delivered in boxes containing flasks. Upon arrival, the plantlets are quickly removed from the boxes and placed, at intervals, in a cool place with artificial lighting or indirect sunlight. They are then counted and their numbers recorded according to variety (**Photos 3** and **4**).

In this step, a **pre-selection** is also carried out, consisting of separating the flasks according to the *in vitro* plants' height and vigor and eliminating those observed as contaminated, broken, abused, or malformed.

b. Pre-adapting the plantlets

If the *in vitro* plants have spent several days being transported in closed boxes, the flasks are placed as indicated previously, but left until the plantlets recover. Or, the *in vitro* plants can be left for 1 or 2 days in the installations where they will be submitted to HP. This period also offers the opportunity of making a second pre-selection for vigorous *in vitro* plants.

c. Preparing the soil substrate

To prepare the substrate in which the plantlets will be grown, one part of black soil (i.e., from the non-clayey arable layer) that has been milled and sieved is mixed with three parts of coarse sand that has been washed and sieved (**Photo 5**). The substrate should be "sterilized" with steam where the presence of nematodes and fungi is suspected (**Photo 6**). If no sterilization equipment is available, then:

- The sand can be placed in a metal pipe or drum, with sufficient water added, and the whole heated to 100°C.
- To sterilize the soil, a thin layer is spread over black plastic, covered with another, but transparent, plastic, and a hermetic seal made between them both. The soil is left for one week under full exposure to the sun.

d. Preparing for transplanting

Before transplanting, the installations should be disinfected, the small bags for the *in vitro* plants filled with substrate, the mixture of fertilizer and fungicide prepared, and the trays and large bags made available for further use in miniature humidity chambers.

Likewise, personnel should be re-trained in transplanting. This exercise will verify the personnel's productivity: usually, a skilled technician transplants about 600 plants on a working day and a beginner about 200 plants.

Disinfecting and cleaning the site. All the installations should be disinfected with sodium hypochlorite and rigorously disinfested. The equipment and implements should be organized in their places. Cleaning should be extended to the site where transplanting will be done and to the screenhouse or greenhouse where the plantlets will be hardened.

Preparing the bags. Either black or transparent plastic bags (7 × 14 cm) are filled with the previously prepared mixture of sand and soil (see above) to three quarters their volume. The mixture is firmly compressed into the bag to obtain a compact substrate. Such compaction will later stimulate root production, making the roots longer and thicker.

Preparing the trays. The bags containing the already compacted substrate are placed on the trays and the following solution is prepared:

- In 1 liter of deionized water (or rainwater) mixed with 1 g of a fungicide that controls soil fungi (e.g., Banrot) and 2 g of a fertilizer rich in phosphorus (e.g. formula 10-52-10).
- Immediately irrigate each bag with 10 cc of this mixture (first irrigation).

Preparing humidity chambers. The base of each tray is introduced into a bag of transparent plastic (1 × 1 m when folded) that has been rolled down, concertina style, to its base (**Photo 7**). Later, the bag can be quickly unfolded upwards, and its mouth tied firmly (**Photo 8**). The setup will then function as a "humidity chamber".

Stage 3: Transplanting

Transplanting is a very "traumatic" stage for the plantlets, especially when it is carried out by unqualified or inexperienced labor. Plantlets undergo microclimatic stress when moved from their flasks to the miniature humidity chambers, suffering dehydration and nutrient stress, as they change from a substrate rich in nutrients to one that is very poor (soil/sand mixture); and almost unavoidable mechanical damage to several parts of the plantlet (e.g., root cap, absorbent hairs, roots, stem, and leaves). The success of the plantlets' acclimatization and survival depends on the care with which transplanting is done.

Transplanting must be done immediately after the *in vitro* plants are extracted from their flasks. Transplanting activities include:

a. Selection

A first selection is carried out, choosing those flasks with the most vigorous plantlets, that is, colored an intense green, standing erect, and between 5 and 7 cm tall.

b. Extracting the in vitro plants

This operation consists of:

- Removing the plastic tape and flask covers. Adding deionized water or rainwater to the flask to moisten the agar substrate and facilitate extraction of the whole (plantlet + agar)
- Holding the flask in one hand while gently smacking the flask with the other to loosen the agar from the flask's walls. If it does not separate, a spatula is used, taking care not to damage the roots
- Carefully extracting the plantlet by inclining the flask; tweezers are not used because of the risk of damage to the stem
- Placing the plantlet in a broad container such as a deep tray containing deionized water or rainwater, which is gently moved by hand to dislodge the agar
- Gently removing the particles of agar that still adhere to the roots with the flask washer
- Carrying out a second selection of vigorous plantlets to eliminate small, poorly formed, or weak plantlets

c. Transplanting into bags

With one hand, a plantlet is taken to a bag, introducing the roots and lower part of the stem. This hand must be held rigid to prevent breaking the absorbent hairs and roots. With the other hand, the fourth part of the substrate is added, ensuring that the roots remain in their "normal position", as they were in the flask, thus preventing either physical or physiological damage caused by change of position.

Once transplanting has been achieved for all the bags in the tray, the plantlets receive a second irrigation with 10 cc of the mixture of fertilizer and fungicide used previously.

d. Humidity chambers and hardening

The following steps start the real process of hardening the plantlets:

- The tray is marked with a label on which appear the variety's name, number of bags, date and hour of transplanting, and the transplanter's name.
- The large transparent bag (1 × 1 m) in whose bottom the tray had been placed is unfolded, and its mouth closed by tying with a string. Each large bag then becomes a humidity chamber.
- The humidity chambers are then transferred to the site in the installation where HP will be carried out. To prevent the upper part of each chamber from lying on top of the plantlets and damaging them, the cord is tied to a wire strung over the chambers.

Stage 4: Maintaining the transplanted plantlets

In this stage, considerable attention must be given to the microclimatic changes occurring within the installations, the irrigation the plantlets require, their nutrition, and the presence of pests and diseases.

The bags containing the plantlets should not be moved during the first month after transplanting so as not to cause root damage, especially to the cap and absorbent hairs. These parts are particularly fragile in this early stage of development. Damage or breakage in radical tissues increases the probability of pathogen invasion and of slowed growth and development. Such care also assumes considerable importance in Stages 5 and 6 of the HP.

a. Microclimate and humidity chambers

Between days 8 and 12 after transplanting (DAT), the string closing the humidity chamber is removed—if possible in the afternoon —and the large transparent bag is opened up completely (**Photo 9**).

- The goal of this operation is to enable the plantlets to adapt to the microenvironment of the installations.
- If a tendency to wilting is observed, the bag should be re-closed and the humidity chamber treatment continued.
- If the plantlets have adapted well to the microenvironment by the second or third day after opening the large bag , the bag is rolled down to the tray's base or removed altogether, leaving the tray with its plantlets. During this step, the plantlets must be protected from strong dehydrating winds (**Photo 10**).

b. Irrigation

If the plantlets have been irrigated with the correct quantity of nutrient solution and the environment within the miniature humidity chamber properly formed, the plantlets will not need further irrigation.

However, if, and only if, the first symptoms of physiological wilting are presented in plantlets after being removed from the humidity chamber, the substrate receives the third irrigation. To reduce risk of attack from pathogens, care is taken not to wet the leaves. Each plantlet is irrigated with 10 cc of a nutrient solution consisting of a mixture of 2 g of fertilizer rich in phosphorus to promote root formation (e.g., formula 10-52-10) and 1 g of Agrimins (a fertilizer rich in micronutrients) per liter of deionized water (or rainwater).

According to the microclimatic conditions of the installations and the state of appearance of the plantlets, one or two daily irrigations can be programmed, each with 10 cc of water normally used to irrigate other plants. Between 21 and 25 DAT, a microspray irrigation (MSI) system should be implemented in the screenhouses, thus significantly reducing labor costs. At CIAT, the plantlets are given from 2 to 3 minutes of MSI in the morning and, if necessary, another 2 or 3 minutes in the afternoon (**Photo 11**).

- When MSI is applied, rigorous inspections must be made to detect any phytopathological problem in the plantlets.
- The "secret" of this operation, which is crucial to the success of HP, is in applying irrigation when the first symptoms of physiological wilting are observed. Thus, the substrate will not remain too moist and thus promoting possible pathogen attack in the roots. It is important to remember that, at this stage, cassava plantlets are highly susceptible to excess moisture in the substrate.

c. Fertilizer applications

The substrate used (1 part of soil and 3 parts of sand) is of low fertility, and a program for fertilizer applications is thus indispensable. Every eight days, the plantlets will receive applications of macro- and micro-nutrients so they may develop normally.

A compound rich in phosphorus is first applied to favor root development (e.g., formula 10-52-10). This application is alternated (at 8-day intervals) with a complete fertilizer containing macro- and micro-nutrients. If formula 10-52-10 is not available on the market, it can be replaced by combining formula 10-30-10 and Agrimins. Fertilizer application is suspended when the plantlets' color is normal for the varieties to which they belong (**Photo 12**).

If symptoms of a nutrient deficiency are observed, the affected plantlets can be given a foliar fertilizer application containing simple or complete fertilizers. One deficiency that tends to appear in plantlets during the first month is that of zinc, which can be corrected by adding the element to the soil in one of the irrigations, at a rate of 3 g of Zn SO_4 dissolved in 1 liter of water and the solution applied at 10 cc per plant.

Stage 5: Separating the plantlets

Between 30 and 34 DAT, the plantlets need more light and higher temperatures for growth and development. Accordingly, the plants are placed more widely apart in an area that is double or triple the one occupied initially (**Photo 13**).

Stage 6: Transplanting to the field

The plants remain in the mesh house or greenhouse for 70 to 90 days before being taken to the field.

Transfer

On transporting the bags from the greenhouse (or mesh house) to the field, the plantlets must be protected from strong air currents that could cause abrasion or dehydration (**Photo 14**).

b. Adaptation and final transplanting

The plants should be brought together in a large group within the site chosen for planting and left for 3 to 6 days so that they may adapt to the new environment. The plants are then transplanted to their final sites in the field (**Photo 15**). For the next few days, the farmer should watch out for the appearance of any nutritional deficiency or presence of pests or diseases, and apply the corresponding integrated management. In cases when the transplanting is done in the dry season, the plants need to be irrigated. Some weeks after the transplanting operation, the plants are adapted to their new conditions and will continue to grow until they reach maturity (**Photo 16**).

CONCLUSIONS

1. Hardening of the plants that have been produced through *in vitro* methods is a very delicate phase during which plants need to receive special care and maintenance.
2. Handling large numbers of plants that are coming from a biotechnology laboratory is a process that demands time, specialized labor and resources. This process ends when the plants are already established. Up to this moment, the unit costs of producing each plant could be considered relatively high.
3. The main advantage of the hardening method is that it gives farmers the opportunity to obtain a first harvest of a given cassava variety which the farmer wants to plant in large areas. With the vegetative planting material obtained in this first harvest, the farmer can start to establish his commercial fields.
4. Another advantage of the availability of a safe method for hardening cassava vitroplants is that it allows research and technology transfer institutions to multiply

varieties that have desired traits, in massive amounts, to facilitate the dissemination of improved varieties.

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Photo 1. Work area.

Photo 2. A screenhouse useful for hardening vitroplants.

Photo 3. A box containing 50 flasks and 200 cassava plantlets

Photo 4. Plantlets just removed from box and kept in a cool place with indirect sunlight.

Photo 5. Preparation of the substrate for transplanting the plantlets.

Photo 6. Steam sterilization of the substrate to avoid the presence of nematodes.

Photo 7. The tray placed inside the plastic bag.

Photo 8. The tray and the plastic bag acting as "humidity chambers".

Photo 9. Opening the humidity chamber.

Photo 10. Transplanted plants after the plastic bag is completely removed.

Photo 11. Microspray irrigation helps to maintain good quality plants during hardening phase.

Photo 12. A fertilization programe is essential to obtain healthy plants.

Photo 13. Plants in final stages of hardening process demand wider spaces, more light and higher temperatures.

Photo 14. Hardened plants ready for transfer to the field.

Photo 15. Transplanting hardened plants.

Photo 16. An established field with hardened plants.

CASSAVA AGRONOMY RESEARCH AND ITS CONTRIBUTION TO A SECURE FOOD SYSTEM IN INDONESIA

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ABSTRACT

Cassava production in Asia is projected to grow at an annual rate of 1.95% from now to 2020, while cassava production in Indonesia during the past ten years increased at a rate of 0.8%. Since 67% of cassava production in Indonesia is used for human food, the growth in cassava production should be higher than that of the population. Rice is the main staple food, but its production growth over the past ten years has stagnated. Increasing cassava production for food diversification would be a way to help achieve food security in the country. Most cassava production areas in Java island are located on soils classified as Inceptisols, while cassava soils outside of Java are generally Ultisols. Average cassava yields of about 12.2 t/ha of fresh roots are much below the potential yield obtained in experiments, which ranges from 20 to 40 t/ha. Therefore, there is still a potential to improve production technologies so as to increase yields and food security, as well as farmers' income. Most areas where cassava is grown in Indonesia have relatively infertile soils. Agronomy research that focuses on maintaining or improving both soil fertility and cassava productivity will be discussed.

INTRODUCTION

By 2020 over two billion people in Asia, Africa, and Latin America will use roots and tubers for food or feed, or as a source of income (CGIAR, 2000). In Indonesia the main staple foods are rice, maize, cassava and sweetpotato. Demand for rice and cassava as food are about 48 million tonnes dry grain and 11 million tonnes fresh roots, respectively; that for maize and sweetpotato are less than those for rice and cassava (CBS, 2000).

In Indonesia rice production during the last ten years has stagnated. Maize production satisfies only 60% of demand, while cassava demand for food during the last five years has increased about 20% (CBS, 2000). This indicates that cassava will be more important as a food security crop. As cassava production has increased during the last ten years at about 0.8% per year, that growth rate will need to be increased to 1.95% per year according to CGIAR projections.

By 2020 cassava will be integrated into emerging markets through the efficient and environmentally sound production of a diversified range of high-quality competitive products for food, feed and industry. In Southeast Asia, in particular in Indonesia, demand for cassava will increase for use as food or processed food, animal feed and for specialized starch products (dTp Studies, 1998). The availability of cassava in the global food system, the competitiveness of these products and the resulting benefits to low-income households will be assured by the continued reduction of production costs through the development of suitable high-yielding and high-dry matter content varieties (to maximize the conversion rates from raw material to processed products), low external input, the adoption of technologies to maintain fertility and control erosion.

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CASSAVA IN THE FOOD SECURITY SYSTEM

The food security system consist of food availability, distribution and diet pattern sub-systems. Factors affecting the food availability system are production, processing, stocking and storing. Factors affecting the distribution system are infrastructure and the marketing system, while factors affecting diet or food consumption are culture or tradition, income, food availability, nutritient content and food hygiene.

1. Food Availability System

Production system

The nutritional requirement of each household (4.14 persons) varies from 3,113 to 6,143 Kcal/day and 167-242 gram/day of protein (CBS, 2000). Production of rice, maize and cassava, being the main sources of calories, should meet this demand.

Rice production in Indonesia has been stagnant and the continued importation of rice indicates that rice production is below demand. As rice productivity is leveling off and the area under rice has decreased, food diversification is one way to improve food security. About 40% of demand for maize is supplied by imported maize. It means that food diversification using cassava is one way to achieve food security. The problem of cassava is that it is low in protein; as such, legumes should be part of the diet when rice is substituted by cassava **(Table 1).**

Table 1. Scenario to partially substitute rice by cassava and legumes to maintain a balanced diet in the household.

Substituted rice (%)	Cassava	Legumes[1)]
	(kg/year/household)	
20	372	13
40	744	26
60	1,116	39
80	1,488	52
100	1,813	65

[1)]to increase the protein content of the substituted food in the diet.

Cropping patterns to be established to meet the energy and protein requirements are:

- Irrigated lowland: Rice – rice – legumes + maize
  Cassava planted on plot borders, in back-yards or as an upland crop
- Rainfed lowland: Rice – cassava + legumes + maize
- Upland: Cassava + maize + rice – legumes
  Cassava + maize + legumes
  Cassava + maize – legumes

Processing system

Cassava can substitute for rice both in the form of snack food and staple food. The raw material for snack food can be both fresh roots or processed roots, such as flour or starch, while the raw material for staple food is generally flour. Substituting rice through food diversification is commonly done as follows:

- 20% substitution of rice: as snack or breakfast food
- 40%, 60% and 80% substitution of rice: mixing of rice and cassava flour in the proportions of 60:40, 40:60 and 20:80; or by consuming during the year rice for 8, 6 or 4 months, followed by consuming cassava for 4, 6 or 8 months, respectively. The period of rice consumption generally starts after the rice harvest at the end of the rainy season.
- Cassava being consumed as staple food is common for communities in marginal upland areas that traditionally consume cassava as a staple food.

Processing cassava roots into flour allows it to be stored and to prevent pests such as dried cassava borer. The use of a mobile flour processor is very practical, especially in those villages that process large amounts of dried cassava into flour.

Storing system

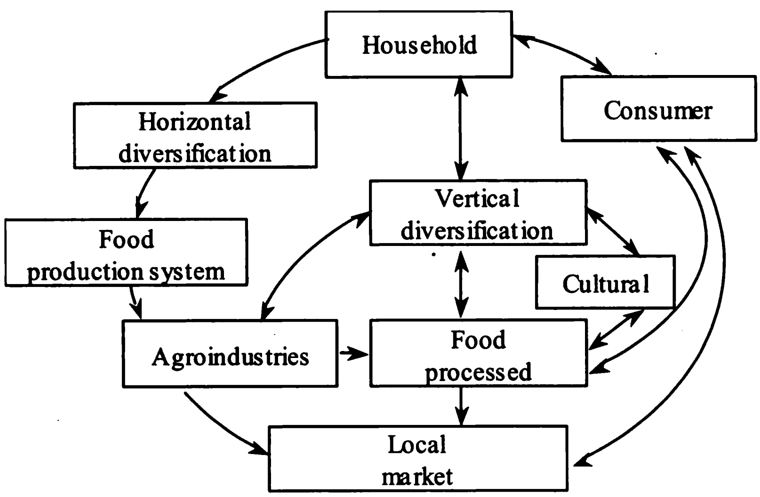
Cassava can be stored as follows:

- Farmers with small land holdings generally store cassava in the form of dried cassava pieces (called *gaplek*), or as flour stored in plastic bags.
- Farmers with larger land holdings generally harvest cassava at monthly intervals in amounts that are needed for the monthly consumption of the household.

2. Distribution System

In any particular region the production of rice as a main staple food and that of cassava as either a staple food or for rice substitution do not always correspond to the demand. Rice is mostly available in both supermarkets and the local market, so it is easy for the consumer to buy rice. Fresh cassava, on the other hand, is both bulky and perishable, making transportation expensive. As such, cassava should be produced locally to reduce transportation costs and it should be harvested periodically to minimize losses due to spoilage.

The cassava distribution system in Indonesia can be schematically presented as follows:



3. Diet

Factors affecting people's diet are food availability, nutritient content, tradition and food hygiene.

- Food crop production is affected by the environment, especially the climate and soil; therefore, people's diet generally depend on the food crops that can be grown in their region.
- The micro-nutritient content of rice is rather low, while that of cassava is higher. As such, the diversification of the diet by eating cassava is a good way to increase micro-nutrient consumption.
- The consumption of cassava as a staple food is traditionally done in a variety of ways such as by substitution of cassava for rice during certain periods of the year or by consuming rice mixed with cassava in various proportions.
- The cost of production to supply the daily per capita requirement of calories in the form of rice, maize or cassava are Rp 172, 84 and 59, respectively. This means that using cassava as a staple food can save the household's expenditure for calories. To support the ample availability of cassava and maintain its low production cost of calories, suitable production technologies should be developed for each agro-ecosystem. More agronomy research to identify these suitable technologies is urgently needed.

CASSAVA AGRONOMY RESEARCH

The expected output of agronomy research are technologies that will increase crop production, and reduce the cost of production of fresh roots and that of the various processed products. Suitable component technologies in sustainable cassava farming systems include suitable varieties, cropping patterns and fertilization.

1. Suitable varieties

On calcareous soils in the southern part of Yogyakarta province, cassava yields are very low. **Table 2** shows that the local varieties Kirik, Bodin and Inak as well as the introduced variety KM 98-1 had slightly higher yields than others. However, Ispandi (2001) obtained very high yields on another type of soil in Patuk, Yogyakarta (**Table 3**). Breeding lines OMM90-3-76 and OMM90-7-74 produced yields of 56.8 and 60.5 t/ha, respectively, when managed optimally by the application of 6 t cattle manure plus 90 kg N, 35 P_2O_5 and 60 K_2O/ha. The yield of Adira 1 was 14.0 t/ha under farmer management and 32.1 t/ha in the experiment, indicating that application of both organic and inorganic fertilizer increased yields significantly. Since most cassava production areas are located in soils with low contents of both organic matter and nutrients, the application of both organic and inorganic fertilizers to increase the yield of suitable varieties is advised.

2. Cropping systems

Most farmers in Indonesia plant cassava in the early rainy season. Factors that influence the time of planting are: 1) water availability is dependent on rainfall; 2) small land holdings; and 3) cassava is generally intercropped with other food crops, to increase land use efficiency (Wargiono, 1997). The root yield decreased when cassava was planted one to three months after that of the intercrop, because the young cassava plants could not compete with interplanted crops that had already grown tall (Wargiono, 1997). The higher root yields of cassava intercropped with maize or after maize may be due to residual effect of fertilizers, since the amount of fertilizers applied to maize is much higher than that applied to peanut. Applying fertilizer to both the main crop and the interplanted crops in intercropping systems is one way to minimize the competition effect between the main and interplanted crops.

Table 2. Root yields of cassava varieties grown in a highly calcareous soil in Playen, Yogyakarta, in 2000/01 and 2001/02.

Varieties	Root yield (t/ha)		
	2000/01	2001/02	Average
Peking	0.32	-	-
Kirik	5.97	2.91	4.44
Sekong	0.51	-	-
Garbu	3.15	-	-
Bodin	6.41	3.79	5.10
Ireng	5.60	1.29	3.44
Enak	3.96	4.50	4.23
Sonoyo	4.96	3.18	4.07
Cilacap 1	4.48	2.14	3.31
Valenca	3.10	-	-
KM 98-5	4.48	2.05	3.26
KM 99-4	3.93	1.02	2.48
KM 937-26	3.73	1.10	2.42
KM 98-1	6.17	3.52	3.84
Adira 1	1.06	-	-
Adira 4	0.41	1.49	0.95

Table 3. Varietal performance in an Alfisol when optimally managed in Patuk, Yogyakarta, 1997.

Varieties	Root yield (t/ha)
KTKN	51.3 b
OMM90-6-72	40.9 c
OMM90-2-66	41.3 c
OMM90-3-76	56.8 ab
OMM90-7-74	60.5 a
Faroka	20.7 e
Adira 1	32.1 d

Source: *Ispandi and Lawu 2002.*

3. Fertilization

Most cassava production areas have marginal soils. Soil analysis of cassava production areas of Gunung Kidul, Yogyakarta indicate that most of the soils are low in organic matter and macro- and micro-nutrients (Ispandi, 2002). This means that high yields can only be obtained by applying both organic and inorganic fertilizers.

3.1 Micro-nutrient fertilization on calcareous soil

Symptoms of serious deficiencies of Zn and Fe in cassava have been observed in some farmers' fields in Playen, Yogyakarta. An experiment on Zn and Fe fertilization in this soil indicate that foliar spraying at one, two and three months with 1% $ZnSO_4$ or a stake dip for 15 min in 2% $FeSO_4$ before planting increased root yields as well as the Fe and Zn contents of upper leaves as compared to that of the control (**Tables 4** and **5**). Since stake dipping is easier than foliar spraying this practice might be adopted by farmers. Growing varieties that are tolerant of micro-nutrient deficiencies to obtain high yield is much simpler and cheaper than applying micronutrient fertilizers; thus, the application of $FeSO_4$ and/or $ZnSO_4$ is recommended only when suitable varieties are not available.

Table 4. Effect of stake treatment or foliar sprays with Zn and Fe on the yield of Adira 1 in Playen, Yogyakarta, in 1999/00 and 2000/01.

	Root yield (t/ha)		
	1999/00	2000/01	Average
1. Without micro-nutrients	6.25	4.07	5.16
2. Stake dip in 2% $ZnSO_4$	8.29	2.37	5.33
3. Stake dip in 4% $ZnSO_4$	7.36	3.52	5.44
4. Foliar spray with 1% $ZnSO_4$	6.62	5.37	6.00
5. Foliar spray with 2% $ZnSO_4$	6.43	5.06	5.74
6. Foliar spray with 1% $FeSO_4$	5.13	5.75	5.44
7. Stake dip in 2% $FeSO_4$	9.53	3.58	6.56
8. Stake dip in 4% $FeSO_4$	5.44	5.00	5.22

Table 5. Effect of stake treatment or foliar sprays of Zn and Fe on the nutrient concentration of youngest fully-expanded leaf (YFEL) blades of Adira 1 at 3 months after planting in Playen, Yogyakarta, in 2000/01.

	N	P	K	Ca	Mg	B	Fe	Mn	Cu	Zn
Treatments	%					ppm				
1. Without micro-nutrient	3.54	0.30	1.13	0.80	0.29	13.2	59.9	99.3	6.50	27.3
2. Stake dip in 2% ZnSO4	3.77	0.33	1.15	0.65	0.24	12.9	63.8	82.3	6.58	28.2
3. Stake dip in 4% ZnSO4	3.52	0.28	1.22	0.66	0.23	15.2	63.4	85.3	7.28	31.2
4. Foliar spray with 1% ZnSO4	3.39	0.30	1.16	0.68	0.29	15.3	64.9	68.3	6.75	29.3
5. Foliar spray with 2% ZnSO4	3.47	0.31	1.20	0.70	0.27	17.0	67.9	127.3	6.61	40.4
6. Foliar spray with 1% FeSO4	3.49	0.31	1.16	0.68	0.27	16.4	76.1	95.6	7.04	34.5
7. Stake dip in 2% FeSO4	3.40	0.29	1.11	0.79	0.28	14.7	91.2	76.8	6.45	27.0
8. Stake dip in 4% FeSO4	3.98	0.38	1.37	0.72	0.29	15.3	76.3	97.6	6.78	38.9

3.2 Macro-nutrient fertilization on an Alfisol

The chemical characteristics of the soil where the trial was conducted indicate a low content of N, P, K, Zn, Cu, OM, and a medium content of Mg and S. **Table 6** shows that applying macro-nutrients for cassava intercropped with peanut increased yields and gross income significantly. The highest root yield and gross income were obtained when cassava was fertilized with 90 kg N applied as urea (200 kg/ha) and ammonium sulfate

(430 kg/ha) and 54 kg P_2O_5 + 60 kg K_2O/ha. The S content of this soil is rather low and the application of S in the form of ammonium sulfate increased the cassava root yield and gross income by 19% and 18%, respectively, as compared to that without application of S. When S was applied to peanut only, the cassava root yield decreased 14% as compared to S applied to cassava. It means that S should be applied to both cassava and the interplanted crop to obtain the highest gross income for cassava intercropping systems on low-S soils.

Table 6. Effect of NPK fertilization of cassava monoculture or intercropped with peanut or maize, on the yield value and soil nutrients in Patuk, Yogyakarta in 1998.

Treatments			Yield value (Rp' 000/ha)			Characteristics of soil nutrients		
Cropping system	Crop fertilized	Fertilizers applied	Cassava	Interplanted crops	Total	K	Ca	SO_4
Cm	C	-	4,660	-	4,660	-	-	-
Cm	C	N+P+K	7,090	-	7,090	-	-	-
C+P	C	N+P+K	8,100	985	9,085	M	H	M
C+P	C	N	7,141	577	7,991	H	H	M
C+P	C	N+P	8,114	938	9,052	L	H	M
C+P	C	N+ZA+P+K	9,616	1,087	10,701	L	H	M
C+P	P	N	5,634	1,085	6,719	H	M	H
C+P	P	N+P	7,440	1,417	8,857	L	H	H
C+P	P	N+P+K	7,384	1,277	8,671	L	H	M
C+P	P	ZA+P	8,294	1,330	9,624	H	H	M
C+P	P	ZA+P+K	7,826	1,480	9,308	L	H	M
C+M	M	N+P+K	8,104	1,050	9,154	M	H	H
C+M	M	N+P+K	4,634	1,260	5,894	M	H	M
	C	N+P+K				H	H	M

*compared to soil nutrients before planting
Cm : Cassava monoculture
C : Cassava
P : Peanut
M : Maize
ZA : ammonium sulfate
***Source:** Ispandi and Lawu, 2002.*

3.3 Long-term NPK fertilization of intercropped cassava on an Utilisol

Since rice is the main staple food, farmers will always try to grow rice on their land. Cassava farmers in Lampung province generally have small land holdings, they have limited capital and family labor, and their subsistence farming system is dependent on rainfall (Wargiono *et al.*, 1997). Therefore, most farmers grow various food crops in intercropping systems during the rainy season, as their main objective is to obtain enough household food for the year. The objective of a long-term NPK trial was to determine the most suitable annual application of N, P and K to maintain high yields of both cassava and intercrops over time. The data in **Table 7** indicate that after ten years of continuous cropping the highest production of calories and net income were obtained by applying annually 90 kg N + 25 P_2O_5 + 90 K_2O/ha or 90 kg N + 50 P_2O_5 +180 K_2O/ha.

In Lampung province each household requires an annual supply of about 479 kg of rice and 393 kg of cassava to meet their calorie requirements. The average upland land holding is about 0.5 ha. Thus, the data in **Table 7** indicate that with adequate NPK fertilization their calorie requirements can be met even if they have somewhat less than 0.5 ha. By growing soybeans after the harvest of rice, the consumption of protein is also increased. This cropping pattern can thus be recommended for maintaining food security.

Table 7. Effect of annual applications of various levels of N, P and K on the yield of cassava and intercropped rice, the total calories, and crude protein produced, as well as the net income obtained in Tamanbogo, Lampung, in 2001/02 (10th year).

Fertilizer treatments $N-P_2O_5-K_2O$ (kg/ha			Cassava monoculture: Roots yield (t/ha)	Calories (Kcal/ha)	Protein (kg/ha)	Net income ('000 Rp/ha)[1)]	Cassava intercropped: Root yield (t/ha)	Rice yield (t/ha)	Calories (Kcal/ha)	Protein (kg/ha)	Net income ('000 Rp/ha)[1)]
0	0	0	6.23	9,030	68.53	1,246	6.22	0.05	9,133	72.87	1,299
0	50	90	11.62	16,849	127.82	1,744	10.17	1.61	18,402	255.16	3,225
45	50	90	12.53	18,169	139.93	1,806	8.40	1.97	16,652	267.73	3,147
90	50	90	17.66	25,675	194.26	2,712	11.23	2.24	21,369	322.89	3,890
180	50	90	15.20	22,040	167.20	1,980	10.26	1.49	18,259	245.47	2,631
90	0	90	15.07	21,852	165.77	2,444	8.49	1.04	14,672	184.17	2,272
90	25	90	19.01	27,565	209.11	3,107	11.21	2.07	20,954	307.44	3,824
90	100	90	13.36	19,372	146.96	1,602	9.19	1.87	17,571	267.52	2,825
90	50	0	6.38	9,251	70.18	786	4.24	0.83	8,032	120.51	1,271
90	50	45	17.45	25,303	191.95	2,835	8.49	1.89	16,601	266.11	3,122
90	50	180	19.03	27,594	209.33	2,656	10.93	2.63	21,819	354.30	3,929
180	100	180	16.26	23,577	178.86	1,612	9.46	1.90	18,030	273.22	2,342

[1)]Net income = gross income-fertilizer cost

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CASSAVA AGRONOMY IN INDIA – LOW INPUT MANAGEMENT

T.V.R. Nayar, G. Suja, K. Susan John and V. Ravi[1]

ABSTRACT

Agronomic research on cassava in India during the past three decades was instrumental in the development of management practices that led to substantial increases in yield, mainly in Tamil Nadu and Kerala. Research efforts have recently focused on the development of low-input technologies with special emphasis on the identification of genotypes adapted to low-input conditions, the utilization of locally available organic wastes as soil amendments, exploitation of indigenous nutrient carriers, biofertilizers, and the economic use of irrigation water. The major accomplishments in the above mentioned areas and the recent progress in cassava agronomy research in India are briefly reviewed.

A series of field experiments were conducted from 1990 to 1998 at the Central Tuber Crops Research Institute (CTCRI) to identify cassava genotypes adapted to low input management. The genotypes were evaluated on the basis of fresh root yield, total biomass production, harvest index and low-P adaptation index. The land race *Mankuzhanthan* was found to be well adapted to low fertility conditions. It was also observed that the genotypes TCH-2 (Sree Prabha), *Mankuzhanthan* and Malayan 4 (M4) were capable of producing satisfactory yield in low-P soil, even in the absence of applied phosphorus. Monitoring the vesicular-arbuscular mycorrhiza (VAM) association on cassava roots indicated that in the absence of P-fertilization the fungal colonization was higher on all the genotypes. Research on low-cost soil fertility management practices for cassava showed that green manuring *in situ* with cowpea has both agronomic and economic advantages. The results of long-term fertility management studies conducted at CTCRI for the past 12 years also proved that green manuring *in situ* with cowpea or the incorporation of cassava crop residues can replace comparatively expensive farm-yard manure (FYM). Application of Mussoorie rock phosphate, a cheap indigenous source of P, was found to be equally effective as single superphosphate. In another experiment conducted at CTCRI, the response of cassava to locally available organic manures, such as mushroom spent compost, sawdust compost, press mud and coir pith compost, was also studied. These organic manures, especially coir pith compost and press mud, were found to be cheaper and very effective substitutes to FYM and they had no adverse effect on the available N, P and K status of the soil. Studies on integrated nutrient management practices for cassava grown on red lateritic soils indicate that the application of chemical fertilizers to cassava could be reduced to 50% if combined with biofertilizers and organic manures.

When cassava was intercropped with groundnut in Tamil Nadu, the application of 54 kg N, 72 P_2O_5 and 180 K_2O/ha along with biofertilizers, i.e., *Azospirillum* for cassava and *Rhizobium* for groundnut, promoted crop growth and yield and generated higher profits from the system. Sequential cropping studies conducted at Coimbatore, Tamil Nadu, and Peddapuram, Andhra Pradesh, sponsored by the All-India Coordinated Research Project on Tuber Crops, revealed that vegetable cowpea-cassava sequential cropping was a viable proposition and resulted in a saving of applied nutrients, especially P.

A comparison between surface and drip irrigation for cassava at Bhavanisagar, Tamil Nadu, showed that by using the drip system about 50% of irrigation water can be saved without affecting root yields.

Results of studies on nutrient management to obtain targeted yield, large-scale screening of cassava genotypes for drought tolerance, and storage of planting material of short-duration lines of cassava at Peddapuram, Andhra Pradesh, are also presented.

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INTRODUCTION

Cassava is cultivated in about 13 states in India as a source of food security in rural areas and as raw material for industries, mainly starch, sago and livestock feed. In Kerala, cassava is currently grown in an area of 111,000 ha producing 253,000 tonnes of roots (**Figure 1**), used mainly for food. Compared to 1991, the cassava area in Kerala has declined by 25% due to farmers' preference for more remunerative crops. On the other hand, cassava is now a major industrial crop in Tamil Nadu and is also gaining importance in Andhra Pradesh. The phenomenal growth in the starch and sago industries over the years has markedly increased cassava production in Tamil Nadu. **Figure 1** shows that in comparison to 1991 production of cassava in Tamil Nadu has increased by 55%, while the area increased by 20%.

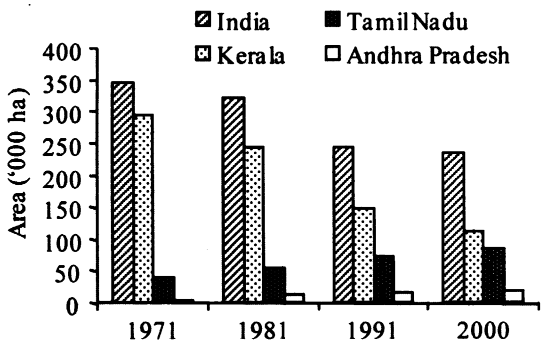

Figure 1a. Cassava area ('000 t)

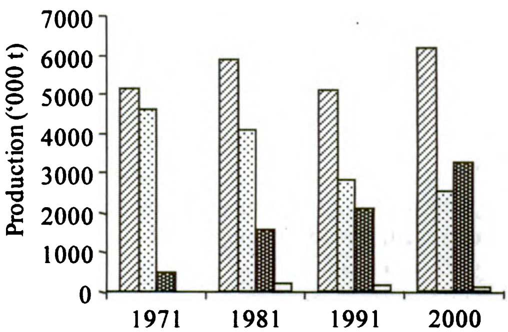

Figure 1b. Cassava production ('000 t)

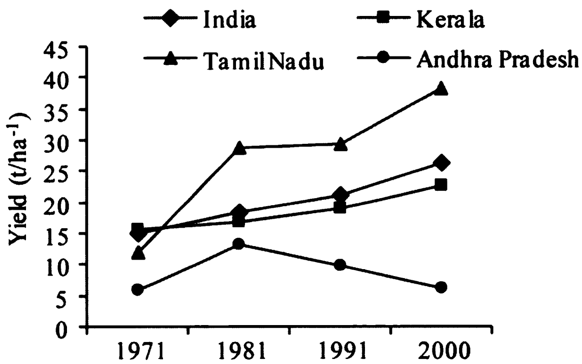

Figure 1c. Cassava yield (t/ha)

Figure 1. Cassava area, production and yield in major cassava growing states of India

Wide variation in soil type and climatic parameters exists within these cassava-growing areas (Nayar, 1993). In Kerala cassava is cultivated on Ultisols (lateritic soils), Alfisols (red soils) and Entisols (alluvial soils), under rainfed conditions, taking advantage of the bimodal precipitation prevalent in the region (Nayar and Nayar, 1997). In Tamil

Nadu the crop is grown on Vertisols (black soils) and Alfisols (red soils), usually with supplemental irrigation (Nayar, 1994). In Andhra Pradesh cassava is grown mainly on Entisols (sandy loams) as a rainfed crop.

Agronomic research on cassava in India during the past three decades was instrumental in the development of better management practices that led to substantial increases in productivity, especially in Tamil Nadu and Kerala. The productivity in Tamil Nadu is very close to 40 t/ha, the highest in the world. Research in the recent past has focused mainly on the development of low-input technologies with a thrust on the identification of genotypes adapted to low-input conditions, utilization of locally available organic wastes as soil amendments, exploitation of indigenous nutrient carriers, biofertilizers and on economizing irrigation water. An overview of the major accomplishments in the above fields and the recent progress in cassava agronomy in India is presented.

1. CASSAVA GENOTYPES ADAPTED TO LOW-INPUT MANAGEMENT

Cassava is mostly cultivated by small-scale farmers, especially in Kerala, in marginal environments and on soils of low fertility. To realize the production potential of high-yielding cassava varieties, application of farm-yard manure (FYM) at 12.50 t/ha and chemical fertilizers to provide 100 kg/ha of N, P_2O_5 and K_2O has been recommended (KAU, 1986). This high manurial dosage is very expensive and many cassava farmers are not in a position to adopt the above recommendation (Anantharaman *et al.,* 1986). Hence, identification and popularization of cassava genotypes adapted to lower levels of soil fertility management will be an appropriate low-input technology. With this objective, field experiments were conducted at the Central Tuber Crops Research Institute (CTCRI). In the experiment undertaken during 1990-1993 six genotypes, having characteristics described in **Table 1,** were evaluated at lower levels of soil fertility management (Nayar *et al.,* 1998). The results showed that the land race 'Mankuzhanthan' (MK) was adapted to low soil fertility management as measured by higher fresh root yield, storage root biomass production, total biomass production and harvest index **(Table 2).**

Table 1. Characteristics of several cassava genotypes in India.

Genotype	Characteristics
H22/86	Hybrid of Sree Prakash (short duration) and Malayan 4 (M4). Medium yielder with roots of good cooking quality.
H2/82	Hybrid of H-165 and Malayan 4. Early bulking, with roots of good cooking quality.
Triploid 237/84	Spontaneous triploid resulted from the hybridzation between Sree Sahya and H-165. High yielding but having low root dry matter content.
Triploid 76/9	Obtained from the cross of OP4 (2x) and S 300 (4x). High yielder with high root dry matter content.
Mankuzhanthan	Land race adapted to partially shaded conditions. Roots have high dry matter and starch contents.
Sree Prakash	Short duration variety, having roots with good cooking quality.

Source: *Nayar et al.,1998.*

Table 2. Cassava varietal response to low-input management (mean of three years).

Treatments $N:P_2O_5: K_2O$ in kg/ha and varieties	Fresh root yield (t/ha)	Dry root yield (t/ha)	Dry top yield (t/ha)	Dry total biomass (t/ha)	Harvest Index
50:50:50					
H22/86	19.73	5.77	5.60	11.37	50.64
H2/82	16.79	4.25	5.46	9.71	41.90
Triploid 237/84	18.90	5.11	5.66	10.33	47.39
Triploid 76/9	19.65	6.82	5.65	12.46	54.24
Mankuzhanthan	23.14	8.02	5.49	13.51	59.11
Sree Prakash	20.68	6.24	5.52	11.83	52.70
75:50:75					
H22/86	20.45	6.01	5.72	11.73	51.18
H2/82	17.11	4.97	5.52	10.49	46.61
Triploid 237/84	24.16	6.82	5.76	12.58	53.84
Triploid 76/9	23.86	8.32	5.63	13.96	58.84
Mankuzhanthan	23.10	7.90	5.58	13.49	58.22
Sree Prakash	21.64	6.61	5.54	12.14	54.23
100:50:100					
H22/86	19.37	5.93	5.74	11.66	50.48
H2/82	18.66	5.39	5.58	10.97	48.61
Triploid 237/84	26.66	7.08	5.77	12.85	54.79
Triploid 76/9	27.11	9.23	5.79	15.01	60.86
Mankuzhanthan	23.30	7.94	5.60	13.54	58.62
Sree Prakash	24.18	7.32	5.57	12.89	56.41

Source*: *Nayar et al., 1998

At CTCRI field experiments were also carried out during 1996-1999 to identify cassava genotypes adapted to low-P soil. Eight contrasting genotypes of cassava were grown with and without application of phosphatic fertilizer, in lateritic soil (Ultisol) having low (9 kg/ha) initial available P status. Recommended levels of N and K (100 kg ha) were also applied, but no farm-yard manure (FYM) was given as basal dressing. From this study it was observed that the genotypes TCH-2 (later released as Sree Prabha), Mankuzhanthan (MK) and Malayan 4 (M4) were capable of producing satisfactory yields (CTCRI, 1998) even in the absence of applied phosphorus. (**Figure 2**). The P-adaptation index, calculated according to the formula used at CIAT (CIAT, 1993) had higher values in the case of the above genotypes, indicating their ability to yield well in low-P soils. Monitoring the VAMF association on cassava roots indicated that for all the genotypes the colonization was higher in the absence than in the presence of phosphorus fertilization (**Table 3**). However, total microbial activity, particularly the population of bacteria and fungi in the rhizosphere of cassava, was significantly higher in plots that received phosphatic fertilizer (**Figure 3**).

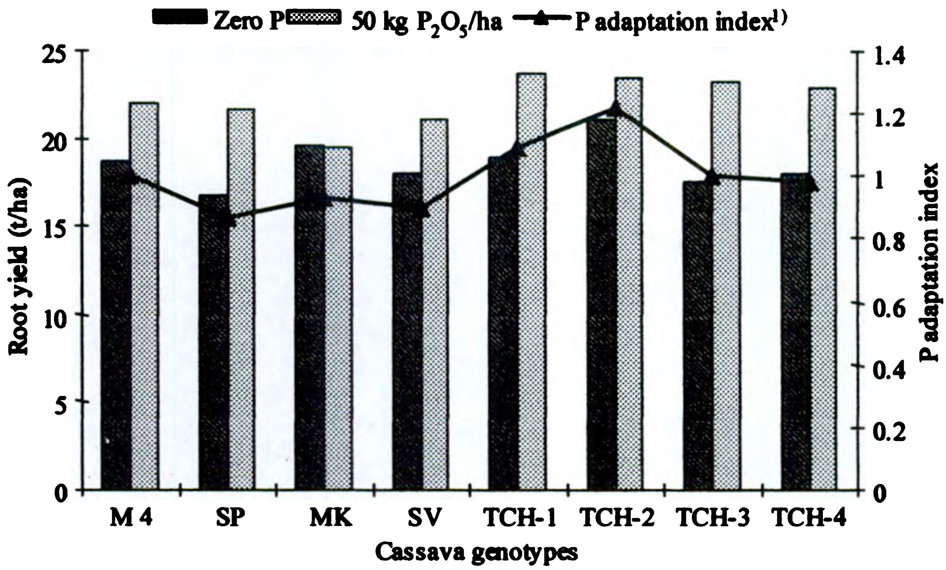

Figure 2. Cassava genotypes adapted to low phosphorus soil.
[1)]P-adaptation index= {Yield (-P) x Yield (+P)} / {Av. Yield (-P) x Av. Yield (+P)}
***Source:** Nayar and Potty, 1998.*

Table 3. Percentage VA mycorrhizal root infection and soil spore population in the rhizosphere of eight cassava varieties at 3 and 6 months after planting, with and without P application.

	VAM colonization (%)				Spore population (per 100 ml soil)			
	3rd month		6th month		3rd month		6th month	
Treatments	P_0	P_1	P_0	P_1	P_0	P_1	P_0	P_1
TCH-4	90	50	80	60	300	100	400	200
Sree Prakash	80	40	80	30	300	200	300	150
Mankuzhantan	80	30	90	40	300	100	350	120
H-1687	90	60	100	57	200	-	200	110
M4	90	30	90	40	400	-	300	210
TCH-2	80	40	90	63	400	-	570	140
TCH-1	90	40	100	51	200	100	300	150
TCH-3	100	40	100	60	100	-	230	140

[1)] P_0 = 100 N-0 P-100 K_2O; P_1 = 100 N - P_2O_5-100 K_2O
***Source:** CTCRI, 1997*

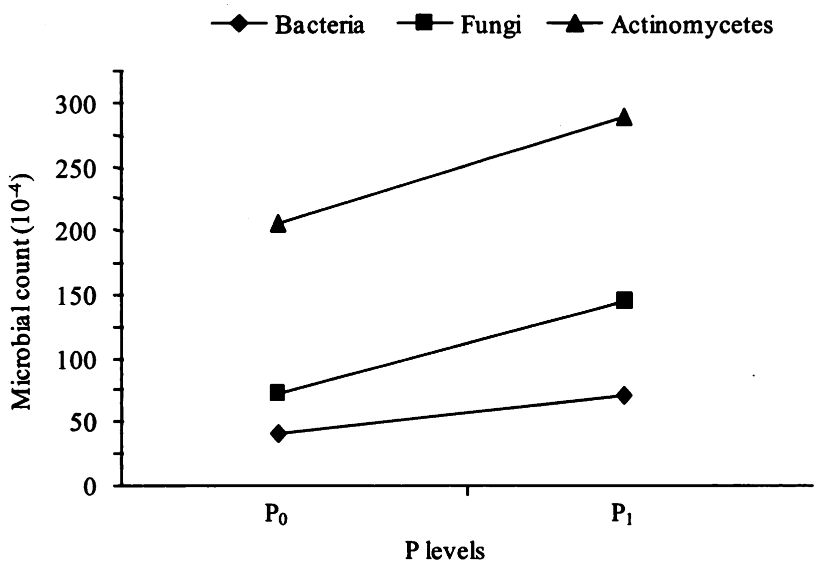

Figure 3. Average total microbial activity in the rhizosphere of eight cassava varieties planted with (P_1) and without (P_0) phosphorus application.
Source: *CTCRI, 1997.*

2. LOW-COST SOIL FERTILITY MANAGEMENT PRACTICES

2.1 Green manuring in situ with cowpea

Research on low-cost soil fertility management practices for cassava showed that green manuring *in situ* with cowpea has agronomic and economic advantages (Nayar *et al.*, 1993). There were no statistically significant differences in cassava yields between plots with FYM and those with *in situ* green manuring with cowpea varieties Arkagarima and C-152 (**Figure 4**). It was also found that by practicing green manuring *in situ* with cowpea the FYM application can be eliminated and the nitrogen and phosphorus can be reduced to 50% of the recommended rates (Nayar and Potty, 1996).

The results of long-term fertility management experiments conducted at CTCRI for the past 12 years also indicate that green manuring *in situ* with cowpea or incorporation of cassava crop residues (CR) can replace the rather expensive farm-yard manure (**Figure 5**). However, in years of delayed onset of the Southwest monsoon or insufficient rainfall, the practice of green manuring *in situ* may reduce the productivity of long-duration varieties of cassava.

The long-term impact of green manuring *in situ* with cowpea on chemical properties of lateritic soil (Ultisol) was also investigated. There was no significant difference in soil pH and organic carbon content between green manuring and FYM. Under all treatments there was a slight increase in the soil organic carbon content (**Table 4**) by the 11^{th} year. The available nitrogen status determined at the 5^{th} and 11^{th} year, showed no significant variation. However, the plots with incorporation of crop residues had lower available N when compared to other treatments, i.e. FYM at 12.5 t/ha and green manuring in *situ* with cowpea (**Figure 6**). There was considerable accumulation of available soil P and K in both the 5[th] and 11[th] year of cropping (**Figures 7 and 8**).

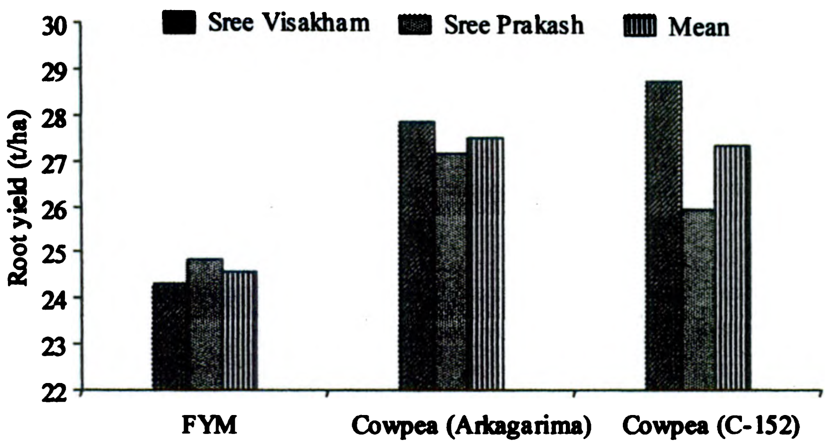

Figure 4. Root yields of three cassava varieties as influenced by green manuring in situ with cowpea.
Source: Nayar et al., 1993.

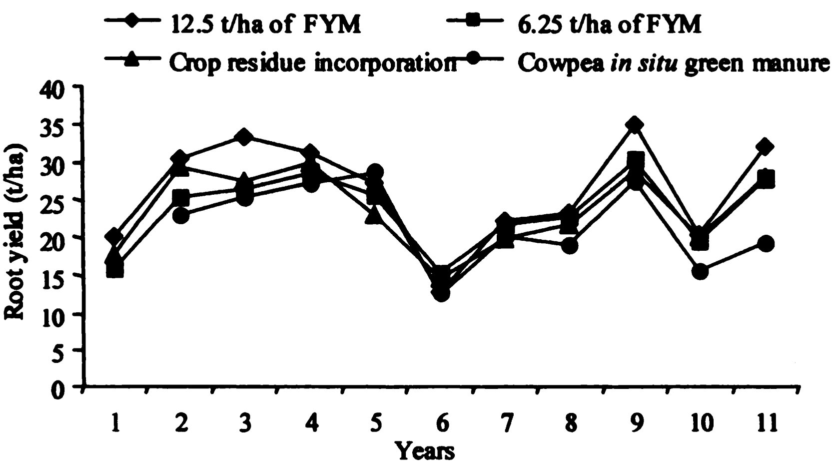

Figure 5. Influence of various organic manures on cassava root yields during 11 years of continuous cropping. All plots received 100 kg N, 50 P_2O_5 and 100 K_2O/ha as chemical fertilizers.
Source: Susan John, 2002. (unpublished)

Table 4. Long-term effect of green manuring *in situ* with cowpea on soil pH and organic carbon.

Treatments[1)]	pH			Organic carbon (%)		
	Initial	5^{th} year	11^{th} year	Initial	5^{th} year	11^{th} year
12.5 t/ha FYM	4.75	4.94	4.61	0.80	0.78	1.14
6.25 t/ha FYM	4.78	5.03	4.72	0.64	0.71	1.17
crop residues incorporated	4.75	5.35	4.73	0.71	0.80	1.06
green manuring *in situ* with cowpea	4.45	4.80	4.78	0.67	0.77	1.02
CD (0.05)	NS	NS	NS	NS	NS	NS

[1)] All plots received annual application of 100 kg N, 50 P_2O_5 and 100 K_2O/ha

***Source:** Adapted from CTCRI Annual Reports 1991, 1996 and 2001.*

T_1: FYM 12.5 kg/ha T_3: Crop residues incorporated

T_2: FYM 6.25 kg/ha T_4: Green manuring *in situ* with cowpea

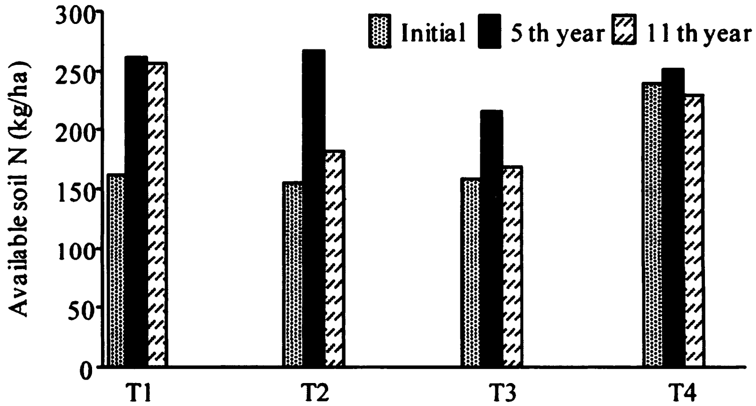

Figure 6. Influence of sources of organic manures on available soil N. All treatments received 100 kg N+50 P_2O_5+100 K_2O/ha.
***Source:** Adapted from CTCRI 1991, 1996, 2001.*

2.2 Use of locally available composted organic manures

The advantages of composting organic wastes and using these as soil amendments are well-known. Organic wastes, such as coirpith, press mud (sugar factory waste), mushroom spent compost, paddy straw and sawdust, are available and marketed in the cassava producing areas of southern India, While composting, small amounts of urea and fungal cultures (*Pleurotus* + *Trichoderma* + *Penicillium*) are used as starter (Rajendran, 1991). Certain compost preparations are also fortified with micronutrients. Most of these have NPK contents comparable to those of FYM, the most widely used organic manure in cassava farming (**Table 5**).

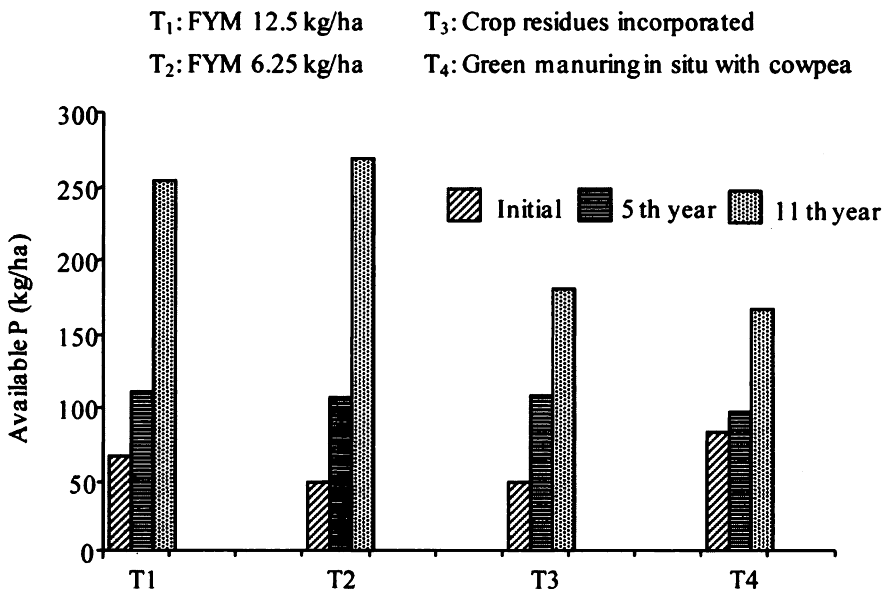

Figure 7. Influence of sources of organic manures on available soil P.
All treatments received 100 kg N + 50 P_2O_5 + 100 K_2O/ha.
***Source:** CTCRI, 1991, 1996, 2001.*

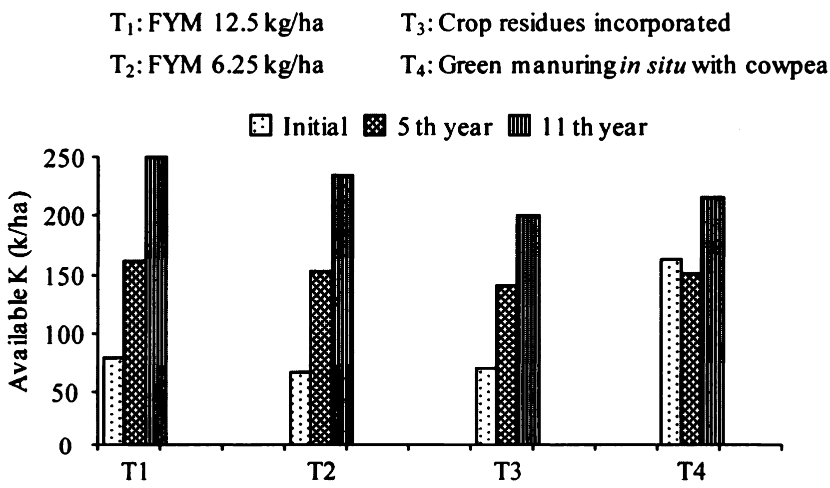

Figure 8. Influence of sources of organic manures on available soil K.
All treatment received 100 kg N + 50 P_2O_5 + 100 K_2O/ha.
***Source:** CTCRI, 1991, 1996, 2001.*

Table 5. Nutrient contents of various organic manures.

Organic manures	N (%)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
FYM	0.80	0.30	1.00	-	-	-	91	1.64	46.4	-
Press mud compost	1.30	2.20	0.50	3.50	2.50	0.25	3,000	500	300	65
Mushroom spent compost	1.84	0.69	1.19	-	5.10	0.38	2,200	225	1,260	-
Coir pith compost	1.08	0.06	1.20	0.50	0.50	0.48	1,800	125	212	6
Sawdust compost	1.00	0.50	0.50	-	-	-	-	-	-	-

***Source**: Rajendran et al., 1991.*

During 1996-1998 the efficacy of mushroom spent compost (MSC), sawdust compost (SDC), coirpith compost (CPC) and press mud compost (PMC) were compared to FYM as organic manure (on equal nutrient basis) at CTCRI using three cassava varieties, i.e. Mankuzhanthan, Sree Prakash (SP) and Sree Visakham (SV) . The effect of these organic manures on the fresh root yield of cassava is shown in **Figure 9**. There were no significant differences in yield of all three varieties due to the source of organic manure. Further, these composted manures had no significant effect on the available N, P and K status of the soil (**Figure 10**). These results suggest that any of the above organic manures can be used as substitute to FYM, depending on their cost and availability. Coirpith compost is available at cheaper prices throughout the coastal regions of Kerala, and press mud is available in large quantities in the cassava producing zones of Tamil Nadu and Andhra Pradesh. Hence, coirpith compost and press mud compost are recommended as substitutes for FYM in cassava production. (Nayar and Potty, 1998).

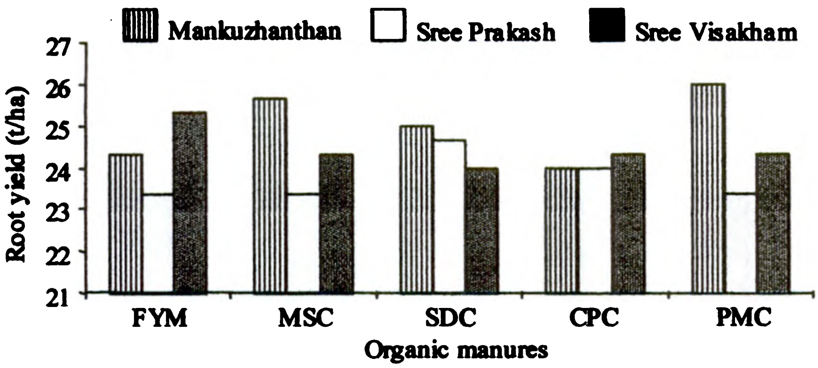

Figure 9. Effect of organic manures on the root yields of three cassava varieties grown at CTCRI.
***Source:** Nayar and Potty, 1998.*

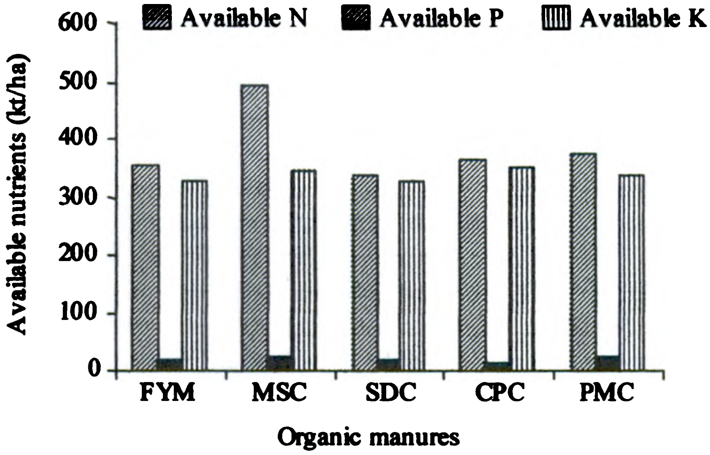

Figure 10. Effect of organic manures on the available NPK contents of the soil
***Source:** Nayar, 1998. (unpublished)*

2.3 Use of neem cake-coated urea as a slow-release N fertilizer

Earlier studies conducted under the All-India Coordinated Research Project on Tuber Crops have shown that the use of neem cake coated urea is beneficial to enhance the fertilizer's efficiency. To confirm this and to demonstrate the same to farmers, on- farm trials (OFT) were conducted at five locations in Tamil Nadu (TNAU, 2002). The results show that by using neem cake-coated urea, a 27% increase in cassava yield was obtained (**Figure 11**).

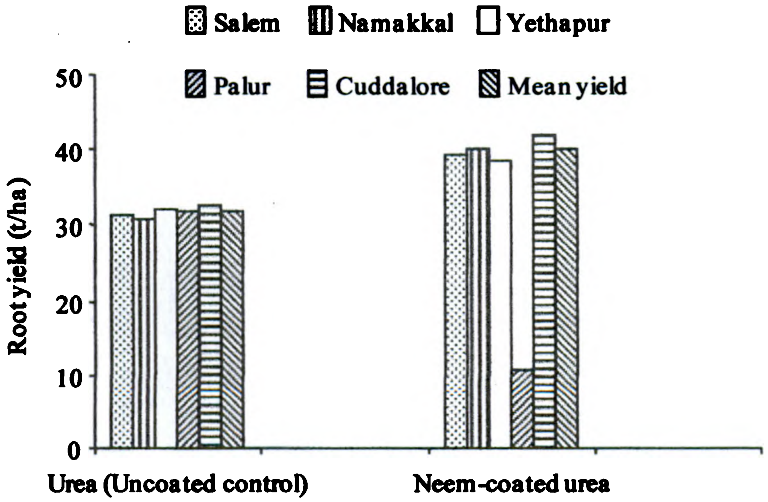

Figure 11. Influence of the use of neem-coated urea as a slow-release nitrogenous fertilizer on the root yield of cassava, cv. Co-2 in on-farm trials conducted in five locations in Tamil Nadu.
***Source:** Adapted from TNAU, 2002.*

2.4 Indigenous rock phosphate as P source

In India the necessity to utilize indigenous rock phosphate to supply P to crops arises mainly due to economic and soil property considerations. The direct application of indigenous rock phosphate saves foreign exchange needed to import high-grade rock phosphate as well as the cost of acidulation in the manufacture of superphosphate. Investigations conducted in many parts of the country have shown that indigenous rock phosphate is agronomically as efficient as single superphosphate in soils with pH less than 6.8. The long-term effect of application of Mussorie rock phosphate (MRP) in comparison to single superphosphate (SSP) for cassava was studied at CTCRI. Results of the past 11 years show that MRP was equally effective as SSP (**Figure 12**). The chemical properties, such as soil pH, organic carbon, available N, P and K of the soil, were also not significantly affected by the sources of P (**Table 6 and Figure 13**).

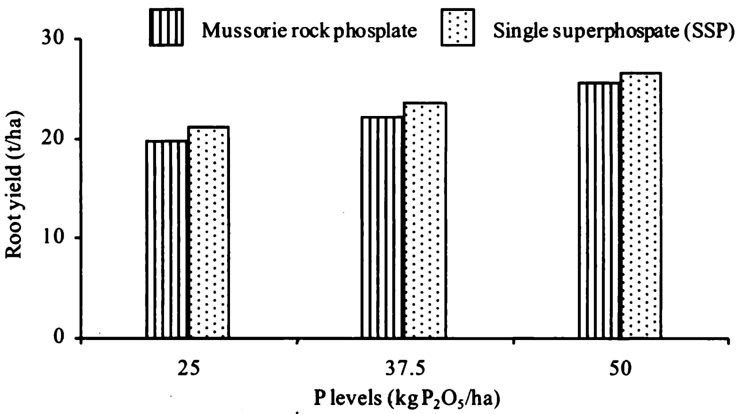

Figure 12. Influence of levels and sources of P on root yield of cassava (mean of 11 years).
***Source:** Susan John, 2002. (unpublished)*

Table 6. Influence of three levels and two sources of applied P on soil pH and organic carbon content.

P level (kg P_2O_5/ha)	P source[1)]	pH Initial	pH 5th year	pH 11th year	Organic carbon (%) Initial	Organic carbon (%) 5th year	Organic carbon (%) 11th year
25	MRP	4.58	5.18	4.90	0.63	0.63	1.05
37.5	MRP	4.80	5.05	4.68	0.66	0.73	1.04
50	MRP	4.58	4.93	4.68	0.80	0.67	1.09
25	SSP	4.56	5.03	4.85	0.77	0.91	1.37
37.5	SSP	4.53	4.98	4.93	0.68	0.78	1.21
50	SSP	4.88	4.95	4.53	0.79	0.90	1.19
CD (0.05)		NS	0.55	NS	NS	NS	NS

[1)] MRP = Mussorie rock phosphate; SSP = single super phosphate
***Source:** CTCRI, 1991, 1996, 2001.*

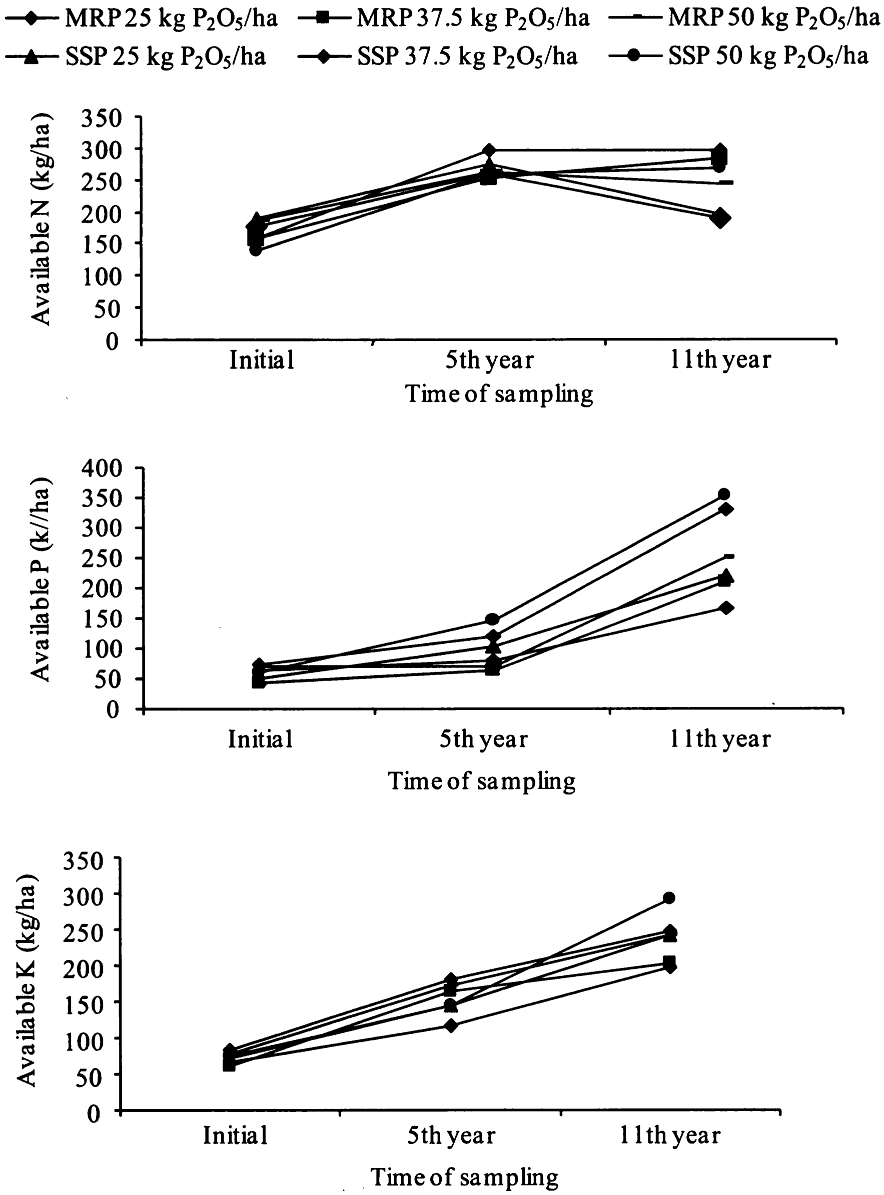

Figure 13. Effect of levels and sources of applied P on available soil-N (top), soil-P (middle) and soil-K (bottom).
Source: *CTCRI, 1991, 1996, 2001.*

2.5 Utilization of biofertilizers

Experiments were conducted to determine the best integrated nutrient management practice for cassava in laterite soils (Geetha *et al.,* 2000). The treatments consisted of factorial combinations of four biofertilizers and three levels of chemical fertilizers. The organic inputs were *Azospirillum* and *Phosphobacterium, Azospirillum* and VAM, and vermicompost at 20 t/ha. The levels of chemical fertilizer were 100, 75 and 50 per cent of the recommended dose for the crop (50:50:50 kg N: P_2O_5: K_2O/ha). The results show that neither the biofertilizers nor the chemical fertilizer levels influenced the yield significantly. Their interaction effect was also not significant. The results indicate that chemical fertilizer application could be reduced to 50% when biofertilizers were used in an integrated manner. A higher dose of biofertilizers did not increase root yields. Preliminary experiments conducted at CTCRI have shown similar results (**Table 7**).

Table 7. Effect of integrated use of organic manures, chemical fertilizers and biofertilizers on cassava production yield parameters at CTCRI.

Treatments	No. of roots per plant	Mean root weight (g)	Root yield (t/ha)
FRD[1)]: FYM at 12.5 t/ha and N-P_2O_5-K_2O at 100:50:100 kg/ha	5.33	371	24.28
FYM+P+K+75% N+*Azospirillum*	5.93	300	21.85
FYM+P+K+50% N+*Azospirillum*	5.78	282	20.20
FYM+N+K+75% P+*Phosphobacterium*	6.11	296	21.89
FYM+N+K+50% P+*Phosphobacterium*	5.04	312	23.58
FYM+K+75% N and P+*Azospirillum* + *Phosphobacterium*	5.58	321	22.22
FRD[1)]+FYM+K+50% N and P+*Azospirillum*+ *Phosphobacterium*	5.33	321	21.19
FRD[1)] +Azospirillum + *Phosphobacterium*	5.39	375	24.93
Half recommended dose + *Azospirillum*+ *Phosphobacterium*	5.70	304	21.48
Absolute control	5.51	291	19.66
CD	NS	NS	NS

[1)] FRD = full recommended dose
Source: *Nayar et al., 2002.*

2.6 *Fertilizer recommendation for targeted yield*

Targeted yield models have been developed for achieving specific yields through balanced fertilizer recommendations mainly based on soil test values. In this approach the soil nutrient status and the crop requirements are taken into consideration.

Swadija and Sreedharan (1998) developed fertilizer recommendation equations for specific yield targets of cassava, var. M4, grown on laterite soils for the following two scenarios:

a) Without FYM

$$F\,N = 12.10\,T - 0.74\,SN$$
$$F\,P_2O_5 = 5.04\,T - 2.02\,SP$$
$$F\,K_2O = 11.93\,T - 1.10\,SK$$

b) With FYM

$F\,N = 12.10\,T - 0.74\,SN - 1.44\,ON$

$F\,P_2O_5 = 5.04\,T - 2.02\,SP - 2.79\,OP$

$F\,K_2O = 11.93\,T - 1.10\,SK - 1.58\,OK$

where F N, F P_2O_5, and F K_2O are fertilizer N, P_2O_5, and K_2O, respectively, in kg/ha, T is the target of root yield in t/ha; SN, SP and SK are soil available N,P and K in kg/ha, respectively, and ON, OP and OK are quantities of N, P and K supplied through organic manure in kg/ha.

Selvakumari *et al.* (2001) also used the soil test crop response (STCR) approach to develop fertilizer recommendations for the state of Tamil Nadu as fertilizer adjustment equations for targeted yield of cassava as follows:

$F\,N = 5.60\,T - 0.61\,SN - 0.81\,ON$

$F\,P_2O_5 = 3.53\,T - 1.80\,SP - 0.53\,OP$

$F\,K_2O = 9.42\,T - 0.67\,SK - 0.70\,OK$

Wherever FYM/composted coir waste/press mud is applied at 12.5 t ha, on an average 40 kg N, 22 kg P_2O_5 and 40 kg K_2O can be reduced from the recommended fertilizer rates. For the addition of *Azospirillum* and *Phosphobacterium* each at 2 kg/ha, 11.3 kg N and 10 kg P_2O_5, respectively, can be reduced from the recommended fertilizer rate Using this approach, recommended rates of fertilizer at varying soil test values for a specific yield target in cassava are shown in **Table 8.**

Table 8. Fertilizer rates remommended at varying soil test values for specific yield targets in cassava.

Initial soil test value (kg/ha)			Nutrients needed (kg/ha) for a root yield target of 40 t/ha		
N	P	K	N	P_2O_5	K_2O
180	10	180	114	123	256
190	12	190	108	119	250
200	14	200	102	116	243
210	16	210	96	112	236
220	18	220	90	109	230
230	20	230	84	105	223
240	22	240	78	101	216
250	24	250	71	98	209
260	26	260	65	94	203
270	28	270	59	91	196
280	30	280	53	87	189

Source: *Selvakumari et al.,2001.*

3. CROPPING SYSTEMS RESEARCH

Sequential cropping involving short duration legumes and cassava is beneficial not only to generate higher net returns per unit area per unit time, but also for the improvement of soil fertility. Field experiments on crop rotations were conducted at Coimbatore and Peddapuram under the aegis of the All-India Coordinated Research Project on Tuber Crops. The results of the trial at Coimbatore, Tamil Nadu, indicate that FYM and P application to cassava could be reduced to 50% by using the vegetable cowpea-cassava sequential cropping system. This treatment also proved to be cost effective and generated net returns as high as Rs. 61,298/ha and a very high benefit cost ratio (BCR) **(Table 9)**. Apart from a cassava root yield of 41.2 t/ha, about 5.75 t/ha of pods and 16.75 t/ha of crop residues of vegetable cowpea were also obtained (**Table 10**). At Peddapuram, Andhra Pradesh, vegetable cowpea-cassava sequential cropping generated the highest root yield of 17.62 t/ha when only 50% of FYM and no P were applied (**Table 11**).

Table 9. Economics of sequential cropping with cassava and vegetable cowpea at Coimbatore. Data are the means of two seasons.

Treatments[1)]	Cassava root yield (t/ha)	Total cost of production (Rs/ha)	Gross income (Rs/ha)	Net returns (Rs/ha)	Cost/ Benefit ratio
Zero FYM + zero P_2O_5	26.9	16,041	56,235	40,193	1:3.5
Zero FYM + half P_2O_5	33.2	18,389	60,985	42,596	1:3.3
Zero FYM + full P_2O_5	35.9	19,430	65,302	45,872	1:3.4
Half FYM + zero P_2O_5	36.4	20,012	67,717	47,705	1:3.4
Half FYM + half P_2O_5	41.2	19,596	80,895	61,299	1:4.1
Half FYM + full P_2O_5	36.1	20,133	71,476	51,343	1:3.6
Full FYM + zero P_2O_5	31.3	22,797	64,417	41,620	1:2.8
Full FYM + half P_2O_5	35.2	23,184	70,877	47,693	1:3.1
Full FYM + full P_2O_5	40.9	24,944	80,732	55,788	1:3.2

[1)] Half FYM: 12.5 t/ha; Full FYM: 25 t/ha
Half P_2O_5: 30 kg/ha; Full P_2O_5: 60 kg/ha
***Source**: TNAU, 2002.*

Table 10. Yield of fresh vegetable cowpea pods and haulms from a vegetable cowpea-cassava sequential cropping system at Coimbatore, Tamil Nadu, when half the recommended rates of FYM and P were applied. Data are the mean of two seasons.

Haulm yield (t/ha)	Pod yield (t/ha)	Total biomass yield (t/ha)
16.75	5.75	22.50

***Source:** TNAU, 2002.*

The feasibility and profitability of cassava + groundnut intercropping already has been reported under CTCRI conditions. In a cassava + groundnut intercropping system at Tamil Nadu, the application of NPK at 54:72:180 kg/ha, along with biofertilizers, i.e. *Azospirillum* for cassava and *Rhizobium* for groundnut, promoted crop growth, increased yield and generated higher profits from the system (Thanunathan *et al.*, 2000).

Table 11. Performance of cassava in a vegetable cowpea-cassava sequential cropping system at Peddapuram.

	Treatments[1)]	Root yield (t/ha)		
		1997	1998	Mean
1.	Zero FYM + zero P_2O_5	20.56	9.89	15.21
2.	Zero FYM + half P_2O_5	15.39	10.79	13.09
3.	Zero FYM + full P_2O_5	19.47	13.89	16.68
4.	Half FYM + zero P_2O_5	23.19	12.05	17.62
5.	Half FYM + half P_2O_5	16.83	14.46	15.65
6.	Half FYM + full P_2O_5	18.14	11.91	15.05
7.	Full FYM + zero P_2O_5	18.97	11.14	15.06
8.	Full FYM + half P_2O_5	16.77	10.45	13.61
9.	Full FYM + full P_2O_5	19.69	11.82	15.76
10.	Control (No FYM or P_2O_5)	17.64	7.23	12.44

[1)] Half FYM: 12.5 t/ha; Full FYM: 25 t/ha
Half P_2O_5: 30 kg/ha; Full P_2O_5: 60 kg/ha
Source: *ANGRAU,2002.*

4. PRODUCTIVITY OF CASSAVA UNDER DROUGHT STRESS

In India a considerable area of cassava is in the states of Tamil Nadu and Andhra Pradesh where rainfall is low and is received for only a limited period of 3-4 months. Hence, the identification of drought tolerant genotypes would be very useful. With this objective, 59 cassava genotypes, including 49 exotic genotypes (CE) and 10 indigenous genotypes (CI) were planted under upland rainfed conditions at CTCRI in Thiruvananthapuram during two seasons. The crop was planted in August and harvested 8 months after planting. During the first season, the crop received 810 mm rain between August-December in 49 days during the initial 4-month period, and 94 mm rain between January-April in 11 days during the second 4-month period. During the second season the crop received 690 mm rain between August-December in 34 days during the initial 4-month period and 185 mm rain between January-April in 21 days during the second 4 month period. Thus, during both seasons, the crop faced four months drought, which coincided with its root-bulking period.

Out of 59 cassava genotypes evaluated, the root yield and extractable starch yield of some promising genotypes are listed in **Table 12.** The highest root yield was obtained with the genotype CE-534, while the highest extractable starch yields were obtained in genotypes CE-534 and CE- 273 (CTCRI, 2002).

5. STORAGE TECHNIQUE FOR CASSAVA STEMS IN NON-TRADITIONAL AREAS

In Andhra Pradesh, cassava is planted in June with the onset of the monsoon rains and is harvested in the next year during January at 7 months after planting. As a result, farmers have to store the cassava stems for the next planting for a period of 4 to 5 months, which are very hot (33-41^{0}C) and dry. Under such adverse weather conditions, farmers usually store the cassava stems horizontally under tree shade. In this method they lose about 60% of their planting material. Hence, a study was conducted during 2000 and 2001 to identify the best storage technique for cassava stems.

Table 12. Root yield and extractable starch yield of cassava genotypes grown under rainfed conditions.

	Fresh root yield (t/ha)			Extractable starch yield (t/ha)		
Genotype	1999/00	2001/02	Mean	1999/00	2001/02	Mean
CE - 77	22.7	16.4	19.6	4.9	2.7	3.8
CE –94	22.9	15.2	19.1	4.8	3.5	4.2
CE –123	30.1	9.1	19.6	6.0	2.9	4.5
CE –127	17.3	9.5	13.4	3.6	3.2	3.4
CE –152	22.6	8.7	15.7	4.1	2.2	3.2
CE –166	17.3	9.0	13.2	4.0	2.6	3.3
CE –273	28.0	11.1	19.6	6.9	3.1	5.0
CE –274	25.9	11.5	18.7	4.6	2.9	3.8
CE –326	16.9	12.3	14.6	4.0	2.2	3.1
CE -328	19.8	11.1	15.5	4.7	2.3	3.5
CE –440	22.2	7.4	14.8	6.0	2.0	4.0
CE- 534	34.1	18.9	26.5	10.6	6.0	8.3
CI-82	28.0	4.1	16.1	8.2	0.9	4.6
CD	NS	5.28		3.73	1.51	

***Source:** CTCRI, 2002.*

In the above study, healthy and mature cassava stems of three short duration varieties, Sree Prakash, Sree Jaya and H-165, were stored for 5 months under 10 treatments. The stems stored vertically under tree shade retained high moisture content (68%), less spoilage due to drying (7%) and had high sprouting efficiency (88%). With the horizontal method, stems stored in zero-energy cool chambers (ZECC) showed less drying (31%) than stems stored under tree shade (70%). Stems stored vertically under tree shade or in the open with their bottom portion (2-3 cm) buried in sand bed and wetting the bed once every 10 days was identified as the best method of storage under hot dry weather conditions for five months. The cassava yields as influenced by the stem storage treatments are shown in **Table 13.** Treatments 1 and 2 (stems with or without shoot apex stored vertically under tree shade) gave the highest root yields (37 t/ha).

6. RESPONSE OF CASSAVA TO DRIP IRRIGATION

With the objective of economizing irrigation water through the use of a drip system, field studies were conducted for three years at the Agricultural Research Station, Bhavanisagar, Tamil Nadu, during 1996-2000 with the cassava variety MVD1 (Manickasundaram *et al.,* 2002). The experiment was laid out in split plot design with three replications. In the main plot, surface irrigation at 0.60 IW/CPE ratio to 5 cm depth was compared with drip irrigation once in two days at three levels, i.e. 100, 75 and 50% of surface irrigation. In the subplot, three levels of nitrogen at 40, 60 and 80 kg N/ha were applied through irrigation water in the drip treatments and as band placement in surface irrigation.

Table 13 . Cassava yield of three varieties as influenced by the stem storage treatments.

Treatments	Root yield (t/ha)			
	Sree Prakash	Sree Jaya	H-165	Mean
1. Stems with shoot apex stored vertically under tree shade	32.2	37.2	41.1	36.8
2. Stems without shoot apex stored vertically under tree shade	34.7	33.8	41.8	36.8
3. Stems with shoot apex stored vertically on sand bed under tree shade	38.8	33.6	33.2	35.2
4. Stems without shoot apex stored vertically on sand bed under tree shade	33.3	34.1	34.2	33.9
5. Stems with shoot apex stored horizontally under tree shade	36.4	32.2	32.2	33.6
6. Stems without shoot apex stored horizontally under tree shade	26.8	34.0	34.1	31.6
7. Stems without shoot apex treated with cow dung and stored vertically under tree shade	29.9	31.3	31.7	31.0
8. Fresh stems (without storage)	35.0	34.6	37.9	35.8

Variety NS; Treatment NS

***Source:** Ravi, 2002. (unpublished)*

The results revealed that the fresh root yield was significantly influenced by the irrigation treatments and irrigation through drip at 100% of surface method of irrigation produced the highest mean yield of 58.7 t/ha (**Table 14**). However, the fresh root yields at 100% and 75% of surface irrigation through drip were not significantly different. The fresh root yield was the lowest at surface irrigation scheduled at 0.60 IW/CPE ratio and this was not significantly different from drip with irrigation at 50% of surface irrigation. Nitrogen levels had no significant effect on root yields.

Table 14. Effect of drip irrigation on root yield and water use efficiency of cassava (mean over three years).

Irrigation levels	Fresh root yield (t/ha)	Irrigation water applied (mm)	Irrigation water saving (%)	Total water used (mm)	Water use efficiency (kg/ha.mm)
Surface at 0.60 IW/CPE	51.37	915	-	1,255	41.0
Drip at 100% of surface	58.69	851	6.9	1,192	49.2
Drip at 75% of surface	56.32	652	28.7	993	56.7
Drip at 50% of surface	53.32	472	48.4	812	65.5

***Source**: Manickasundaram et al., 2002.*

Drip irrigation at 75% of surface irrigation consumed 933 mm of water for the whole period, equivalent to a water saving of 28.7% and this treatment had a water use efficiency of 56.7 kg/ha.mm. The percent saving in irrigation water under drip irrigation applied at 50% of surface irrigation was 48.4% compared to that of surface irrigation. The water use efficiency was 20 to 60% higher in drip irrigation treatments compared to that of surface irrigation.

FUTURE THRUST

Future research on cassava agronomy will focus on :

- Refinement of agro-techniques for cassava in non-traditional areas
- Resource management for short-duration cassava-based cropping systems
- Integrated nutrient management strategies for cassava
- Development of labor-saving and drudgery-reducing agro-techniques
- Rationalization of water and nutrients for cassava production in industrial areas
- Soil conservation practices for cassava in slopy and high-rainfall areas
- Tackling micronutrient deficiency problems

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CASSAVA AGRONOMY RESEARCH IN VIETNAM

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ABSTRACT

During the last decade to the year 2002, cassava agronomy research in Vietnam has been supported by CIAT and the Nippon Foundation. Research has been conducted throughout the country with the objectives of developing new and well adapted technologies, which require only low inputs and result in high net incomes for farmers, while maintaining soil fertility and reducing erosion. The results of this research indicate the following:

-In fertilizer trials, the response of cassava depends on the type of soil and the kind of fertilizer used. In three sites cassava showed strong responses to the annual application of N and K and only slight responses to P. In long-term NPK trials conducted in Thai Nguyen University and in Hung Loc Agricultural Research Center the application of 80-40-80 and 160-80-160 kg/ha of N-P_2O_5-K_2O, respectively, gave higher yields and economic returns than other treatments.

-In long-term intercropping trials conducted on flat land at Hung Loc Research Center, cassava intercropped with grain legumes and with application of fertilizers increased net incomes, but cassava grown between hedgerows of *Leucaena leucocephala* and *Gliricidia sepium* (alley cropping system) gave the highest yields and net incomes, both with and without fertilizer application.

-In sloping areas, intercropping cassava with peanut and/or planting contour hedgerows of vetiver grass or *Leucaena* reduced soil losses by erosion and maintained or improved soil fertility.

INTRODUCTION

In Vietnam cassava is the third most important food crop, after rice and maize; it is used mainly for human consumption and for animal feed. In the last decade of the 20^{th} century, the crop has changed from a subsistence food crop to a cash crop; the planted area is ranked in fifth position, after rice, maize, sweet potato, vegetables and legume crops. According to the national statistics, in 2002 the area under cassava in Vietnam was 246,172 ha, with the estimated total production of 2.0 million tonnes fresh roots and an average yield of 8 t/ha. The Northern Mountainous Region, the Southeastern region, the North Central Coast and the South Central Coast are the four ecological zones of greatest cassava production in Vietnam.

Although cassava is a crop with a capacity to produce high yields, until now the average yield of cassava production and the economic returns for the farmers in Vietnam has been low, as the areas under cassava production were not quite suitable. The main reasons are that cassava was usually grown by small farmers in very marginal areas or on sloping lands and poor soils, using local varieties and without any improved technologies or external inputs.

From 1989 and up to now, cassava breeding and agronomy research in Vietnam

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have been strengthened and supported by CIAT and the Nippon Foundation with the following objectives: to develop new cassava technologies which require low inputs but result in higher yields and incomes while maintaining soil fertility.

RESEARCH RESULTS

Soil Fertility Maintenance through Fertilizer Application

Since 1990 two long-term NPK experiments have been conducted, one on the red latosol clay soil in Hung Loc Agricultural Research Center in South Vietnam, and one on yellow sandy clay loam soil in Thai Nguyen University of Agriculture and Forestry in North Vietnam. Both experiments have 12 treatments, consisting of 4 levels each of N, P and K in an incomplete factorial design. Two cassava varieties were planted in subplots, with fertilizer treatments in main plots.

In the red latosol soil at Hung Loc Agricultural Research Center, the response of cassava to any of the three nutrients was initially not clear, even after four years. But, starting in the fifth year, the response to K application became significant and this response increased year after year. After 12 years of continuous cropping on the same plots the response to N, P and K was very clear, especially the response of cassava to K and N. Among the 12 treatments, the treatment with 80 kg N+40 P_2O_5+80 K_2O/ha gave the highest yield and net income (**Figure 1A**).

In the yellow clay loam soil in Thai Nguyen University of Agriculture and Forestry, the response of cassava to K was clear even in the first and second years. And after 12 years the response of cassava to all three nutrients was very clear, but specially to the application of K. The root yield of cassava was 2.4-2.8 t/ha in the treatment without K applied, and was more than 20 t/ha in the treatment with adequate K applied. Again, application of 80 kg N+40 P_2O_5+80 K_2O/ha gave a high yield and produced the highest net income (**Figure 1B**).

Figure 2 shows that the exchangeable K level of the soil after 12 years of continuous cassava cultivation was markedly reduced when no K was applied. The soil K level increased with increasing levels of applied K, but remained below the critical level of 0.15 me K/100 g even with the application of 80 kg K_2O/ha in Hung Loc Center and of 160 kg K_2O/ha in Thai Nguyen (**Figure 3**).

Soil Fertility Maintenance by Intercropping

An experiment on cassava intercropping and alley cropping has been conducted at Hung Loc Center for ten years. The experiment has eight treatments, two with intercropping of grain legumes, three with intercropped green manures and two with leguminous trees planted as hedgerows in alley cropping system, and a check. The objective of the research is to determine the long-term effect of intercropping, green manuring and alley cropping on soil fertility and cassava root yields. **Table 1** shows that the annual yield of cuttings of leaves and stems and the nutrients returned to the soil were highest in case of the two legume tree species, *Leucaena leucocephala* and *Gliricidia sepium,* planted in hedgerows. Also, the soil K levels were highest in these two treatments while soil P was not much affected by any of the treatments except that hedgerows of *Leucaena leucocephala* increased the available P-content of the soil (**Figure 4**).

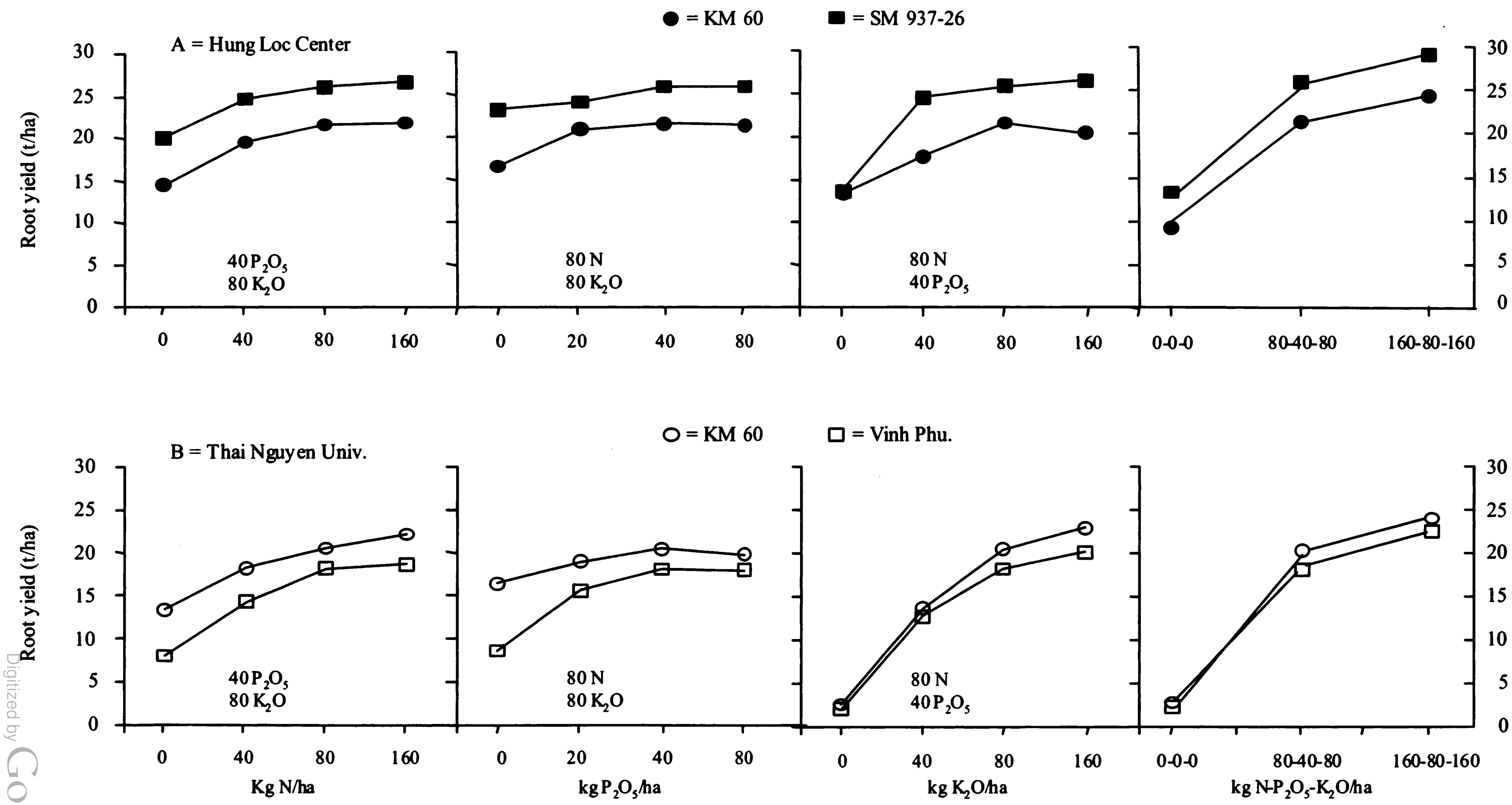

Figure 1. The effect of annual applications of various levels of N, P and K on the root yields of two cassava varieties planted in Hung Loc Agric. Research Center (top) and at Thai Nguyen Univ. of Agric. and Forestry. Data are average values for 1999 to 2001 (10th to 12th cycle).

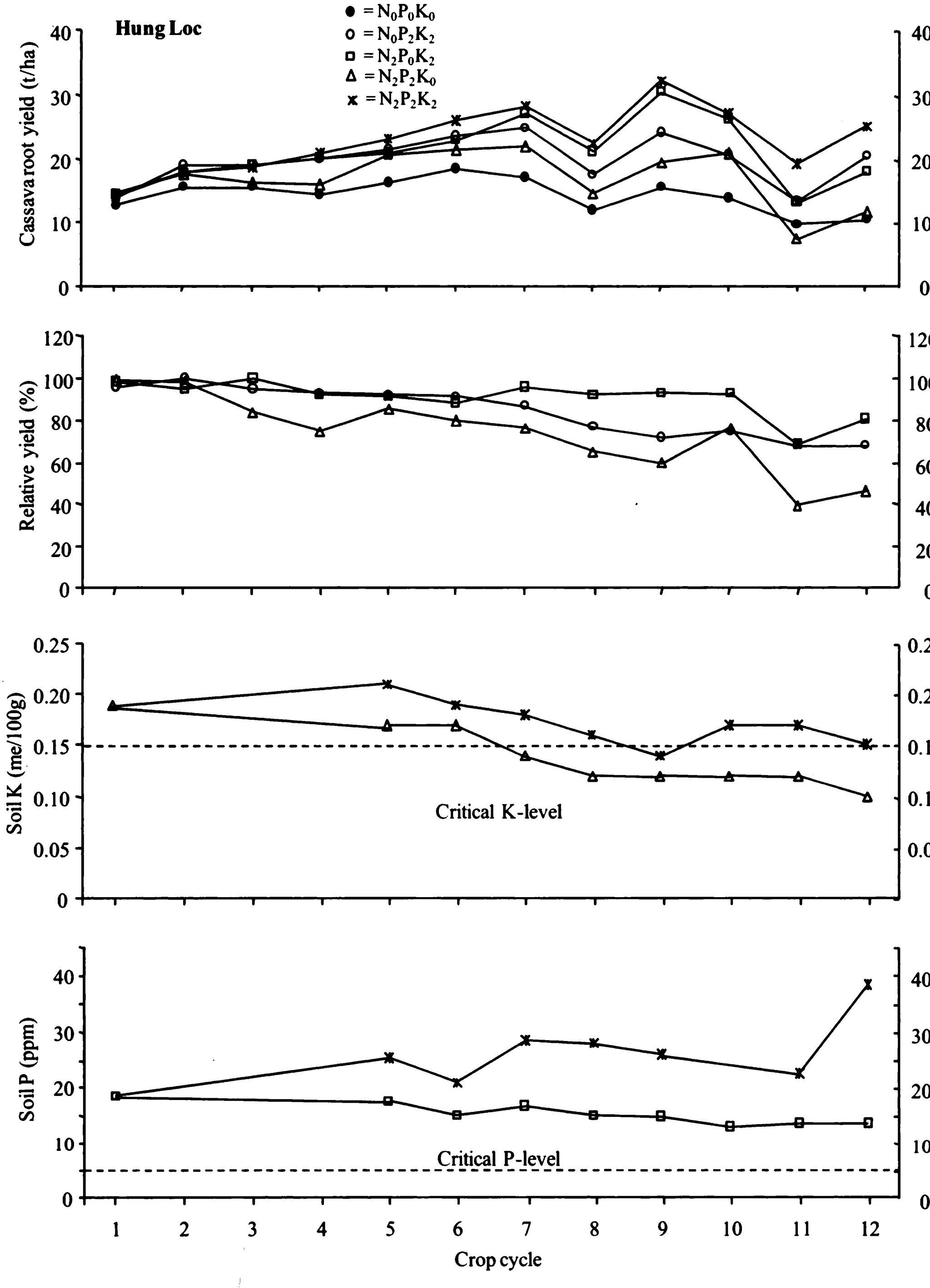

Figure 2. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during twelve years of continuous cropping in Hung Loc Agric. Research Center, Dong Nai, Vietnam.

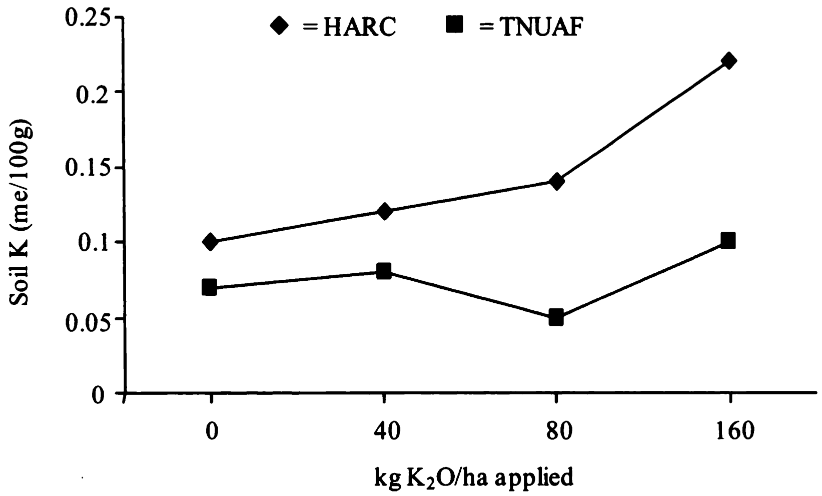

Figure 3. The effect of annual application of four rates of K on the K level of the soil in two long-term NPK trials conducted in Thai Nguyen University of Agriculture and Forestry (TNUAF) and in Hung Loc Agricultural Research Center (HARC), Vietnam in 2002 after 12 years of continuous cassava cultivation.

Table 1. The amount of annual cuttings of legume leaves and stems and the nutrients which returned to the soil in 1999/2000 during the 8th year of continuous cropping in a long-term soil improvement experiment conducted at Hung Loc Agric. Research Center in Dong Nai, Vietnam.

Treatment	Crop residues or leaf/stem cuttings (t DM/ha)	Nutrient content (%)			Nutrients returned (kg/ha)		
		N	P	K	N	P	K
1. Cassava monoculture	-	-	-	-	-	-	-
2. C+pigeonpea green manure	4.92	3.47	0.92	3.88	17.1	4.53	19.1
3. C+*Mucuna* green manure	2.86	2.52	0.41	1.38	7.2	1.18	3.9
4. C+peanut intercrop	4.75	2.87	0.44	1.35	13.6	2.08	6.4
5. C+cowpea intercrop	3.56	2.42	0.32	2.10	8.6	1.15	7.5
6. C+*Canavalia* green manure	4.23	2.59	0.65	2.79	10.9	2.75	11.8
7. C+*Leucaena* alley crop	8.67	3.36	0.65	1.59	29.1	5.60	13.8
8. C+*Gliricidia* alley crop	7.71	3.50	0.78	2.77	26.9	6.03	21.4

Table 2 shows that the cassava root yields in the *Canavalia* green manure and the two alley cropping treatments were significantly higher as compared to cassava grown in monoculture. And among the eight treatments, cassava planted as an alley crop with *Leucaena leucocephala* and *Gliricidia sepium* hedgerows, gave the highest yields and economic benefits, while cassava intercropped with peanut and *Mucuna* produced the lowest yields and net income.

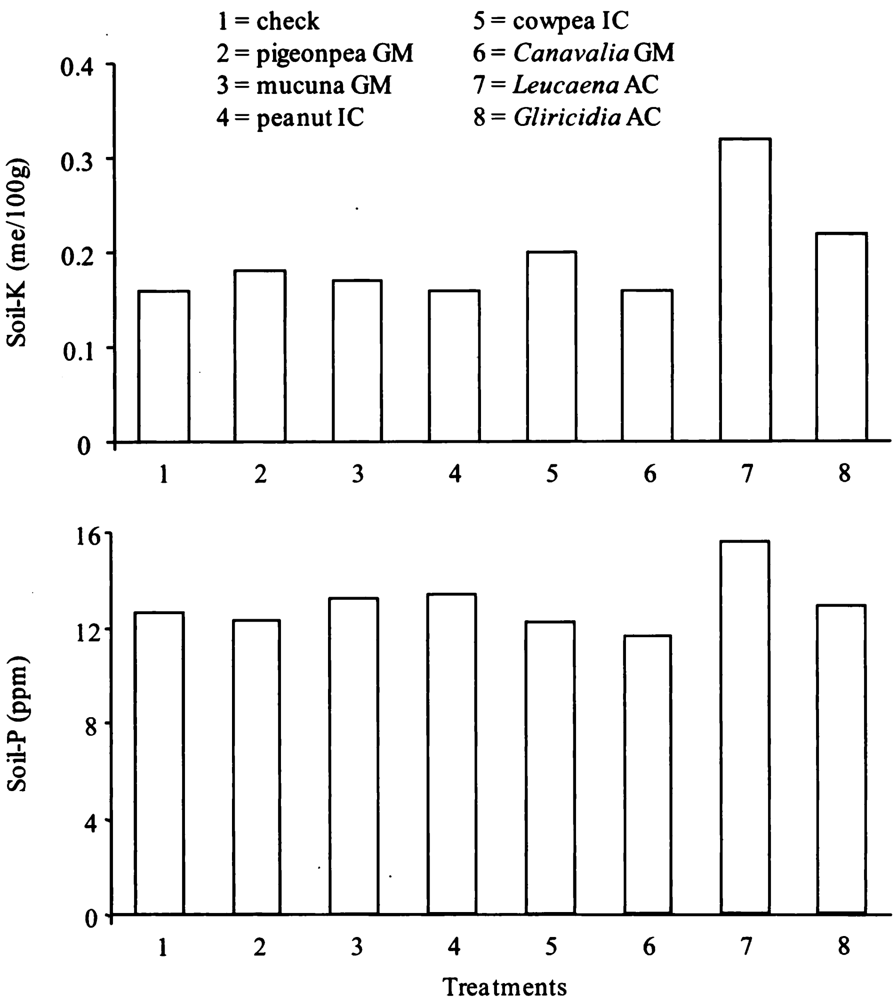

Figure 4. The effect of green manures (GM), intercropping (IC) and alley cropping (AC) on the exchangeable K and available (Bray II) P-content of the soil after ten consecutive years of cassava cultivation without fertilizers at Hung Loc Agric. Research Center in south Vietnam in 2002.

Erosion Control

In Vietnam, mountainous areas occupy about 75% of the total area. According to estimates of Nguyen Tu Siem and Thai Phien, deforestation, and the practice of slash-and-burn for growing upland rice and cassava without control of erosion, resulted in one million ha of soil being eroded and degraded with little or no production capacity.

Table 3 indicates that on sloping land in Hung Loc Agricultural Research Center cassava intercropping with mungbean or peanut, or the planting of contour hedgerows of vetiver grass, *Leucaena* or *Gliricidia* reduced the soil loss and gave higher yields than cassava grown in monoculture. Also, intercropping cassava with peanut or planting hedgerows of *Leucaena* produced the highest economic benefits.

Table 2. The effect of green manures, intercropping and alley cropping on the yield of cassava and intercrops, as well as on gross and net income when casssava was grown without fertilizer for the tenth consecutive year at Hung Loc Agricultural Research Center in Dong Nai, Vietnam in 2001/02.

Treatments[1)]	Cassava yield (t/ha)	Starch content (%)	Intercrop yield (t/ha)	Gross income[2)]	Product. cost[2)]	Net income
				('000 dong/ha)		
1. Cassava monoculture	12.10c	26.6c	-	5,324	3,100	2,224
2. C+pigeonpea green manure	13.27bc	27.0bc	8.30b	5,839	3,700	2,139
3. C+*Mucuna* green manure	8.71d	25.8d	1.90d	3,832	3,700	132
4. C+peanut intercrop	12.21c	26.7bc	4.59c	5,372	3,700	1,672
5. C+cowpea intercrop	13.77bc	27.2b	2.41d	6,059	3,700	2,359
6. C+*Canavalia* green manure	15.87b	26.0d	2.46d	6,983	3,700	3,283
7. C+*Leucaena* alley crop	21.14a	28.1a	12.67a	9,367	3,400	5,967
8. C+*Gliricidia* alley crop	21.45a	26.8bc	8.35b	9,438	3,400	6,038
CV (%)	12.00	3.85	12.82			
LSD (0.05)	2.62	0.51	0.95			

1) Cassava and intercrops were fertilized annually with a total of 100 kg N, 40 kg P_2O_5 and 100 kg K_2O/ha only for the first seven years.

2) Prices: cassava dong 440/kg fresh roots
cassava cultivation without fertilizers or intercrops: 3.1 mil. dong/ha
intercrop planting 200,000 dong/ha
intercrop seed 200,000 dong/ha
intercrop harvest/cutting 300,000 dong/ha
weeding with intercrop 100,000 dong/ha less than without intercrop

Table 3. The effect of intercropping and contour hedgerows on soil losses by erosion, the yield of cassava and intercrops, the root starch content, and the gross and net incomes when cassava, SM937-26, was grown on 8% slope at Hung Loc Agricultural Research Center in Dong Nai, Vietnam in 2001/02.

Treatment	Dry soil loss (t/ha)	Cassava yield (t/ha)	Starch content (%)	Intercrop yield Residue	Intercrop yield Grain	Gross income	Product. cost[2)]	Net income
				(t/ha)		('000 dong/ha)		
1. Cassava monoculture	39.1a	32.13	28.8a	-	-	14,137	4,986	9,151
2. C+mungbean intercrop	30.9b	34.54	27.3b	-	-	15,197	5,686	9,512
3. C+peanut intercrop	25.0bc	33.13	28.9a	3.15	0.129	15,222	5,686	9,536
4. C+vetiver hedgerows	11.3d	33.68	28.8a	13.32	-	14,819	5,686	9,232
5. C+*Leucaena* hedgerows	17.8c	37.00	29.6a	7.24	-	16,280	5,686	10,694
6. C+*Gliricidia* hedgerows	20.5c	34.11	26.7b	6.14	-	15,008	5,686	9,422
CV (%)	19.2	NS	2.9					
LSD (0.05)	6.9		1.2					

1) Prices: cassava dong 440/kg fresh roots
peanut 5,000/kg dry pods

2) Cost: cassava planting material 0.5 mil. dong/ha
intercrop seed or material 0.2 mil. dong/ha
labor for cassava cultivation 3.3 mil. dong/ha
fertilizers 1,186 mil. dong/ha
labor for intercropping 0.5 mil. dong/ha
labor for hedgerow cutting 0.6 mil. dong/ha

FUTURE DIRECTION

Based on the results obtained from this research, future cassava agronomy research in Vietnam will focus on the following research topics:
-Maintenance of soil fertility by intercropping and fertilizer application
-Erosion control in cassava areas with sloping land in various parts of the country
-Using FPR and PRD methods to develop practical agronomic practices and enhance the adoption of these practices by farmers.

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CASSAVA LONG-TERM FERTILITY EXPERIMENTS IN THAILAND

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ABSTRACT

Cassava in Thailand is normally planted on flat or undulating land (0-10% slope), having sandy or sandy loam soils of low fertility. In some areas cassava has been cultivated continuously for more than 50 years; in that case the soil's productivity has steadily declined resulting in a decrease in growth and yield.

In 1975 and 1976, long-term fertility experiments for cassava were initiated in three locations, i.e. at Rayong Field Crops Research Center (clayey, mixed, Typic Paleudult; Huay Pong soil series); at Banmai Samrong Field Crops Experiment Station (fine-loamy, siliceous, Oxic Paleustult; Korat soil series); and at Khon Kaen Field Crops Research Center (fine loamy, siliceous, Oxic Paleustult; Yasothon soil series). The treatments consisted of the application of different combinations of N, P and K, as well as municipal compost, with or without incorporation of cassava stalks (stems and leaves) after each harvest.

The results of 31 years of continuous cassava cropping at Rayong and Banmai Samrong, and 30 years at Khon Kaen show a clear response of cassava to annual fertilizer applications in all three locations. Without fertilizer application, cassava growth and yields decreased, and the soil's fertility status declined, especially in Khon Kaen. The omission of K reduced the growth and yield of cassava more than the omission of either P or N, while the annual incorporation of cassava stalks after harvest 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 per ha, combined with 12.5 t/ha of municipal compost or with about 18 t/ha of incorporated cassava stalks, resulted in better growth and higher cassava root yields than the application of only complete chemical fertilizers; these treatments were able to maintain roots yields of 20-40 t/ha and to maintain or improve the fertility status of the soils. Based on these results, it can be concluded that long-term productivity of cassava can be sustained with the application of adequate N, P and K fertilizers in combination with crop residues or other organic materials.

INTRODUCTION

Thailand is presently among the world's major producers of cassava roots, and is the biggest exporter of cassava products. About 70% of the total cassava production is exported, mainly as pellets, chips and starch (TTTA, 2003). Most cassava in Thailand is grown on coarse textured soils, with sandy clay loam and sandy loam textures and having low fertility (Duangpatra, 1988). These soils have rather unfavorable physical and chemical properties, having a very light texture, low levels of organic matter, low contents of available phosphorus (P) and potassium (K), and low clay content. 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. And the cultural practices used by almost all cassava farmers is continuous cassava cultivation without fertilizer application or soil erosion control measures. These factors have caused the soil's productivity to steadily decline, resulting in a decrease in cassava growth and yield.

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It has long been recognized that certain nutrient elements are essential for plant growth and normal development. It has also been known that the lack of one or more of the essential elements leads to abnormalities of one sort or another. Lack of one or another of the essential elements in available form in the soil solution may lead to disease symtoms, reduced growth, lower yields and inferior quality products. Moreover, organic materials such as compost, plant biomass and manures can improve soil properties and the soil's biochemical properties, especially in infertile acid soil.

Three cassava long-term fertility experiments were initiated in major cassava growing areas. The main objective of these experiments is to study the effect of chemical fertilizers, compost and the return of cassava crop residue on cassava growth and root yield, and soil fertility status for cultivation in Thailand

MATERIALS AND METHODS

A randomized complete block design of 8 treatments and 4 replications was used. The plot size was 8 x 10 meters and plant spacing was 1 x 1 meter. Stem cuttings of cassava were planted vertically during the early rainy season (May-June) and plants were harvested at about 11 months after planting. Chemical fertilizers were applied at about 1-2 months after planting in moist soil. In one treatment, compost was applied and incorporated before planting. In most treatments cassava stems and leaves were removed from the field after harvest, but in two treatments these tops were left on the plots and incorporated during land preparation. Weeds were controlled by 4-5 times hand weeding during the crop cycle.

Locations and Soils

The same experiment was conducted in three agro-ecological zones of Thailand:

1. Rayong Field Crops Research Center; Huay Pong soil series, sandy clay loam; clayey, mixed, Typic Paleudult, in the eastern seaboard region.
2. Banmai Samrong Field Crops Experiment Station; Korat soil series, sandy loam; fine loamy, siliceous, Oxic Paleustult, in the southwestern part of the northeastern region.
3. Khon Kaen Field Crops Research Center; Yasothon soil series, sandy loam; fine loamy, siliceous, Oxic Paleustult, in the central part of the northeastern region.

Treatments

1. $N_0P_0K_0$
2. $N_1P_0K_0$
3. $N_1P_1K_0$
4. $N_1P_0K_1$
5. $N_1P_1K_1$
6. $N_1P_1K_1$+municipal compost (12.5 t/ha)
7. $N_1P_1K_1$ +tops incorporated
8. $N_0P_0K_0$ +tops incorporated

From 1975 to1998: N_1 = 50 kg N/ha, P_1 = 50 kg P_2O_5/ha and K_1 = 50 kg K_2O/ha
From 1999 to 2005: N_1 = 100 kg N/ha, P_1 = 50 kg P_2O_5/ha and K_1 = 100 kg K_2O/ha.
In two treatments tops were incorporated at 18.75 t/ha after each harvest.

Varieties

From 1975 to 1992 all three trials were planted with the local variety Rayong 1; later Rayong 1 was gradually replaced by the higher yielding new varieties Rayong 90, Rayong 5 and Rayong 72, as indicated in **Table 1.**

Table 1. Cassava varieties planted in the long-term fertilizer trials conducted from 1975 to 2005 in three locations in Thailand.

Variety	Rayong FCRC	Banmai Samrong	Khon Kaen FCRC
Rayong 1	1975-1992	1975-1995	1976-1996
Rayong 90	1993-1995		
Rayong 5	1996-2005	1996-2005	1997-1999
Rayong 72			2000-2005

Duration

The two experiments in Rayong and Banmai Samrong were initiated in 1975 and the one in Khon Kaen in 1976; they have been replanted in the same plots with the same treatments every year until the present.

RESULT AND DISCUSSION

1. Effect on Cassava Yields

The results of 31 years of continuous cassava cropping in Rayong and Banmai Samrong and 30 years in Khon Kaen show a clear response of cassava to annual fertilizer applications in all three soils.

In the two soil series of Yasothon and Huay Pong in Khon Kaen and Rayong, respectively, the growth and root yields of cassava decreased rapidly during the first 10-15 years of cassava cultivation in the treatments without any chemical fertilizer or in treatments without K; thereafter, the yields remained low in Khon Kaen, but improved slightly in Rayong (**Figure 1** to **3**). The growth and yield of cassava cultivated in Korat soil series in Banmai Samrong did not show a major response to fertilizer application, but yields varied from year to year due to fluctuations in rainfall. The application of NK and NPK fertilizers resulted in better growth and higher cassava root yields than the application of N or NP fertilizers without K, in a similar fashion in all three soil series. Hence, potassium appeared to be the most limiting nutrient, followed by nitrogen.

The application of complete chemical fertilizers of N, P and K with an additional 12.5 t/ha of municipal compost, or with about 18.75 t/ha of incorporated cassava stalks (stems and leaves), resulted in the best growth and highest cassava root yields of 30-50 t/ha; this is considerably higher than the yield of 20-30 t/ha obtained with only complete chemical fertilizers (**Figures 1** to **3**). The continuous application of compost or cassava stalks over many years improved the soil nutrient status resulting in higher yields. Yields obtained after 1993-1996 may also have increased due to the use of new higher-yielding varieties (**Table 1**).

Both with and without chemical fertilizer application, the incorporating of cassava stalks at about 18.75 t/ha resulted in better growth and higher yields than when these crop residues were removed from the field (**Figures 1 to 3**).

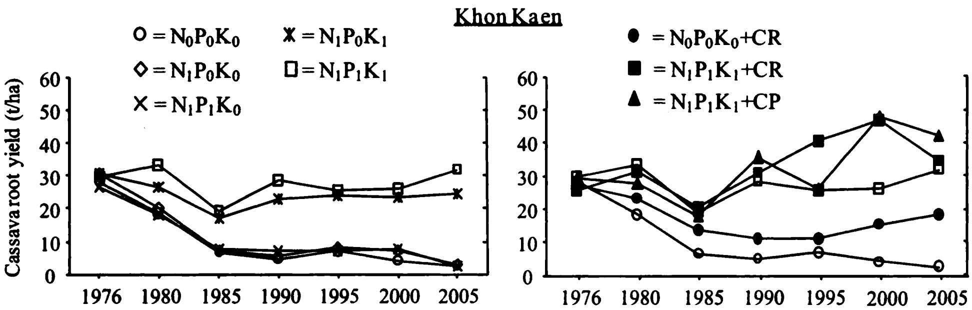

Figure 1. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on cassava root yields during 30 consecutive crops grown in Khon Kaen.

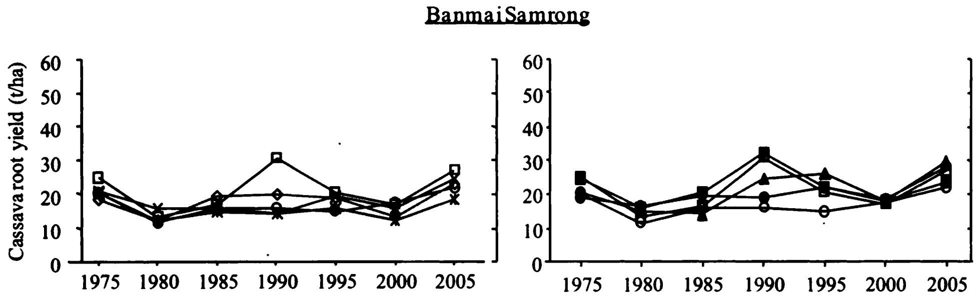

Figure 2. Effect of annual applications of fertilizers and compost (CP), and crop residue (CR) management on cassava root yields during 31 consecutive crops grown in Banmai Samrong.

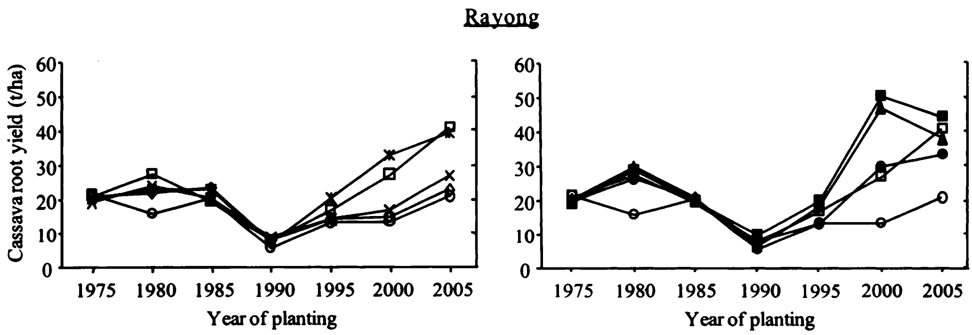

Figure 3. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on cassava root yields during 31 consecutive crops grown in Rayong.

The average starch yield of cassava grown in all three sites were significantly higher in the treatments of complete chemical fertilizers combined with 12.5 t/ha of compost or with 18.75 t/ha of incorporated cassava stalks, than in that of the complete chemical fertilizer alone (**Table 2**). This is partly due to the higher root yields obtained in those two treatments but also due to the higher starch contents of the roots. The three treatments without K application and with crop residues removed had the lowest root starch contents and starch yields in all three soil series indicating the importance of K application for obtaining high yields and high starch contents. In contrast, application of N alone tended to decrease the starch contents and starch yields, while P application had little benefial effect (**Table 2**).

Table 2. Effect of annual applications of various combinations of N, P, K and municipal compost as well as cassava crop residue management on the average fresh root yield, starch content and starch yield during the last five years (2001-2005) in long-term (>30 years) fertilizer trials conducted in three locations in Thailand.

Fertilizer treatments[1)]	Root yield (t/ha)	Starch content (%)	Starch yield (t/ha)
Khon Kaen			
$N_0P_0K_0$	4.81	14.3	0.69
$N_1P_0K_0$	4.06	10.8	0.44
$N_1P_1K_0$	4.12	10.7	0.44
$N_1P_0K_1$	30.31	16.3	4.94
$N_1P_1K_1$	33.12	16.6	5.50
$N_1P_1K_1$ + CP	47.62	20.2	9.62
$N_1P_1K_1$ + CR	43.25	18.6	8.06
$N_0P_0K_0$ + CR	19.62	15.0	2.94
Banmai Samrong			
$N_0P_0K_0$	18.56	23.9	4.44
$N_1P_0K_0$	18.44	21.0	3.88
$N_1P_1K_0$	22.19	22.3	4.94
$N_1P_0K_1$	20.12	23.6	4.75
$N_1P_1K_1$	24.00	24.0	5.75
$N_1P_1K_1$ + CP	26.94	24.8	6.69
$N_1P_1K_1$ + CR	25.38	23.8	6.06
$N_0P_0K_0$ + CR	23.75	24.5	5.81
Rayong			
$N_0P_0K_0$	12.69	23.2	2.94
$N_1P_0K_0$	15.25	19.3	2.94
$N_1P_1K_0$	17.88	19.2	3.44
$N_1P_0K_1$	30.00	22.7	6.81
$N_1P_1K_1$	29.88	21.4	6.38
$N_1P_1K_1$ + CP	31.94	24.1	7.69
$N_1P_1K_1$ + CR	38.81	22.0	7.44
$N_0P_0K_0$ + CR	22.56	22.7	5.12

[1)] N_1 = 100 kg N/ha as urea; P_1 = 50 kg P_2O_5/ha as TSP; K_1 = 100 kg K_2O/ha KCl

CP = 12.5 t/ha of municipal compost; CR = cassava stems+leaves incorporated in soil before next planting; in all other treatments CR are removed every year.

2. Effects on Soil Fertility Status

There were significant changes in many soil properties after continuous cultivation of cassava in infertile acid soil, such as in pH, organic matter content, plant nutrient availability and biological activity in the soils. The results of soil analysis indicate that the Yasothon soil in Khon Kaen had a much lower soil fertility status than the Huay Pong soil in Rayong and the Korat soil in Banmai Samrong.

In spite of this, with adequate fertilization, cassava yields tended to be higher in the Yasothon and Huay Pong soils than in the more fertile Korat soil; in the latter, cassava yields may have been depressed by severe Zn deficiency in these high-pH calcareous soils.

The pH of the Yasothon soil decreased from 5.2 to 4.0-4.5 in the treatment of no chemical fertilizer and the treatments of different combinations of N, P and K fertilizers; and slightly decreased in the treatment of incorporating cassava stalks after each harvest. The treatment of combining complete fertilizers with compost increased the pH to about 7.0 in the 10th to 30th year (**Figure 4**). Similar results were obtained in Huay Pong soils with an initial pH of 4.8 which increased to 6.3 with application of compost (**Figure 6**). Also, the initial pH of 6.7 of the Korat soil slightly decreased initially in all treatments with and without chemical fertilizer application but later increased again (**Figure 5**). The application of complete chemical fertilizers with compost or with cassava residues incorporated, and that of cassava residues alone, slightly raised the pH value to 7.0-7.2.

Under regular field crop cultivation, the soil organic matter (OM) content in tropical regions usually declines leading to a reduction in soil pH. The results from all three experiments on continues cassava cultivation indicate that without organic materials incorporated, the soil OM content decreased more in Yasothon soils than in Korat and Huay Pong soils (**Figures 7** to **9**). However, the application of the combination of complete chemical fertilizers with 12.5 t/ha of compost maintained the soil OM content. There was a trend of a slight increase in soil OM content when 18.75 t/ha of cassava residues were incorporated.

With the application of phosphate fertilizer, and even more so with the addition of compost or cassava residues, soil P increased significantly in all soil series (**Figures 10** to **12**).

The exchangeable soil K content increased significantly in the Yasothon and Huay Pong soils (**Figures 13** to **15**). In the Korat soil, however, the soil K content declined over the years from the very high initial value of 198 ppm to less than 100 ppm, without K application and to 130-145 ppm with K fertilizer application. The soil K level was always higher with K than without K application and much higher with the addition of compost. Crop residue incorporation tended to increase the exchangeable-K level of the soil, but this was not consistent.

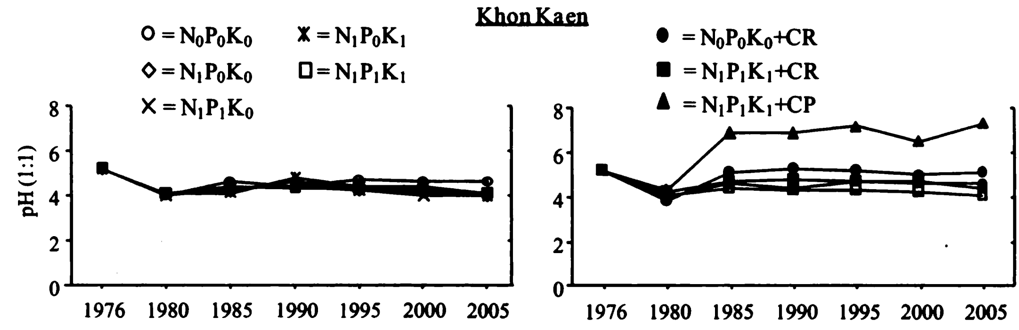

Figure 4. Effect of annual application of fertilizers and compost (CP) ,and crop residue (CR) management on soil pH in Khon Kaen during 1976-2005.

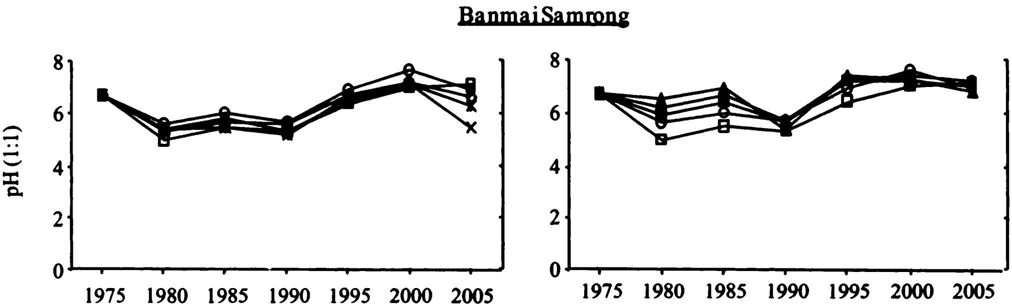

Figure 5. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil pH in Banmai Samrong during 1975-2005.

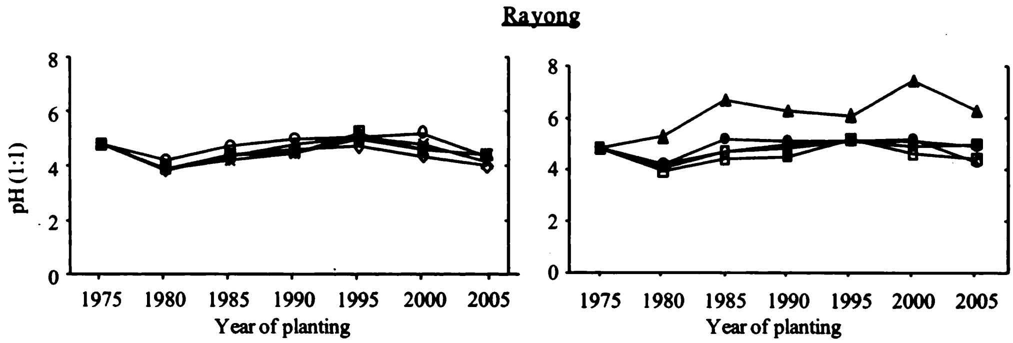

Figure 6. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil pH in Rayong during 1975-2005.

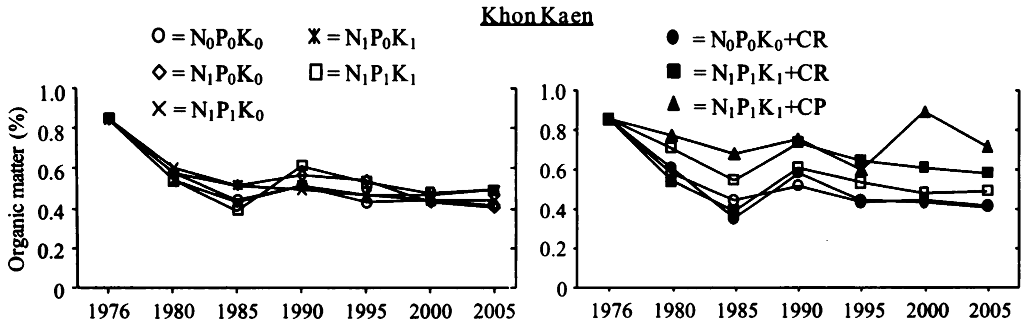

Figure 7. Effect of annual application of fertilizers and compost (CP) ,and crop residue (CR) management on soil organic matter in Khon Kaen during 1976-2005.

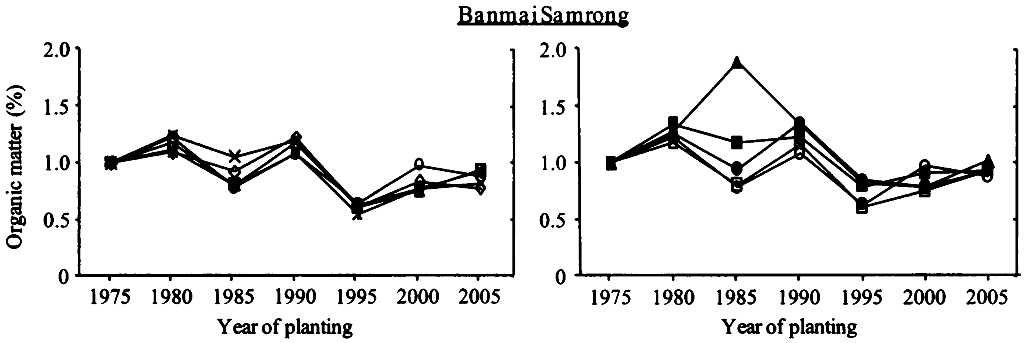

Figure 8. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil organic matter in Banmai Samrong during 1975-2005.

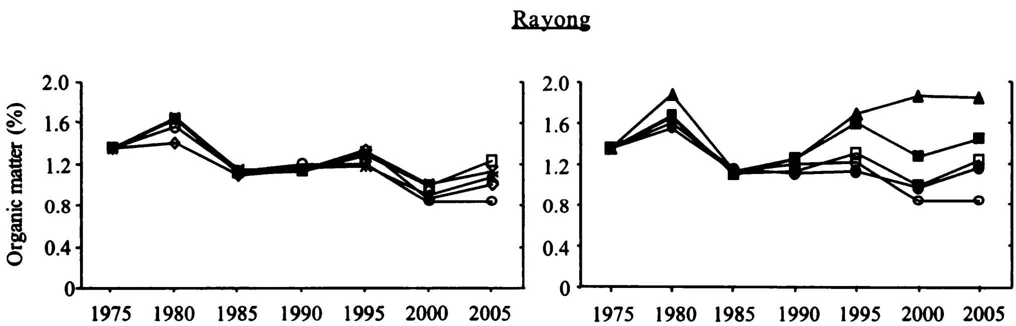

Figure 9. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil organic matter in Rayong during 1975-2005.

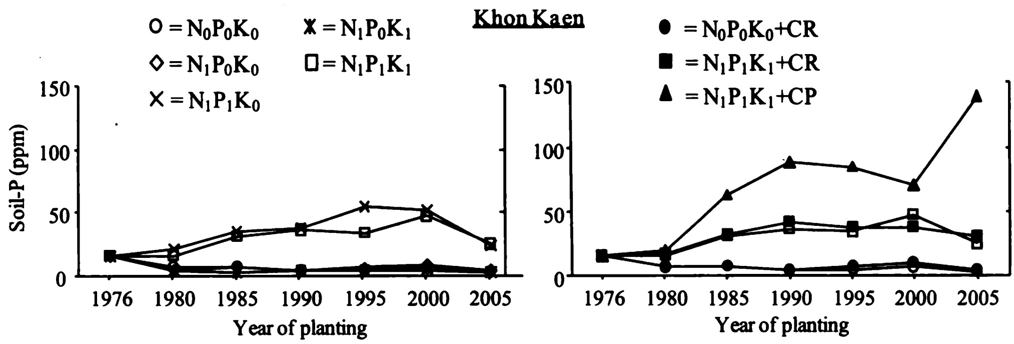

Figure 10. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil-P in Khon Kaen during 1976-2005.

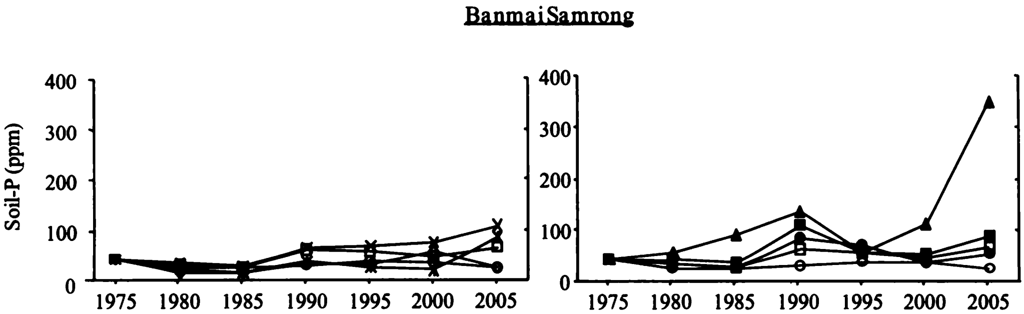

Figure 11. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil-P in Banmai Samrong during 1975-2005.

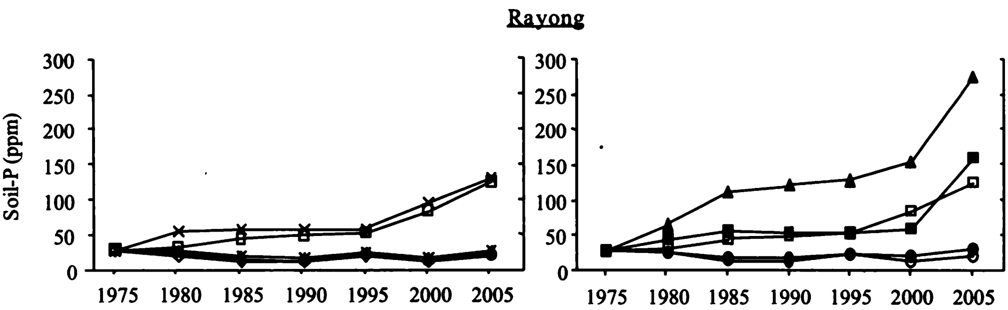

Figure 12. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil-P in Rayong during 1975-2005.

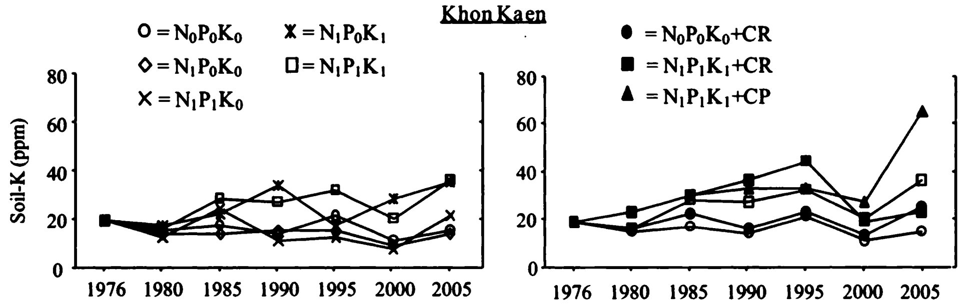

Figure 13. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil-K in Khon Kaen during 1976-2005.

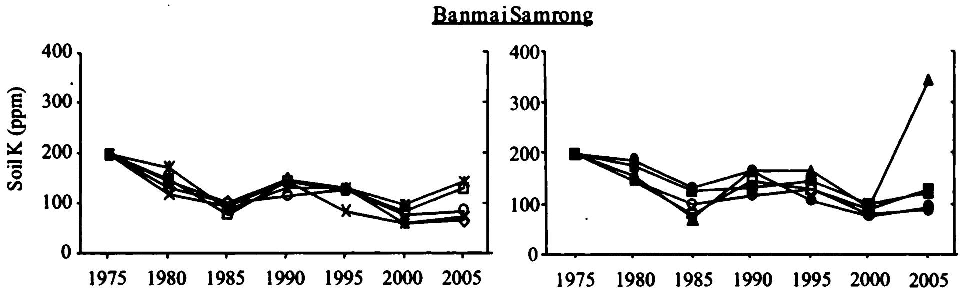

Figure 14. Effect of annual application of fertilizers and compost (CP), and crop residue (CR) management on soil-K in Banmai Samrong during 1975-2005.

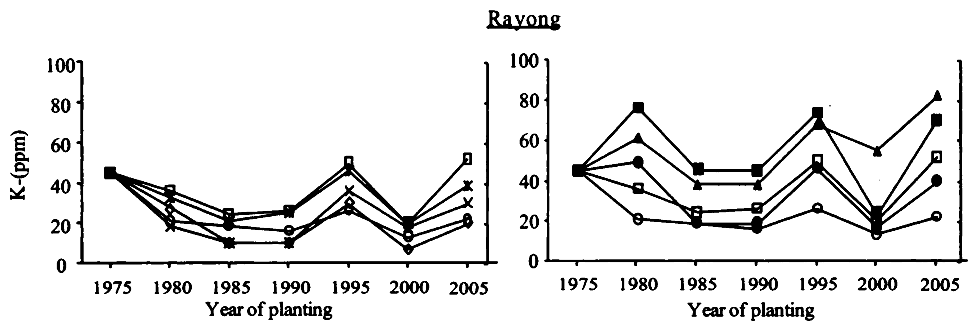

Figure 15. Effect of annual application fertilizers and compost (CP), and crop residue (CR) management on soil-K in Rayong during 1975-2005.

CONCLUSIONS

1. Without fertilizer application, cassava growth and yield, as well as the soil fertility status declined very markedly over the years as a result of continuous cassava cultivation.
2. With the optimum chemical fertilizer application of 100 kg N, 50 P_2O_5 and 100 K_2O/ha, cassava yields could be maintained or increased during 30 years of continuous cassava cultivation on all three soils.
3. To sustain long-term cassava production, 100 kg N, 50 P_2O_5 and 100 K_2O/ha combined with 18 t/ha of cassava tops incorporated after each harvest, or combined with 12 t/ha of compost is recommended.
4. When P or K were applied every year, these two nutrients tended to accumulate in the soil, resulting in a steady increase in available P and exchangeable K.
5. The annual chemical fertilizer application for cassava of 100 kg N, 50 P_2O_5 and 100 K_2O/ha, combined with 18 t/ha. of cassava tops incorporated after each harvest, or combined with 12 t/ha of compost, improved the fertility status of the soils, even after 30 years of continuous cropping.

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SOIL FERTILITY IMPROVEMENT THROUGH MANURES AND CROPPING SYSTEMS AND THE EFFECT ON CASSAVA PRODUCTIVITY IN THAILAND

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ABSTRACT

Cassava (*Manihot esculenta* Crantz), is a widely grown field crop in Thailand. In 2000, the cassava planted area was 1.18 million ha, with a total fresh root production of 19.06 million tonnes, having a value of 20,387 million baht after processing into various export products. Over 80% of the soils in the cassava growing area have a sandy or coarse texture with a high rate of leaching; these are naturally infertile soils. However, these infertile soils are becoming even further degraded due to their undulating to rolling topography, an erratic distribution of rainfall, the slow rate of establishment of cassava after planting, and the use of improper cultural practices, which may lead to severe soil erosion. One long-term fertilizer experiment conducted in Khon Kaen indicated that the yield of cassava without any fertilizer application decreased drastically from 27 t/ha in the first year to 8 and 3 t/ha after 12 and 25 years of continuous cropping, respectively.

To improve the sustainability and increase the productivity of cassava, chemical fertilizers and/or manures should be applied. It was found that the root yield of cassava increased between 30 and 119%, and between 13 and 125%, with the application of adequate amounts of chemical fertilizers and animal manures, receptively. Moreover, the annual application of well-balanced NPK fertilizers tended to maintain the level of root yield, whereas, fertilizer application with incorporation of cassava crop residues (stems and leaves) after harvest, tended to gradually increase the yields in the long-run. In addition, including appropriate leguminous crops in the cassava cropping system, either as green manures or as rotation crops, was shown to contribute to an increase in cassava yields. Many long-term experiments have shown that cassava yields declined under continuous monocropping without application of fertilizers or manure, but could be maintained at a fairly high level when adequate amounts of N and K were applied. However, after the first 3-4 cycles of crop rotation, cassava yields gradually increased in subsequent years. Also, these cropping systems resulted in higher net incomes from the leguminous crops, especially when cassava prices were unstable, which is often the case. In addition, the application of adequate fertilizers and manures, the incorporation of crop residues and proper crop and soil management could maintain and even improve the fertility of the soil.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is widely grown in Thailand, especially in the Northeastern region, which accounts for more than 60% of the total planted area in the country. However, the soil in the cassava growing area is highly infertile, has a sandy or coarse texture, a low buffer capacity, and is characterized by excessive leaching. Besides, many soils become degraded due to an undulating to rolling topography, an erratic distribution of rainfall, and improper practices of crop cultivation; these factors ultimately lead to a reduction in yield potential. Moreover, because of high soil losses caused by erosion, especially at the early growth stage of the crops, there are significant losses of soil nutrients and a reduction in nutrient use efficiency in this region. Making improvements in soil productivity, as done in some small-scale farmers' holdings, revealed that agronomic

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practices such as application of animal manures, the incorporation of green manure crops and cropping system management using leguminous crops, such as sun hemp (*Crotalaria juncea*), pigeonpea (*Cajanus cajan*), cowpea (*Vigna unguiculata*), sword bean (*Canavalia ensiformis*) and verano pasture (*Stylosanthes hamata* cv. *Verano*) could substantially increase cassava yields.

This paper describes some ways to improve soil fertility through fertilizers or manures, and through various cropping systems, and their effect on cassava productivity.

The Effects of Chemical Fertilizer Application and Crop Residue Incorporation

Two long-term cassava experiments, now completing 22 and 25 years, have been conducted on Yasothon infertile sandy soils at Khon Kaen Field Crops Research Center (FCRC). Wongwiwatchai *et al.* (2001) and Nakaviroj *et al.* (2002) reported that annual application of fertilizer at the rate of 50-50-50 kg/ha of N-P_2O_5-K_2O, could maintain cassava yields in the long run, whereas without fertilizers yields decreased drastically year by year (**Figure 1**). Moreover, combining chemical fertilizer application with the incorporation of stems and leaves of cassava after each harvest resulted in a gradual increase in root yields considerably above that obtained with chemical fertilizers alone (**Figure 2**).

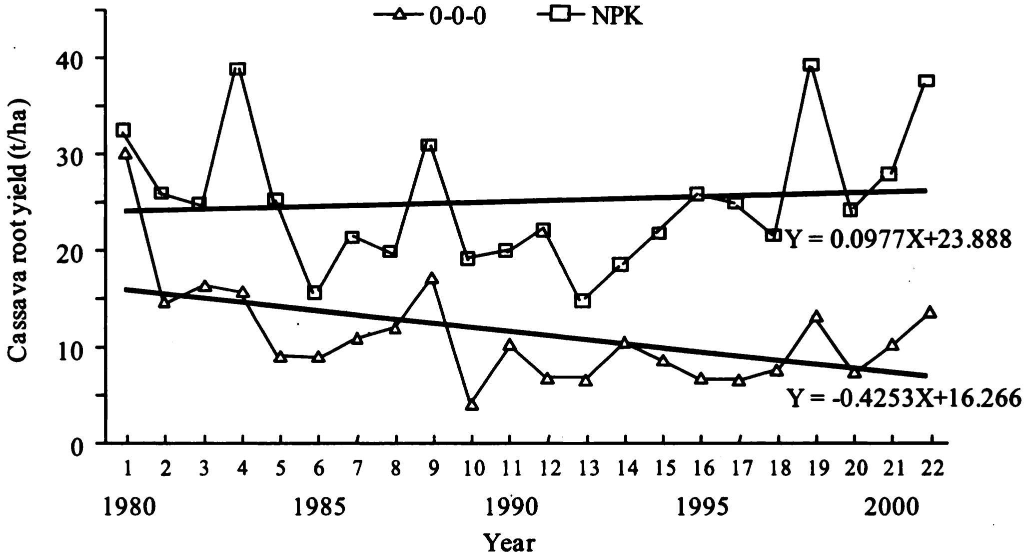

Figure 1. Effect of annual application of chemical fertilizers on the fresh root yield of cassava during 22 consecutive years of cropping at Khon Kaen FCRC from 1980 to 2001.
Note: NPK = 50 kg N+50 kg P_2O_5+50 kg K_2O/ha
***Source:** Wongwiwatchai et al., 2001.*

The Effect of Animal Manures Application

The main purpose of the application of animal manures is to improve the soil's organic matter (OM) content, which results in the release of greater amounts of plant nutrients, a lower bulk density and an increase in buffer capacity of the soil. **Table 1** shows the effect of various rates of animal manure application on the fresh root yield of cassava. In Sakon Nakhon, Chompoonukulrat *et al.* (1996) applied various rates of cattle manure to a cassava field, whereas chicken manure was used by Rammachat *et al.* (2001) in Maha Sarakham. Both manures significantly increased cassava root yields, especially the combination of chemical fertilizer and chicken manure. Moreover, Kokram *et al.* (2002) reported that in Ubon Ratchathani the application of chicken manure mixed with rice husk in the ratio of 1:1 markedly increased the fresh root yield of cassava as compared to the application of chemical fertilizer and the control treatments (**Table 2**).

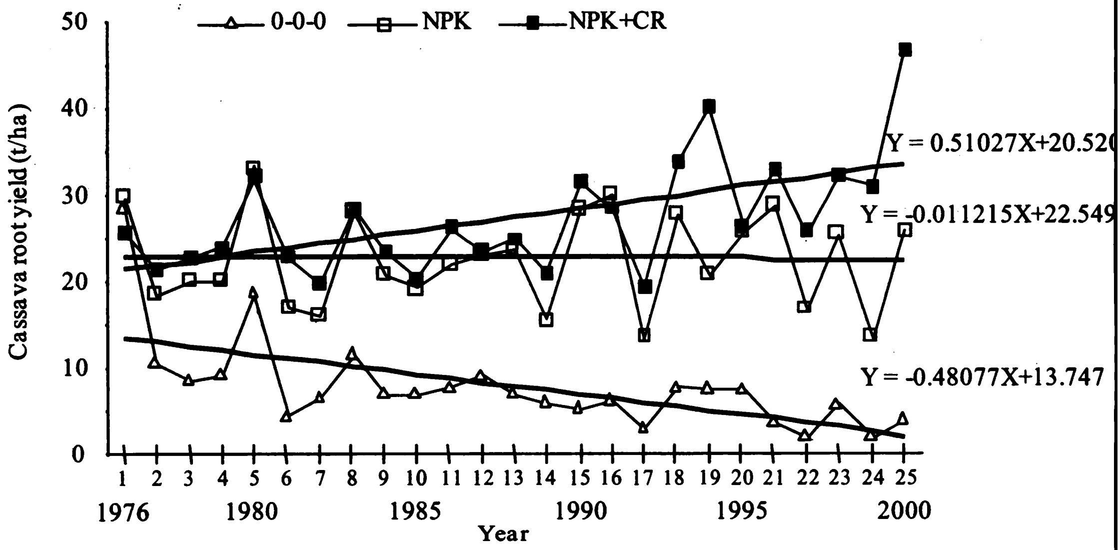

Figure 2. Effect of annual applications of chemical fertilizer, with or without incorporation of cassava stems and leaves, on the fresh root yield of cassava during 25 consecutive years of cropping at Khon Kaen FCRC from 1976 to 2001.
Note: NPK = 50 kg N+50 kg P_2O_5+50 kg K_2O/ha; CR = cassava crop residues incorporated
***Source:** Nakaviroj et al., 2002.*

Table 1. Effect of cattle and chicken manure application with or without chemical fertilizers on the fresh root yield of cassava (t/ha) in Sakon Nakhon province[1] (1996) and in Maha Sarakham province[2] (average over 3 years, 1999-2001), respectively.

Manure rate	Cattle manure (SN)[1]		Chicken manure (MS)[2]		
(t/ha)	-CF	+CF[3]	-CF	+CF[3]	Av.
0	17.6	-	26.7	48.7	**37.7**
3.12	-	-	48.1	52.6	**50.3**
6.25	21.9	-	53.1	58.4	**55.7**
12.50	23.4	-	-	-	-

[1] Sakon Nakhon (Chompoonukulrat *et al.*, 1996)
[2] Maha Sarakham (Rammachat *et al.*, 2001)
[3] +CF application of chemical fertilizer at the rate of 47-47-47 kg N-P_2O_5-K_2O/ha.

Table 2. Effect of the application of chicken manure and chemical fertilizer on the fresh root yield of cassava (t/ha) in Ubon Rachathani province.

Treatments	2000	2001	Av.
Control	14.0	11.6	**12.9**
47-47-47 kg N-P_2O_5-K_2O/ha	28.3	17.8	**23.0**
5 t/ha chicken manure mixed with rice husk (1:1)	31.1	26.2	**28.6**

Source : *Kokram et al., 2002.*

Effect of Green Manures (GM) on Cassava Yields and the Nutrients in the GM residues

Leguminous crops are widely used as green manures for improving the productivity of the soil. Paisancharoen *et al.* (1990) conducted a 5-year (1985-1989) experiment at Khon Kaen Land Development Experiment Station, and found that cowpea was the most promising green manure crop, followed by *Crotalaria* and pigeon pea, for improving the soil and increasing cassava yields, as shown in **Table 3**. This is due to the vigorous early growth of cowpea, which leads to a high amount of biomass being produced within two months before planting cassava. Furthermore, cowpea had a high nutrient content, especially nitrogen and cations such as potassium which is very important for cassava root production. In addition, Jantarak *et al.* (2001) reported that in Maha Sarakham province, the combination of green manure (cowpea) and chemical fertilizers increased the fresh cassava root yields beyond that obtained with chemical fertilizer or the control treatment (**Table 4**).

Table 3. Effect of three green manures on cassava fresh root yields (a), on the biomass of the green manures (b), and on the nutrients in those green manures (c) during five consecutive years (1985-1989) of cassava cultivation in Yasothorn soil in Khon Kaen province.

(a) Fresh root yield (t/ha).

Treatments[1]	1985	1986	1987	1988	1989	Av.
Cowpea	10.2	13.3	16.2	19.1	14.6	**14.7**
Pigeonpea	5.4	12.9	14.2	13.3	14.2	**12.0**
Crotalaria	5.9	13.4	14.9	17.2	15.2	**13.3**
Control	4.4	14.0	14.1	12.4	14.0	**11.8**

(b) Fresh biomass of leguminous crops (t/ha).

Treatments	1985	1986	1987	1988	1989	Av.
Cowpea	17.9	21.2	10.8	25.8	14.6	**18.1**
Pigeonpea	1.8	10.9	2.7	5.2	4.8	**5.1**
Crotalaria	4.1	18.3	3.2	12.8	13.1	**10.3**

(c) Amount of fresh biomass of leguminous crops at 60 DAP and the amount of 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
Pigeonpea	10.9	103.8	16.9	50.0	22.5	11.3
Crotalaria	18.3	114.4	21.3	56.9	41.9	34.4

[1] Leguminous crops incorporated at 60 days after sowing and before planting cassava.

Source: *Paisancharoen et al., 1990.*

Table 4. Effect of incorporation of cowpea green manure and the application of chemical fertilizers on the fresh root yield of cassava (t/ha) during four consecutive years (1998-2001) of cropping in Maha Sarakham province.

Treatments	1998	1999	2000	2001	Av.
Control	31.2	23.0	15.0	16.0	**21.3**
Chemical fertilizer[1)]	27.0	28.0	23.0	23.0	**25.2**
Green manure[2)] + chem. fertilizer[1)]	31.0	31.0	31.0	31.0	**30.7**

[1)] Chemical fertilizer at the rate of 47-47-47 kg N-P_2O_5-K_2O/ha.
[2)] Green manure (cowpea) incorporated at 2 months and before growing cassava.
Source: *Jantarak et al., 2001.*

Kokram *et al.* (1996a) conducted an experiment in infertile sandy soils of Warin soil series at Ubon Ratchatani FCRC using verano (*Stylosanthes hamata*) as a living mulch in cassava during 1993-1995. The 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 (**Table 5**). The negative response was due to the severe competition between the two crops.

Table 5. Effect of a living mulch of verano (*Stylosanthes hamata*) on the fresh root yield (t/ha) of cassava during three consecutive years of cropping at Ubon Ratchathani FCRC, from 1993 to 1995.

Treatments	1993	1994	1995	Av.
Control	22.4	21.0	22.9	**22.1**
Verano (mowed)[1)]	15.7	20.0	22.6	**19.4**
Verano	10.7	13.5	17.5	**13.9**

[1)] 2 cuttings
Source: *Kokram et al., 1996a.*

Effect of Various Cropping Systems on Cassava Yields and Soil Productivity

A study on the effect of cropping systems on soil productivity for cassava cultivation was conducted using either intercropping or a crop rotation with leguminous crops. Paisancharoen *et al.* (1997) conducted a long-term cassava experiment for nine years (1987-1995) in Khon Kaen FCRC using cowpea and sword bean as intercrops. Intercropping treatments were either without fertilizers (**Figure 3**) or with chemical fertilizer application (**Figure 4**). 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 5-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 fertilizers.

Similarly, Kokram *et al.* (1996b) reported the results of a cassava/cowpea trial conducted for four consecutive years (1993-1996) at Ubon Rachathani FCRC, using different sowing dates of cowpea in relation to cassava as the treatments. On average, the root yields of cassava were higher in all intercropping treatments than in monocropping. Planting the intercropped cowpea at 30 days after cassava tended to produce the highest cassava yields (**Table 6**).

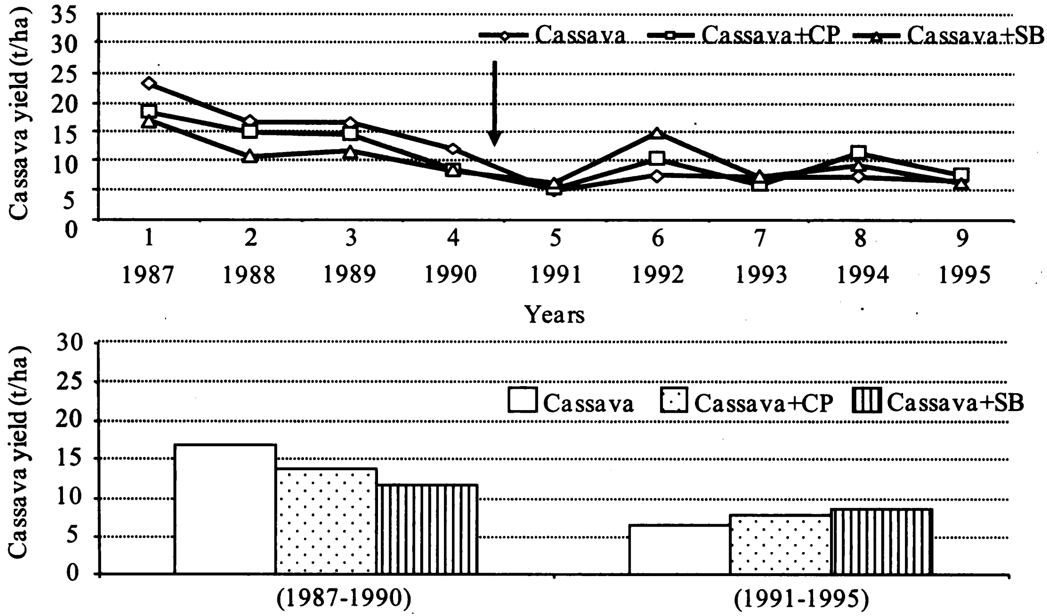

Figure 3. Effect of cassava intercropping with cowpea (CP) or sword bean (SB) on the fresh root yield of cassava during nine consecutive years of cropping without chemical fertilizer application in Khon Kaen FCRC from 1987 to 1995.
Source: *Paisancharoen et al., 1997.*

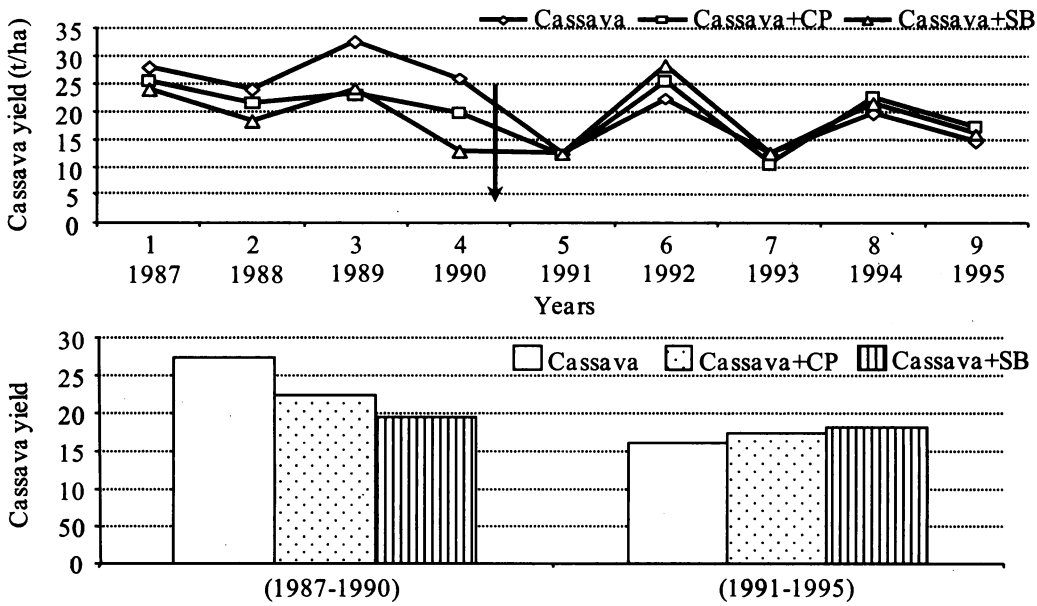

Figure 4. Effect of cassava intercropping with cowpea (CP) or sword bean (SB) on the fresh root yield of cassava during nine consecutive years of cropping with application of 47-47-47 kg/ha of N-P_2O_5-K_2O in Khon Kaen FCRC from 1987 to 1995.
Source: *Paisancharoen et al., 1997.*

Table 6. Effect of the relative time of planting cowpea as an intercrop in cassava on the fresh root yield of cassava (t/ha) during four consecutive years of cropping at Ubon Ratchathani FCRC, from 1993-1996.

Treatments	1993	1994	1995	1996	Av.
Cassava monoculture	29.7	17.5	25.5	19.5	**23.1**
Cassava+cowpea (planted at the same time as cassava)	26.5	20.9	28.2	26.9	**25.6**
Cassava+cowpea (planted at 30 days after cassava planting)	32.9	28.3	31.9	25.8	**29.7**
Cassava+cowpea (planted at 60 days after cassava planting)	24.7	22.8	30.9	25.9	**26.1**

Source: *Kokram et al., 1996b.*

Wongwiwatchai *et al.* (2001) reported the results of a long-term experiment on various cropping systems of cassava conducted since 1980 at Khon Kaen FCRC. Treatments consisted of two combination factors of cropping systems and soil improvements. There were three cropping systems: A. continuous cassava monocropping; B. intercropping with groundnut, *Arachis hypogaea*; and C. a crop rotation with cassava alternated yearly with groundnut followed by pigeon pea in the same year; and four methods of soil improvement : 1. control; 2. chemical fertilizer (CF); 3. soil amendment (SM); and 4. CF+SM. Chemical fertilizer applied for cassava was 50 kg N +50 kg P_2O_5 + 50 kg K_2O/ha., whereas, groundnut, grown in the rotation system was fertilized with 19 kg N + 57 kg P_2O_5 + 32 kg K_2O/ha; pigeon pea grown immediately after the harvest of groundnut did not receive fertilizers. The crop residues of all crops were incorporated into the soil before the next planting. The soil amendments (1.25 t/ha of lime, 1.25 t/ha of phosphate rock and 12.5 t/ha of compost) were applied before cassava growing, only on the first, the fifth and the ninth year of the experiment. **Figure 5** indicates that the root yields of cassava, averaged over four soil improvement methods, gradually increased over time in the crop rotation system, whereas in the other two systems yields tended to decrease, especially in the intercropping system.

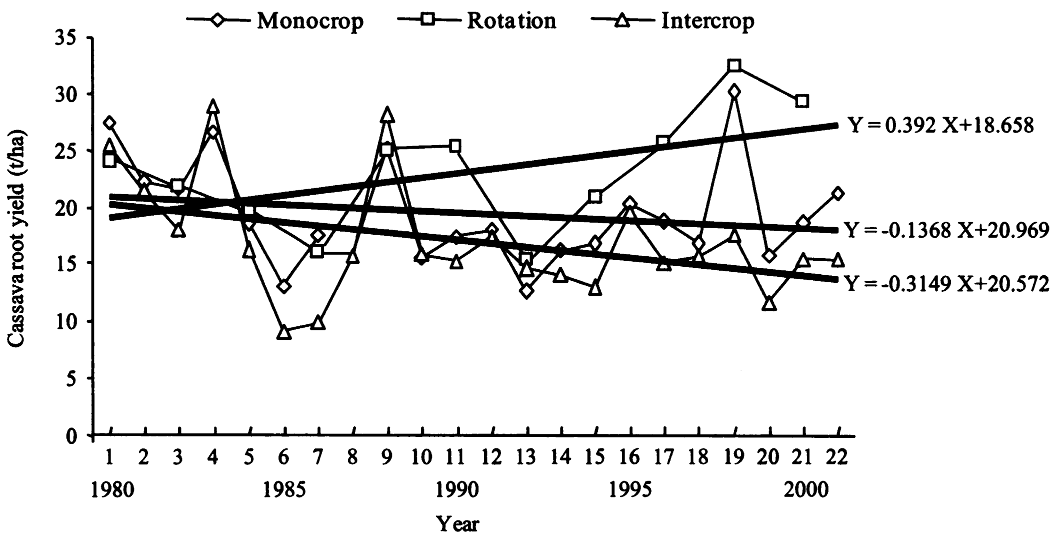

Figure 5. The effect of crop rotation and intercropping with leguminous species on the fresh cassava root yield during 22 years of continuous cropping at Khon Kaen FCRC, Khon Kaen, Thailand from 1980 to 2001.
Source: *Wongwiwatchai et al., 2001.*

Nutrient Management for Sustaining High Cassava Yields

In order to sustain the production of cassava, plant nutrients in the soil should be well managed. A nutrient balance analysis of different cropping systems of cassava was carried out by Paisancharoen *et al.* (2002) in farmers' fields in Khon Kaen, Maha Sarakham and Kalasin provinces. There were five experimental sites in each province. **Figure 6** shows that the most limiting nutrient for cassava was potassium, followed by nitrogen and phosphorus. The analysis, averaged over sites in each province, also revealed that for K the balance was negative in all three provinces, both in monocropping and intercropping systems. This indicates that K removal in the root harvest was greater than the K input in fertilizers or manures; as such, soil K was being depleted. For nitrogen, in the monocropping system inputs and outputs were more or less in balance, whereas in the intercropping system the inputs exceeded outputs leading to a positive balance. However, in case of phosphorus, both cropping systems had a highly positive balance indicating that P inputs far exceeded its removal. In monocropped cassava rather large amounts of nutrients were removed, especially potassium. In contrast, in the intercropping system there was a positive balance of N and P due to the incorporation of crop residues.

CONCLUSIONS

Many researchers have investigated how to improve the management of the infertile soils in the northeast of Thailand, in order to increase soil productivity and make cassava production more sustainable. The results can be summarized as follow:

1. Chemical fertilizers and organic fertilizers such as animal manures and compost, can be directly applied to cassava to increase and maintain high yields. The optimum rates and the N-P-K balance, as well as the best time of application depend on the fertility status of the soil.
2. The planting and incorporation of leguminous crops as green manures before planting cassava is a viable alternative for the farmer. Green manures may supply N and recycle P and K, and improve the soil physical conditions.
3. The choice of cropping system is also very important in soil management. Some research results indicate that intercropping maintains the soil's productivity better than monocropping. Crop rotations, also tended to increase cassava yields in the long-run. Monocropping of cassava, without incorporating crop residues from leguminous crops, could lead to soil degradation. Incorporation of the leaves and stems of cassava after each harvest will also contribute to the maintenance of soil productivity.

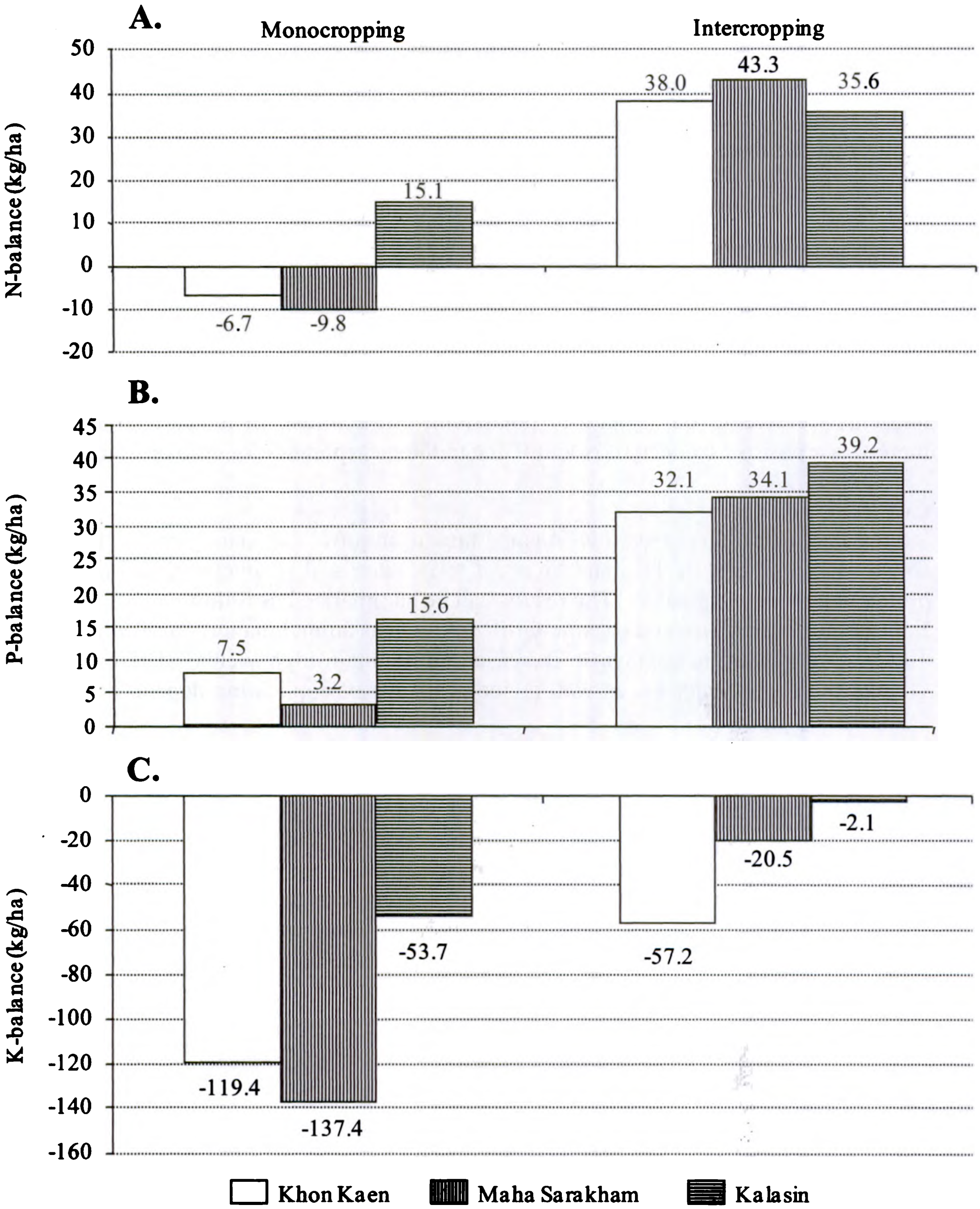

Figure 6. N, P and K balance for monocropped and intercropped cassava cultivation at three locations in northeastern Thailand in 1997/98: (A) Nitrogen; (B) Phosphorus; and (C) Potassium.
Source: *Paisancharoen et al., 2002.*

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SOIL ORGANIC MATTER MANAGEMENT FOR SUSTAINABLE CASSAVA PRODUCTION IN VIETNAM

Thai Phien and Nguyen Cong Vinh[1]

ABSTRACT

Soil nutrient depletion and exhaustion can be prevented by application of adequate amounts of chemical fertilizers, organic manures or compost, or by incorporation of cassava plant tops, green manures, intercrop residues or prunings of hedgerows.

Farm-yard manure (FYM) is an essential source of nutrients to improve soil fertility and increase growth and yields of crops grown in upland areas. Application of FYM can increase available P, exchangeable K, mineralizable N and soil organic matter (OM).

Intercropping cassava with grain legumes and returning their residues to the soil is a profitable technology which also improves soil fertility. Planting contour hedgerows of green manure crops can significantly reduce soil losses and run-off on sloping lands. The nutrient balance in the soil under cassava cropping is normally negative, especially with respect to K. Returning the residues of intercropped grain legumes could alleviate this problem. A combination of FYM, inorganic fertilizers, and incorporation of residues of leguminous crops often increases yields significantly. This is an easily adoptable technology. Farmers have successfully participated in research and the transfer of this technology to other farmers in the community.

It has been estimated that cassava takes up 99-153 kg N, 57-113 kg P_2O_5, 38-56 kg K_2O, 50-81 kg Ca and 19-32 kg Mg/ha. These amounts could be removed from the soil. Where cassava was intercropped with leguminous crops and the crop residues were returned, about 49-80 kg N, 34-57 kg P_2O_5, 12-18 kg K_2O, 24-39 kg Ca and 9-15 kg Mg/ha were returned to the soil.

Alley cropping cassava with contour hedgerows of *Tephrosia candida* is a well-established practice in some parts of north and central Vietnam. *Tephrosia* hedgerows produced an average of 0.5-1.0 t/ha/year of dry biomass for incorporation into the soil. This may contribute 10-20 kg N/ha. In intercropping systems, black bean could supply about 1.5-2.0 t/ha of dry residues containing 35-40 kg N/ha, or peanut could supply about 4-5 t/ha of dry residues with 50-70 kg N/ha. By intercropping grain legumes with cassava and returning the residues, in three years the soil OM had increased by 0.22% in the surface and 0.19% in the subsoil, as compared to the control treatment. Returning the bean residues and applying FYM increased the soil OM and N; soil OM was increased by 0.28-0.61% in the surface soil and increased by 0.25-0.82% in the subsoil. Planting *Tephrosia candida* as contour hedgerows and returning pruned leaves and stems to the soil, soil OM was increased by 0.3-0.4%, compared to the previous two years.

Soil organic matter plays an essential role in soil fertility. Soil OM management by the use of FYM, green manures, intercropping and green hedgerows, and returning crop residues to the soil, is a technology widely applied by farmers for achieving sustainable agriculture in Vietnam.

INTRODUCTION

Of the total land area of 33 million ha in Vietnam, 75% is hilly or mountainous. About 21% of the total land area, or 6.9 million ha, is used for agriculture, of which 5.3 million ha for annual crops, while 42%, or 13.8 million ha, has been abandoned or is left in fallow. Thai Phien and Nguyen Tu Siem (1996) stated that "as a direct consequence of planting upland rice and cassava for food self sufficiency, more than one million ha have become eroded skeleton soils with no value for agriculture or for forestry". Similarly, ISRIC (1997) reports that of the 38.6 million ha of total land area in Vietnam, 8.6 million

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ha (22%) are suffering from various degrees of water erosion, and 5.0 million ha (13%) from fertility decline.

In Vietnam, cassava (*Manihot esculenta* Crantz) is the fifth most important food crop in terms of area planted, after rice, maize, vegetables and sweet potato. In 1998 cassava was harvested in 238,700 ha, with a production of 1.98 million tonnes of fresh roots and a yield of 8.3 t/ha.

Howeler (1992) estimated that 66% of cassava in Vietnam is grown on Ultisols, 17% on Inceptisols, 7% on Oxisols, 4% on Alfisols and the remaining 6% on Entisols and Vertisols. Most of the Ultisols and Inceptisols are characterized by a light texture, acid pH and low levels of organic matter (OM) and nutrients. According to a farm-level survey conducted in 1990/91 of over 1,100 households in 45 districts of all cassava growing regions of Vietnam (Pham Van Bien *et al.*, 1996), 59% of cassava is grown on sandy soils, 3.9% on silty soils, 11.7% on clayey soils and 25.3% on rocky soils. About 45% of cassava is grown on sloping land.

Extensive farming and shifting cultivation are common practices in upland areas. Cutting forests for agricultural production results in increased soil erosion and degradation of soil fertility. Upland soils have more constraints for crop growth. Low organic matter, soil acidity and low levels of nutrients are found in large areas. Previous research indicate that soil organic matter had a positive relationship with crop yield, especially in the uplands (Thai Phien and Luong Duc Loan, 1994; Huynh Duc Nhan *et al.* 1995; Thai Phien *et al.*, 1995; Le Sinh Sinh et al., 1998). Building up the soil organic matter improves soil fertility, and crop yields could significantly increase.

This paper deals mainly with the aspect of organic matter management and erosion control on sloping lands with the objective of increasing yields and/or income for the farmer.

1. Soil Fertility Changes as a Result of Cassava Production in Vietnam

1.1. Soil Nutrient Depletion Under Cassava With No Soil Protection

Growing cassava and other annual crops on sloping lands may cause serious soil loss by erosion. **Table 1** shows the amount of soil loss by erosion under different cropping systems in upland areas. Land under secondary forest covered 80-90% of the soil surface, and annual soil loss was relatively low. With cassava cultivation, the soil loss was highest (98.6 t/ha/year). Differences in soil loss between different cropping systems was related to the degree of soil cover. More soil cover reduces the impact of rain drops falling directly on the soil.

Water erosion removed a layer of 12.3 mm of soil/year in areas of cassava cultivation, while in a tea plantation a layer of 2.6 mm was lost. Soil covered by natural grass lost a layer of 1.0 mm (**Table 2**). At the same time, nutrients in the sediments were also lost by water. Cassava cultivation resulted in the greatest nutrient loss from the soil. The loss of N, P and K was least from land under natural grass.

Table 1. Land cover and soil loss under different cropping systems.

Cropping	Soil cover (%)	Soil loss (t/ha)
1. Secondary forest	80-90	12.4
2. Maize	30-50	14.7
3. Upland rice	10-15	95.1
4. Cassava	10-15	98.6

Source: *Luong Duc Loan, 1997.*

Table 2. Soil and nutrient loss as affected by different cropping systems.

	Soil layer eroded	Soil loss by erosion		Nutrients lost with soil loss (kg/ha)		
	(mm)	(t/ha)	(%)	N	P_2O_5	K_2O
Monoculture cassava	12.3	145.1	100	145.1	110.0	31.3
Tea plantation	2.6	33.3	23	22.9	16.6	7.3
Natural grass	1.0	12.0	8	9.6	4.8	2.6

Source: *Nguyen Dinh Kiem, 1989.*

Nutrient losses from land under natural grass, averaged 10 kg N, 5 kg P_2O_5 and 3 kg K_2O/ha/year. Cassava cultivation without good soil management could result in a nutrient loss that is 14 times higher for N, 22 times for P, and 10 times for K as compared to that of land under natural grass.

Extensive cassava cultivation caused a reduction in soil organic matter (OM) content. Soil humus became depleted in both quantity and quality. The total soil OM and humic acid were reduced, so the Ch/Cf ratio was reduced **(Table 3)**.

Table 3. The effect of continuous cassava cultivation on various soil organic matter compounds.

Length of cassava cultivation	OM (%)	AH	AF	Ch/Cf	Compound (R_2O_3)
1 year	1.72	0.48	0.64	0.75	0.45
6 years	0.80	0.21	0.33	0.64	0.17
10 years	0.55	0.09	0.36	0.17	0.08

Source: *Nguyen Tu Siem and Thai Phien, 1993.*

Long-term cassava cultivation resulted in a loss of bases such as Ca and Mg which in turn increased soil acidity. After six years of continuous cassava cultivation, the soil OM was reduced to about 50% and the Ch/Cf ratio had decreased from 0.75 to 0.64. After 10 years, this ratio was as low as 0.17 while the soil OM was only 1/3 of the initial amount.

Results of soil chemical analyses under forest and under cassava plantations are presented in **Table 4**. It is clear that after 1-2 years of cassava cultivation without adequate inputs of fertilizer and without erosion control, resulted in soil nutrient depletion. Soil pH dropped about 0.1-0.4 units and the soil OM dropped to 59-72% of its initial value.

1.2. Erosion as a Result of Cassava Cultivation

Cassava is oftentimes blamed for causing severe erosion when grown on slopes. There is no doubt that cassava cultivation, like that of all annual food crops, causes more run-off and erosion than leaving the land in forest, in natural pastures or under perennial trees (**Table 5**). This is mainly due to the frequent loosening of soil during land preparation and weeding, as well as due to the lack of canopy and soil cover during the early stages of crop development. The question is whether cultivation of cassava results in more or less soil loss than that of other annual crops.

Table 4. Chemical properties of a ferralsol derived from basaltic rock, under forest and under one or two years of cassava.

Cropping system	Soil depth. (cm)	pH in KCl	Total contents (%) OM	N	P_2O_5	Exch. cations (me/100 soil) Ca++	Mg++
Forestry	0-20	4.2	5.80	0.26	0.25	2.00	0.80
	20-40	4.1	3.30	0.11	0.10	1.18	0.40
	40-60	4.4	3.01	0.10	0.09	1.60	0.76
Cassava 1 year	0-20	3.8	4.18	0.08	0.11	1.46	1.20
	20-40	4.1	2.19	0.11	0.21	1.40	0.40
	40-60	4.3	1.08	0.10	0.11	1.20	1.60
Cassava 2 years	0-20	3.8	3.40	0.14	0.24	0.12	0.04
	20-40	3.8	2.08	0.06	0.20	0.04	0.04

Source: *Nguyen Tu Siem and Thai Phien, 1993.*

Table 5. Amount of soil erosion on sloping land, as influenced by different land use systems in Vietnam.

Land use system	Eroded soil (t/ha/year)	(%)
Cassava (monoculture)	145.1	100
Tea (10 years old)	33.3	23
Planted pine forest	28.7	20
Natural grass	12.0	8

Source: *Nguyen Dinh Kiem, 1989.*

Compared with other crops cassava establishes a canopy cover only slowly, often requiring 3-4 months to reach full canopy cover (Nguyen Tu Siem and Thai Phien, 1993). Moreover, the cassava canopy cover is effective only in protecting the soil from rainfall-induced erosion, but is not effective in reducing runoff-induced erosion, which occurs near the soil surface, and which becomes increasingly important as the slope increases (Rose and Yu, 1998). This may lead to increased erosion. On the other hand, cassava does not need intensive land preparation and a smooth seed bed like many seeded crops, nor does it require more than one land preparation per year, compared with 2-3 times for short-cycle crops like most grain legumes, maize and sorghum. Moreover, once the canopy is established there is no more need for weeding, while the canopy is effective in reducing raindrop impact, and thus erosion.

When soil particles are dislodged by the impact of raindrops or by the scouring action of overland flow, and move down-slope with runoff, the field not only loses the most fertile part of the soil, i.e. the topsoil, but also associated organic matter, manures, fertilizers and beneficial micro-organisms, such as mycorhizal fungi. Moreover, clay particles, once dislodged are quickly carried down slope, resulting in a preferential loss of clay and a lightening of soil texture. This may be the reason why soils used for a long time for cassava cultivation were found to be much lower in clay, organic C and CEC than those used for forest, rubber or cashew (**Table 6**).

Table 6. Chemical properties of various horizons of a Haplic Acrisols that have been under different land use in southeastern Vietnam.

Criteries	Forest	Rubber	Sugarcane	Cashew	Cassava	CV (%)
Organic C (%)	1.032a	0.839ab	0.796ab	0.579ab	0.496b	44.7
Total N (%)	0.058a	0.054ab	0.040abc	0.032bc	0.022c	36.7
Available P, Bray 2 (ppm)						
-1st horizon	5.21b	20.90a	20.68a	4.85b	15.33ab	37.5
-2nd horizon	2.48b	7.03a	7.92a	3.19b	5.31ab	32.6
-3rd horizon	1.57b	2.83ab	3.82a	1.08ab	3.82a	44.6
CEC (me/100g)	3.43a	2.94a	3.24a	2.39ab	1.53b	27.1
Exch. K (me/100g)						
-1st horizon	0.132a	0.127a	0.051b	0.070ab	0.060b	66.3
-2nd horizon	0.073a	0.046ab	0.022b	0.031ab	0.021b	75.1
Exch. Mg (me/100g)	0.145a	0.157a`	0.055ab	0.046ab	0.036b	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 Deturck, 1998.*

2. Soil Fertility Improvement by Organic Manure

2.1. The Effect of Organic Fertilizer Application on Crop Yields

2.1.1 Effect of farm-yard manure application

When the soil organic matter is low, the application of manures is an effective technology to improve the soil in upland areas. Intercropping leguminous crops with cassava and returning the residues to the soil can increase crop yields (**Table 7**).

In the cassava-black bean or peanut intercropping systems, the application of FYM increased the bean yield between 33.3 and 88.9%, and the peanut yields between 26.7 and 48.5%, compared to the control treatment without FYM application.

In the treatment with *Tephrosia candida* hedgerows, the bean and peanut yields were reduced in the first three years. After that, the peanut yield was similar to that of the control treatment. It indicates that the intercropping of *Tephrosia candida* initially reduced the cultivated area resulting in a reduction of bean yields as compared with the control treatment. After three years, soil fertility had improved by incorporating the leaves of *Tephrosia candida* as well as by reducing soil erosion.

Table 7. Yield of leguminous intercrops in cassava as affected by FYM application.

Treatments[1)]	Black bean yield (t/ha) 1992	Peanut yield (t/ha) 1993	1994	1995	Average
1. NPK	0.09	0.98	0.92	1.14	1.01
2. NPK + 3 t/ha FYM	0.12	1.16	1.17	1.52	1.28
3. NPK + 6 t/ha FYM	0.17	1.35	1.33	1.83	1.50
4. NPK + 12 t/ha FYM	0.14	1.40	1.26	1.63	1.43
5. NPK + *Tephrosia hedgerows*	0.07	0.93	0.93	1.19	1.02
LSD at 0.05	0.08	0.14	0.07	0.28	

[1)] NPK = 60 kg N + 60 P_2O_5 + 120 K_2O/ha
***Source:** Thai Phien et al., 1996.*

After four years of intercropping, the average yield of intercropped peanut with hedgerows of *Tephrosia* was similar to that of the control treatment without hedgerows while the cassava yield with application of manure increased 14-32% as compared to the control treatment without manure (**Table 8**). Growing *Tephrosia candida* hedgerows and returning the residues to the soil could improve soil fertility, resulting in higher yields of cassava and intercropped legumes as compared to the control treatment without hedgerows.

Table 8. Effect of the application of various amounts of FYM on cassava yields from 1992 to 1995. Hoa Son commune, Luong Son distict, Hoa Binh province

Treatments[1)]	Cassava fresh root yield (t/ha) 1992	1993	1994	1995	Average
1. NPK	12.7	15.0	12.5	13.2	13.4
2. NPK + 3 t/ha FYM	15.0	16.9	13.6	15.6	15.3
3. NPK + 6 t/ha FYM	16.8	19.0	14.2	16.3	16.6
4. NPK + 12 t/ha FYM	18.3	18.3	16.8	17.3	17.7
5. NPK + *Tephrosia hedgerows*	11.2	14.0	18.3	19.5	15.8
LSD at 0.5	3.4	2.98	1.97	1.22	

[1)] NPK = 60 kg N + 60 P_2O_5 + 120 K_2O/ha
***Source:** Thai Phien et al., 1996.*

2.1.2. The effect of organic fertilizer application on soil properties

As mentioned above, upland soils are mainly poor in organic matter and total nitrogen. Application of farm-yard manure (FYM) can improve soil organic matter (OM) and nitrogen in the soil. The effect of FYM on the soil OM and nitrogen in the soil is presented in **Table 9**. Bean residues were returned to the soil during three years of cassava-bean intercropping. The OM content was increased by 0.22% in the surface- and 0.19% in the sub-soil as compared to the control treatment. Returning the bean residues combined with FYM, increased the soil OM and nitrogen. The OM content was increased by 0.28-0.61% in the surface soil and increased by 0.25-0.82% in the subsoil. In treatment 4, intercropping *Tephrosia candida* as hedgerows and returning crop residues to the soil, soil OM was increased by 0.3-0.4%, compared to the past two years.

Table 9. Effect of FYM application on soil organic matter (SOM) and N contents in the surface soil (0-15 cm) in a cassava-bean intercropping experiment conducted in Hoa Son commune, Luong Son district, Hoa Binh province from 1992 to 1994.

Treatments[1)]	SOM (%)			N (%)		
	1992	1994	Δ	1992	1994	Δ
1. NPK	2.36	2.58	0.22	0.161	0.179	0.018
2. NPK + 3 t/ha FYM	2.21	2.68	0.47	0.148	0.156	0.008
3. NPK + 6 t/ha FYM	2.40	2.68	0.28	0.148	0.190	0.042
4. NPK + 12 t/ha FYM	1.69	2.30	0.61	0.143	0.174	0.030
5. NPK + *Teph. candida* hedgerows	1.69	2.01	0.32	0.136	0.179	0.043

[1)] NPK = 25 kg N + 50 P_2O_5 + 50 K_2O/ha
Source: *Nguyen Cong Vinh et al., 1998.*

Total nitrogen in the soil increased by application of animal manures. After two years the N content had increased 0.042% in the treatment with 6 t FYM/ha and 0.030% with 12 t FYM/ha. Hedgerows of *Tephrosia candida* increased the N content 0.043%.

Application of organic manures can also change the content of mineralizable N in the soil. Soil organic N need to be mineralized before being absorbed by the plant (**Table 10**). Mineral nitrogen in the soil was analyzed at room temperature (T_0) and after incubation at 40°C for 1 week (T_1). The difference in extracted N between T_0 and T_1 indicates the mineralizable N in the soil. Mineralizable N increased by manure application. Differences between T_0 and T_1 ranged from 15.6 µg/g in the control treatment to 20.9-27.5 µg/g soil in treatments with FYM.

Table 10. Effect of application of various levels of FYM on mineralizable N in the soil after one week of incubation at 40°C.

Treatments[1)]	Mineralizable N (µg/g soil)		
	T_0	T_1	T_0-T_1
1. NPK	10.5	26.1	15.6
2. NPK + 3 t/ha FYM	14.4	36.6	22.2
3. NPK + 6 t/ha FYM	18.3	39.2	20.9
4. NPK + 12 t/ha FYM	18.3	45.8	27.5
5. NPK + *Teph. candida* hedgerows	15.7	31.4	15.7
LSD	1.79	3.62	

[1)] NPK = 25 kg N + 50 P_2O_5 + 50 K_2O/ha
Source: *Nguyen Cong Vinh et al., 1998.*

Table 11 shows the effect of organic manure application on soil fertility improvement. Available P and K in the soil increased by the application of NPK, and by FYM and green manures from beans intercropped or by hedgerows. In the treatment with hedgerows of *Tephrosia candida*, available P increased most, from 2.8 ppm P in the first year to 9.94 ppm P in the 3rd year. Available P and K in the soil increased with increasing rates of FYM application.

2.2. *Effect of the Combined Application of Organic Manure and Inorganic Fertilizer and Lime in Cassava Beans/Peanut Intercropping Systems.*

Combining intercropping cassava with grain legumes and fertilization is an effective way to improve soil fertility. Crop residues were returned to the soil to build up soil organic mater. **Table 12** shows that crop yields in the cassava-beans system increased with the rate of N, P and K combined with lime. When N, P and K were combined with FYM, crop yields were higher than that combined with lime. This indicates that FYM is more effective in increasing the yields of both crops in the cassava-bean system. Crop yields were highest with the combined application of N, P, K, FYM and lime.

This combined application increased cassava yields from 11 to 19 t/ha, black bean yields from 78 to 162 kg/ha and peanut yields from 546 to 870 kg/ha.

Table 11. Available phosphate and potassium in the soil as effected by the application of organic manures in a cassava-bean intercropping experiment conducted in Hoa Son commune, Luong Son district, Hoa Binh province from 1992 to 1994.

Treatments[1)]	P (ppm)			K (mg/100g)		
	1992	1994	Δ	1992	1994	Δ
1. NPK (control)	4.21	7.00	2.79	2.35	3.12	0.77
2. NPK.+3 t/ha FYM						
3. NPK +6 t/ha FYM	4.20	7.65	3.45	2.73	5.85	3.12
4. NPK +12 t/ha FYM	4.69	9.59	4.90	1.95	6.63	4.48
5. NPK + Cont.+*Teph. candida* hedgerows	2.80	9.94	7.14	2.35	4.68	2.33

[1)] NPK = 25 kg N + 50 P_2O_5 + 50 K_2O/ha
Source: *Nguyen Cong Vinh et al., 1998.*

Table 12. Effect of the application of chemical fertilizers, FYM and lime on the yields of crops in a cassava-bean/peanut intercropping experiment conducted in Hoa Son commune, Luong Son district, Hoa Binh province from 1992 to 1994.

Treatments[1)]	Cassava root yield (Mean 1992-94)		Intercropped bean yields: Black bean (1992)		Intercropped bean yields: Peanut (Mean 1993-94)	
	t/ha	%	kg/ha	%	kg/ha	%
1. FYM	11.5	100	78	100	546	100
2. NPK low input+lime	14.4	125	96	123	730	132
3. NPK low input+FYM	16.8	146	129	166	836	156
4. NPK high input+lime	14.8	128	104	134	731	140
5. NPK high input+FYM	16.5	143	143	155	788	145
6. NPK high input+FYM+lime	18.8	163	162	208	870	158
LSD	0.27		56.2		126.8	

[1)] FYM = 3 t/ha; lime = 500 kg/ha; NPK low input = 25 kg N, 50 P_2O_5, 50 K_2O/ha;
NPK high input = 50 kg N, 100 P_2O_5, 100 K_2O/ha
Source: *Thai Phien and Nguyen Cong Vinh, 1998.*

2.2.1. The effect of balanced fertilization

Plant nutrients are usually lost from the soil by plant uptake and removal, soil erosion and leaching. The removal of nutrients with a cassava crop was calculated to be 62-153 kg N, 83-181 kg P_2O_5 and 67-147 kg K_2O/ha. This is one cause of the negative nutrient balance in cassava cultivation.

To overcome this problem, fertilization, intercropping and returning crop residues to the soil are useful solutions. However, previous research showed that the application of 30-60 kg N, 30-60 kg P_2O_5, and 50-100 kg K_2O/ha still did not compensate for the losses **(Table 13)**. When cassava was intercropped with grain legumes, the amount of 49-80 kg N, 33.8-56.8 kg P_2O_5, and 12.1-18.2 K_2O/ha were returned with leguminous residues **(Table 14)**.

Table 13. Effect of the application of various levels of N, P and K on the nutrient balance (kg/ha/year) in a cassava monocropping system in Hoa Son commune, Luong Son district, Hoa Binh province, 1992-1994.

NPK applied	N			P_2O_5			K_2O		
	NA[1)]	NR[2)]	NB[3)]	NA[1)]	NR[2)]	NB[3)]	NA[1)]	NR[2)]	NB[3)]
$N_0P_0K_0$	0	62	-62	0	82.7	-82.7	0	66.7	-66.7
$N_1P_0K_1$	30	108	-78	0	123.4	-123.4	50	102.4	-52.4
$N_1P_1K_0$	30	76	-46	30	111.8	-81.8	0	87.0	-87.0
$N_1P_1K_2$	30	135	-105	30	88.4	-50.4	100	87.8	+12.2
$N_1P_1K_1$	30	125	-95	30	144.2	-114.2	50	116.9	-66.9
$N_0P_1K_1$	0	120	-120	30	140.3	-110.3	50	113.3	-63.3
$N_2P_1K_1$	60	134	-74	30	163.8	-133.8	50	132.5	-82.5
$N_1P_2K_1$	30	138	-108	60	158.5	-98.5	50	130.2	-80.2
$N_2P_2K_2$	60	153	-93	60	180.8	-120.8	100	146.9	-46.9

[1)] NA = nutrients applied by fertilizers; [2)] NR= nutrients removed by crop; [3)] NB = nutrient balance
***Source:** Nguyen Cong Vinh and Thai Phien, 1997.*

Table 14. Effect of fertilization on the nutrient balance (kg/ha/year) in the cassava-peanut intercropping system in Hoa Son commune, Luong Son district, Hoa Binh province, 1992-1994.

Treatment		Stems	N	P_2O_5	K_2O	Ca	Mg
1. FYM	RM*	-	99	57.1	37.5	50	19
	RT**	3,910	49	33.8	12.1	24	9
2. NPK low input+lime	RM*	-	118	84.6	43.6	64	24
	RT**	4,050	60	42.3	14.5	29	11
3. NPK low input+FYM	RM*	-	121	90.2	47.2	63	26
	RT**	4,220	64	45.1	15.7	32	12
4. NPK high input+lime	RM*	-	135	98.7	49.6	71	28
	RT**	4,450	76	50.8	16.9	36	14
5. NPK high input+FYM	RM*	-	136	98.7	54.5	76	29
	RT**	4,910	79	56.4	18.2	38	15
6. NPK high input+FYM+lime	RM*	-	153	112.8	55.7	81	32
	RT**	5,070	80	56.8	18.2	39	15

Note: RM*Removal, RT** returned to the soil; "Stems" are peanut residues.

Plants take up nutrients from the soil for plant growth and yield. Those nutrients can be removed or returned to the soil. The amounts taken up were estimated at 99-153 kg N, 57-113 kg P_2O_5, 38-56 kg K_2O/ha, 50-81 kg Ca and 19-32 kg Mg/ha. These amounts could be removed from the soil. However, when cassava was intercropped with leguminous crops and the residues incorporated into the soil, the amount of 49-80 kg N, 34-57 kg P_2O_5, 12-18 kg K_2O, 24-39 kg Ca and 9-15 kg Mg/ha were returned to the soil.

Those nutrients are equivalent to 100-200 kg urea, 300-500 kg fused magnesium phosphate and 20-30 kg KCl. So, intercropping legumes is considered as a good technology for soil conservation, especially for uplands. This technique has multiple benefits, such as higher income, increase in organic matter, and mineral nutrients returned to the soil.

2.3. The Effect of Green Manure Crops on Run-off and Erosion

Cassava cultivation without fertilizer inputs is a common practice of farmers. Moreover, few farmers use any soil conservation practices. This study focused on the effect of various contour hedgerows on soil erosion. Some results of the study are presented in **Table 15.**

Table 15. Effect of various cassava management practices on run-off and soil losses by erosion from an Acrisol at Tam Dao, Vinh Phu (slope 5-7°) in 1994.

	Run off		Soil loss	
Management treatment[1)]	m^3/ha/year	%	t/ha/year	%
1. Bare land (control)	14,539	100	6.9	100
2. Cassava monoculture; low input	12,678	87	6.9	100
3. C+P; *Tephrosia* hedgerows; low input	12,433	84	6.1	88
4. C+P; *Tephr.* + pineapple hedgerows; low input	12,031	82	4.8	70
5. C+P; *Tephr.* + pineapple hedgerows; high input	11,473	79	2.8	41
6. C+P; *Tephrosia candida*+eucalyptus; high input	10,674	73	3.7	74

[1)] C = cassava; P = peanut

Source: Huynh Duc Nhan et al., 1995.

Data in **Table 15** show that intercropping with peanut and contour hedgerows of green manure crops such as *Tephrosia candida* markedly reduced soil erosion on sloping land. On bare land, water run-off and soil loss were most serious. In the cassava monoculture system, water run-off decreased by 13% compared with bare land. When cassava was intercropped with peanut (T3), run-off decreased to 84% of that from bare land and was 3% lower than that in the monoculture cassava system.

Cultivations of cassava intercropped with peanut and planting hedgerows of green manure crops further reduced run-off and soil loss. Using both a green manure crop and pineapple as a hedgerow, and intercropping, soil loss was only 41-70% of that in the monoculture cassava treatment. In addition, both soil loss and run-off were reduced by increasing the fertilizer inputs.

In treatments (T5, T6) with high inputs, soils losses were 2.8-3.7 t/ha/year, but it was 4.8 t/ha/year in treatment with low input (T4). Research on the degraded Acrisol derived from liparte rock in Tam Dao indicates that the nutrient balance was negative in the monoculture cassava system. They were estimated to be around 7.8 kg N, 8.9 kg P_2O_5, and

8.7 kg K_2O/ha/year. With intercropping and the planting of hedgerows, soil loss and run off were reduced, so that the nutrient loss was also reduced. In addition, green manure and crop residues (peanut) were returned to the soil, so nutrients in the residues were also returned to the soil. The amount of added nutrients was estimated at 55-67 kg N, 12-15 kg P_2O_5, 32-40 kg K_2O/ha. (**Table 16**). Intercropping and hedgerow planting also effected crop yields (**Table 17**). Monoculture cassava produced 10.8 t/ha fresh roots. Intercropping resulted in 7-9 t/ha fresh roots and 450-500 kg/ha/year of peanut pods.

Table 16. The effect of various cassava crop management treatments on the nutrients lost and returned to the soil (kg/ha) in Tam Dao, Vinh Phu, north Vietnam in 1994.

	N			P_2O_5			K_2O		
Treatments[1)]	M[2)]	RT[2)]	Balance	RM	RT	Balance	RM	RT	Balance
T_1	7.8	0	-7.8	8.9	0	-8.9	8.7	0	-8.7
T_2	7.6	0	-7.6	13.1	0	-13.1	7.5	0	-7.5
T_3	6.7	66.2	+59.5	12.8	13.6	13.1	8.8	36.5	+27.7
T_4	8.1	55.3	+47.2	11.0	12.2	+1.2	9.1	31.9	+22.8
T_5	4.5	67.2	+62.7	10.1	14.5	+1.2	7.1	40.1	+33.0
T_6	6.7	60.3	+53.6	9.9	14.5	+4.6	8.0	38.2	+80.2

[1)] Treatments: see Table 15.
[2)] RM: removal, RT: returned to the soil
Source: *Huynh Duc Nhan et al., 1995.*

Table 17. Effect of intercropping and hedgerows on cassava and peanut yields at Tam Dao, Vinh Phu, north Vietnam in 1994.

	Cassava root yield		Peanut pod yield	
Treatments	(t/ha)	(%)	(kg/ha)	(%)
2. Cassava monoculture; low input	10.8	100	0	0
3. C+P; *Tephrosia* hedgerows; low input	9.1	84	498.3	100
4. C+P; *Tephr.* + pineapple hedgerows; low input	7.6	71	450.4	90
5. C+P; *Tephr.* + pineapple hedgerows; high input	7.9	73	465.8	93
6. C+P; *Acacia candida*+eucalyptus; high input	6.9	64	479.2	96

Source: *Huynh Duc Nhan et al., 1995.*

2.4. Soil Management Practices to Maintain or Improve Soil Productivity.

To maintain or improve the productivity of soils used for cassava cultivation, it is necessary to reduce nutrient losses by crop removal and erosion, and prevent physical deterioration through excessive land preparation (especially with heavy machinery), and loss of clay and organic matter through erosion. In addition, the nutrients and organic matter lost should be replaced by application of fertilizers or manures, or by incorporation of green manures or intercrop residues.

2.4.1. Organic manures

Especially in the Red River Delta and in the northern part of the Central Coast, farmers are accustomed to applying 4-10 t/ha of manure, mostly pig or buffalo manure, to cassava. Results from the cassava survey conducted in Vietnam in 1990/91 (Pham Van Bien *et al.,* 1996) indicate that for the whole of Vietnam these manures may account for about 65% of N and K and 92% of all P applied to cassava. Manures are thus a major and indispensable source of nutrients for cassava, while also contributing organic matter and improving the physical conditions of the soil. These manure applications are particularly important when farmers remove all plant parts from the field, as they help restore soil organic matter and supply secondary and micronutrients. Still, **Table 18** indicates that the farmers' practice of high applications of FYM without N, P and K as chemical fertilizers did not result in maximum yields or profits. Highest yields and net income are probably obtained with modest (5-6 t/ha) applications of manure combined with about 60 kg N and 120 K_2O/ha, either without or with 30-60 kg P_2O_5/ha. Applications of Mg as fused Mg-phosphate are probably necessary in case no FYM is applied at all.

Table 18. Average results of five FPR fertilizer trials conducted by farmers in Kieu Tung village of Thanh Ba district, Phu Tho province, north Vietnam in 1996.

Treatment	Yield cassava (t/ha)	Gross income[1)]	Fertilizer costs[1)]	Net income
		(mil. dong/ha)		
1. 10 t/ha of FYM	15.93	7.96	1.00	6.96
2. 10 t/ha of FYM; 60N + $60P_2O_5$ + $120K_2O$	19.34	9.67	2.19	7.48
3. 10 t/ha of FYM; 60N + $60P_2O_5$ + $80K_2O$	18.67	9.33	2.05	7.28
4. 10 t/ha of FYM; 60N + $40P_2O_5$ + $120K_2O$	21.89	10.94	2.07	8.87

[1)] Prices: cassava fresh roots: d 500/kg; FYM: 100/kg; Urea (45% N): 3000/kg; SSP (17% P_2O_5): 1000/kg; KCl (60% K_2O): 2200/kg

Source: *Thai Phien et al., 1997.*

2.4.2. Green manures and alley/intercropping

Few experiments have been conducted in Vietnam to determine the effectiveness of planting and then incorporating a crop of green manure before planting cassava. In north Vietnam where farm size is small, few farmers will want to plant a non-productive crop for the sole purpose of improving soil fertility. However, in remote areas where land is abundant but fertilizers or manures are not available, this may be an attractive option. Moreover, the green manure may help to smother out *Imperata cylindrica* grass.

Alley cropping cassava with contour hedgerows of *Tephrosia candida* is a well-established practice in some parts of north and central Vietnam. It is used to control erosion as well as to improve soil fertility when the prunings of the hedgerows are mulched or incorporated. Thai Phien *et al.* (1995) reported that *Tephrosia* hedgerows produced on average 0.5-1.0 t/ha/year of dry biomass for incorporation into the soil, which may contribute 10-20 kg N/ha. This compares with 1.5-2.0 t/ha of dry residues of intercropped black bean supplying 35-40 kg N/ha, or 4-5 t/ha of dry residues of intercropped peanut supplying 50-70 kg N/ha. Only part of this N is added to the system through biological N fixation by the legumes.

Trials conducted for four years in Hung Loc Center in Dong Nai, south Vietnam, indicate that intercropping cassava with grain legumes, such as mungbean, soybean, cowpea, peanut, winged bean (*Psophocarpus tetragonolobus*) and sword bean (*Canavalia ensiformis*) decreased cassava yields about 10-20%, and that planting cassava in single rows at 1.0x1.0 m produced higher yields than planting in double rows. Intercropping with maize also reduced cassava yields about 20-25%. Profits were highest for cassava monoculture or intercropped with peanut (Nguyen Huu Hy *et al.*, 1995).

Numerous erosion control trials conducted in both north and south Vietnam have shown that run-off and erosion losses can be markedly reduced by intercropping and by planting of contour hedgerows. Intercropping with peanut was generally more effective in reducing erosion than intercropping with other crops (**Table 19**), due to the rapid formation of soil cover. Contour ridging and no- or reduced-tillage were effective in reducing erosion, while adequate fertilization also helped to reduce erosion (Nguyen The Dang *et al.*, 1998). However, contour ridging, fertilization and intercropping require more work and usually imply higher production costs. Hedgerows also require more work in establishment and maintenance and may reduce yields by occupying 10-20% of the land. Thus, farmers have to consider the trade-off between immediate costs and benefits *versus* long-term benefits of less erosion and improved fertility.

Table 19. Effect of intercropping cassava with various grain legumes on the yield of crops, on gross and net income, as well as on dry soil loss due to erosion when grown on 10% slope at Agro-forestry College of Thai Nguyen University, Thai Nguyen, Vietnam in 1997.

Intercropping treatments	Yield (t/ha)		Gross income[1)]	Costs fert. seed[1)]	Net income	Dry soil loss
	Cassava	Intercrop	(mil. d/ha)			(t/ha)
1. Cassava monoculture	18.67	-	7.47	6.22	1.25	31.24
2. C + peanut	16.50	1.08	12.00	8.77	3.23	24.03
3. C + soybean	18.42	0.15	8.27	7.98	0.29	28.50
4. C + mung bean	20.83	0.27	10.49	7.84	2.65	28.61
5. C + black bean	17.92	0.35	9.62	7.94	1.68	28.64
6. C + cuoc bean	17.67	0.17	7.92	7.87	0.05	28.14

[1)] Prices:	cassava:	400d/kg fresh roots		
	peanut:	5000d/kg dry pods	peanut seeds:	7000d/kg dry pods
	soybean:	6000d/kg dry grain	soybean seeds:	7000d/kg dry grain
	mungbean:	8000d/kg dry grain	mungbean seeds:	8000d/kg dry grain
	black bean:	7000d/kg dry grain	black bean seeds:	7000d/kg dry grain
	cuoc bean:	5000d/kg dry grain	cuoc bean seeds:	5000d/kg dry grain

Source: *Le Sy Loi, 2000.*

Intercropping and planting hedgerows of *Tephrosia candida* to conserve soil fertility had other benefits. They reduced soil and nutrients lost by erosion (**Table 20**). Under monoculture cassava, 22.88 t/ha of dry soil were lost, while intercropping with peanut, planting hedgerows of *Tephrosia candida*, and applying NPK fertilizers soil loss was only 0.22 to 3.21 t/ha. This treatment also markebly reduced nutrient losses by erosion.

Intercropping cassava with peanut and planting hedgerows can also return large amounts of green matter and nutrients for soil fertility conservation. **Table 21** shows the amounts of green matter and nutrients returned to the soil. These were generated from two components: hedgerow prunings and peanut residues.

Table 20. Affect of intercropping, hedgerows and fertilizer application on soil and nutrients lost by erosion in Dong Rang commune, Luong district, Hoa Binh province. 1995-1997.

Treatments[1)]	Soil loss (t/ha)	Nutrient loss (kg/ha/year) N	P	K	Ca	Mg
1. C	22.88	45.8	39.90	6.80	4.6	4.4
2. C + P + H + NPK	0.22	0.4	0.39	0.08	0.5	0.5
3. C + P + H + NP	2.56	5.3	4.60	0.83	0.6	0.5
4. C + P + H + NK	0.22	0.4	0.39	0.08	0.5	0.1
5. C + P + H + PK	3.21	6.7	5.60	0.66	0.6	0.7

[1)] C = cassava; P = peanut; H = hedgerows of *Tephrosia candida;* NPK = 40 kg N + 40 P_2O_5 + 80 K_2O/ha; peanuts received separately 7 kg N + 20 P_2O_5 + 20 K_2O/ha

Source: *Le Thi Dung and Thai Phien, 1998.*

Table 21. Effect of intercropping, hedgerows and fertilizer application on organic matter and nutrients returned to the soil in Dong Rang commune, Luong district, Hoa Binh province. 1995-1997.

Treatments[1)]	Organic matter (kg/ha/year) from Hedgerows	Intercropping	Nutrients returned to soil (kg/ha/year) N	P	K	Ca	Mg
1. C	0	0	0	0	0	0	0
2. C + P + H + NPK	864	1276	50.3	7.9	38.0	21.6	23.1
3. C + P + H + NP	864	1296	50.7	8.0	38.5	21.8	23.4
4. C + P + H + NK	864	1354	51.8	8.1	39.6	22.4	24.1
5. C + P + H + PK	864	1351	51.9	8.1	39.7	22.5	24.1

[1)] Treatments: see Table 20.

CONCLUSIONS

Research conducted on experiment stations, on farmers' fields and with direct participation with farmers have shown that:

1. Cultivation of cassava on slopes may cause more severe erosion than that of other annual crops due to cassava's wide plant spacing and slow initial growth. But, it may cause less erosion than short-cycle crops (vegetables, beans) that are planted 2-3 times per year, and which require frequent land preparation and weeding.
2. Nutrient removal in eroded soil and run-off water can be substantial, especially K in run-off and sediments, and N in sediments, but nutrient losses from erosion are generally lower than those due to crop removal.
3. Soil nutrient depletion and exhaustion can be prevented by application of adequate amounts of chemical fertilizers, organic manures or compost; or by incorporation of cassava plant tops, green manures, intercrop residues or prunings of hedgerows.
4. Farm-yard manure (FYM) is an essential source of nutrients to improve soil fertility and increase growth and yields of crops grown in upland areas. Application of FYM can increase available P, exchangeable K, mineralizable N and soil organic matter.
5. Intercropping cassava with grain legumes and returning their residues to the soil is a profitable technology which also improves soil fertility. Planting contour

hedgerows of green manure crops can significantly reduce soil losses and run-off on sloping lands.

6. The nutrient balance in the soil under cassava cropping is normally negative, especially with respect to K. Returning the residues of intercropped grain legumes could alleviate this problem. A combination of FYM, inorganic fertilizers, and incorporation of residues of leguminous crops often increases yields significantly. This is an adoptable technology. Farmers have successfully participated in research and the transfer of this technology to other farmers in the community.
7. From the research it was estimated that cassava took up 99-153 kg N, 57-113 kg P_2O_5, 38-56 kg K_2O, 50-81 kg Ca and 19-32 kg Mg/ha. These amounts could be removed from the soil. Where cassava was intercropped with leguminous crops and the crop residues were returned, about 49-80 kg N, 34-57 kg P_2O_5, 12-18 kg K_2O, 24-39 kg Ca and 9-15 kg Mg/ha could be returned to the soil.
8. Alley cropping cassava with contour hedgerows of *Tephrosia candida* is a well-established practice in some parts of north and central Vietnam. *Tephrosia* hedgerows produced an average of 0.5-1.0 t/ha/year of dry biomass for incorporation into the soil. This may contribute 10-20 kg N/ha. In intercropping systems, black bean could supply about 1.5-2.0 t/ha of dry residues, containing 35-40 kg N/ha, or peanut could supply about 4-5 t/ha of dry residues with 50-70 kg N/ha. By intercropping the grain legumes with cassava and returning the residues, in three years the soil OM was increased by 0.22% in the surface and 0.19% in the subsoil as compared to the control treatment. Returning the bean residues and applying FYM increased the soil OM and N; soil OM was increased 0.28-0.61% in the surface soil and 0.25-0.82% in the subsoil. Planting *Tephrosia candida* as contour hedgerows and returning pruned leaves and stems to the soil, soil OM was increased 0.3-0.4%, compared to the previous two years.
9. Soil organic matter plays an essential role in soil fertility. Soil OM management by the use of FYM, green manures, intercropping and green hedgerows, and returning crop residues to the soil, is a technology widely applied by farmers for achieving sustainable agriculture in Vietnam.

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MINIMUM TILLAGE FOR CASSAVA IN THAILAND

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ABSTRACT

This paper presents the results of four experiments. The first experiment was conducted from 1992 to 1995 on Huay Pong soil series in Rayong province, and studied the effect of land preparation on the cassava yields of Rayong 90 and Rayong 5, comparing various methods. The results indicate that the best land preparation for Rayong 90 was two times plowing using a 3-disk plow followed by 7-disk plow, which gave a yield of 20 t/ha, whereas the use of a 7-disk plow or a 3-disk plow followed by 7-disk plow gave the highest yield of Rayong 5.

The second experiment studied the interaction between land preparation and the incorporation of soil amendments and was conducted in 1999/00 at Rayong Field Crops Research Center. The trial had a split plot design with various land preparation treatments in main plots and soil amendments in sub-plots. The results indicate that land preparation of two times plowing using a 3-disk plow followed by 7-disk plow produced the highest cassava root yield of 36.9 t/ha.

The third experiment is the comparison between no-tillage and conventional tillage, combined with three levels of N (0, 50, 100 kg N/ha) and the effect on the fresh root yield of cassava (cv. Rayong 72). The field trial has been conducted since 2000 on Satuk soil series (fine loamy, siliceous, Oxic Paleustult). Under no-tillage the soil's physical properties were improved compared to conventional tillage. The soil's structural parameters, such as soil porosity and saturated hydraulic conductivity, increased in the no-tillage plot, while soil bulk density decreased compared to conventional tillage. During the first year of the experiment higher yields of fresh cassava roots were obtained in the no-tillage plot. But, in the second year, the two tillage systems had no significant effect on fresh root yield. With respect to N application, yields increased as the N supply increased, but the effect was not statistically significant.

The fourth experiment studied the effect on cassava yields of several land preparation methods, from zero tillage to complete tillage (traditional practice in Thailand). The trials were conducted in 2001/02 and were located in three sites, i.e. Khaw Hin Sorn, Rayong and TTDI. Results indicate that on average the use of a 3-disk plow followed by a 7-disk plow and either contour or up-and-down ridging resulted in the highest yields compared to other treatments. This is probably because the ridging may have helped in the early control of weeds. The soil's physical properties had probably not yet improved as the data represented only the first year results. With respect to varieties, at the Rayong site, cassava yields decreased in the following order: Rayong 5>KU 50>Rayong 72>Rayong 90, whereas at the TTDI site Rayong 90 produced the highest and KU 50 the lowest yields; there were no significant differences among varieties in Khao Hin Sorn.

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INTRODUCTION

In tropical regions, soil ecosystems are often constrained beyond their natural capacity. Consequently, the soils are reduced in productivity and sustainability. The traditional methods of farming in Thailand have resulted in soil quality deterioration as they seldom considered soil improvement. Continuous cultivation at constant depth creates a zone of high compaction in the sub-surface soil. The depth of this zone will depend on the farmer's practices (Spoor, 2000). Thus, soil management will be responsible for important changes in soil quality parameters, particularly those related to soil structure and water movement. Most cassava in Thailand is grown in light- textured soils, which are very susceptible to erosion. In most cases, cassava farmers prepare their land by plowing with a 3-disk plow followed by a 7 disk harrow, which in turn is followed by a ridger. This results in a very loose soil which is free of weeds and easy to plant. It also makes the soil highly susceptible to erosion, while the direct exposure of the soil to sun and rain will cause rapid decomposition of organic matter, leaving many soils almost devoid of organic matter and with very poor structure. Minimum tillage is thought to be a more appropriate technique for these soils. A broad range of minimum tillage systems is used to conserve soil and water, and to enhance and sustain agricultural productivity. No-till is one type of this system whereby crops are sown directly into an untilled seedbed without any primary or secondary tillage. Previous crop residues are left on the surface, and weeds are generally controlled by herbicides. This system is also called "zero-tillage" or "no-tillage" (Lal, 1995). Roth *et al.* (1988) reported that in a Brazilian Oxisol the bulk density at 20-30 cm depth was significantly lower in no-tillage and minimum tillage systems compared with the conventional tillage system. Accordingly, the total porosity was significantly higher in minimum tillage and no-tillage compared with conventional tillage systems. Despite the large amount of information available on no-tillage practices, there is still a lack of information related to the use of these systems in sandy soils on which cassava is generally grown.

The objective of these experiments is to develop "no-tillage" or "minimum tillage" management systems for cassava production, in order to reduce production costs and improve the soil's physical condition.

MATERIALS AND METHODS

Experiment 1. The effect of various land preparation methods on the yields of Rayong 90 and Rayong 5.

The trial was conducted at Rayong Field Crop Research Center, Rayong province, from 1992 to 1995 using Rayong 90 as the test variety. The experimental design was a Randomized Complete Block design with 3 replications. The treatments were as follows: no-tillage, two times with 7-disk plow, one time with 7-disk plow followed by animal ridging, two times plowing with 3-disk plow followed by one time with 7-disk plow, two times of animal ridging, one time of subsoiler followed by 7-disk plow, and one time of cassava harvester followed by 7-disk plow.

The trial was repeated for one more year at Rayong Field Crop Research Center in 1995/96 using Rayong 5 as the test variety. The experimental design was again a Randomized Complete Block design with 3 replications. The treatments were the same as for Rayong 90 above.

Experiment 2. The interaction between various land preparation methods and the use of several soil amendments.

The trial was conducted at the Rayong Field Crop Research Center in 1999/00. The experimental design was a split-plot in RCB with 3 replications. Four land preparation treatments were established in main plots: no-tillage, two times plowing with 7-disk plow followed by ridging, one time with 3-disk plow, and two times plowing using a 3-disk plow followed by 7-disk plow. The sub-plots had the following four soil amendments: control, chemical fertilizer 15-7-18 N-P_2O_5-K_2O at the rate of 312.5 kg/ha, rock phosphate (RP) plus chicken manure at the rate of 6.25 t/ha, and RP + chicken manure + chemical fertilizer. The test variety was Rayong 5. Plants were harvested at 12 months after planting. The fresh root yield and starch content were measured.

Experiment 3. The interaction between two-tillage systems, and three levels of N.

This experiment was established in 2000 at the Japan International Research Center for Agriculture Science (JIRCAS), in Khon Kaen, Thailand. The soil belongs to Satuk series (fine, loamy siliceous, Oxic Paleustults). The experimental design was a split plot in RCB with 4 replications. Main plots comprised of two tillage systems: no-tillage (NT) and conventional tillage (CT). There were three levels of nitrogen application in sub-plots: 0, 50 and 100 kg N/ha. In addition, all plots received 50 kg P_2O_5 and 50 K_2O/ha. Prior to planting cassava, a herbicide was sprayed for weed control in the NT plot. Cassava, cv. Rayong 72, was used as the test crop.

Two undisturbed soil samples were collected at each depth within the profile (0-10, 10-20, 20-30, 30-50 and 50-70 cm) for physical soil analysis before the start of the trial and after the first year harvest. Soil bulk density was determined by the method described by Black (1965). Porosity was calculated using the equation $\varepsilon = 1 - \rho b/\rho s$: where ρb is the measured bulk density and ρs is the density of soil particles taken as 2.65 Mg/m^3. This is a generally accepted figure for soil particle size density, as it represents an average figure that is sufficiently exact for the majority of mechanical analyses (Baver *et al.*, 1972). Changes in the water profile through the experimental period were measured by pressure plate. The other parameters, i.e. soil saturated hydraulic conductivity, were measured by the method of falling head (Klute, 1986). Soil texture was determined by the pipette method (Gee and Bauder, 1986). For chemical soil analysis, a composite soil sample was collected at the start of the trial at 0-10, 10-20, 20-30, 30-50 and 50-70 cm depth for measuring the pH (1:1 soil:water) , organic matter (Walkley and Black), available P (Bray II) and exchangeable K (NH_4OAc). The data obtained were statistically analyzed using IRRI STAT version 92-1 used in the Thai Department of Agriculture.

Experiment 4. The effect of several land preparation methods, from zero tillage to complete tillage, on cassava yield.

The same experiment was conducted in 2001/02 in 3 sites: in a farmer's field near Rayong Field Crop Research Center, in Huay Pong, Rayong; at Kasetsart University Research Station in Khaw Hin Sorn, Chachoengsao; and at TTDI Research and Training Center in Huay Bong, Nakhon Ratchasima. The experimental design was a split-plot in RCB with 4 replications. The following ten land preparation treatments were established in main plots:

1. no tillage; initial weed control by spraying with Glyphosate
2. tillage by chisel plow, spaced at 50 cm; initial weed control with Glyphosate
3. tillage by subsoiler, spaced at 50 cm; initial weed control with Glyphosate
4. tillage by subsoiler followed by chisel plow, both spaced at 50 cm; initial weed control with Glyphosate
5. tillage by cassava harvester; initial weed control with Glyphosate
6. tillage by one pass of 3-disk plow
7. tillage by subsoiler followed by 3-disk plow
8. tillage by one pass of 3-disk plow, followed by 7-disk plow
9. tillage by one pass of 3 disk-plow, followed by 7-disk plow and contour ridging
10. tillage by one pass of 3-disk plow, followed by 7-disk plow and up-and-down ridging

The following four cassava varieties were planted in subplots: V1 = KU 50; V2 = Rayong 5; V3 = Rayong 72 and V4 = Rayong 90. Stakes were planted at a spacing of 100x80 cm. Chemical fertilizer was applied at the rate of 312 kg/ha of 15-7-21 or 15-15-15 $N-P_2O_5-K_2O$ at one month after planting. The plants were harvested at 10-11 months. Main plots were 10 x 19.2 m and subplots 10 x 4.0 m.

RESULTS AND DISCUSSION

Experiment 1. **Table 1** shows the effect of six land preparation methods on the fresh root yield and starch content of Rayong 90, averaged over three years. The results indicate that the various land preparation methods had a highly significant effect on the fresh root yield of cassava but not on the root starch content. Two times plowing with 3-disk plow followed by one time with 7-disk plow resulted in the highest fresh root yield of 20.43 t/ha, whereas the no-tillage system produced the lowest fresh root yield of 13.63 t/ha. The low yield obtained under no-tillage may be due to the fact that the soil at the start of the experiment might be very compacted from the previous cultivation practices. As such, using a 3-disk plow followed by 7-disk plow loosened the soil and incorporated weeds and crop residues. Adequate loosening of the soil during land preparation will generally improve drainage and soil aeration. Moreover, the soil was very poor in fertility; in particular it had a very low organic matter content. The use of no-tillage systems generally requires an adequate level of soil fertility at the beginning of the trial.

Table 2 shows similar results for Rayong 5. Land preparation by two times plowing with a 7-disk plow, resulted in the highest fresh root yield, but this yield was not significantly different from those obtained using two times of plowing with 3-disk plow followed by 7-disk plow, or using a cassava harvester followed by 7-disk plow, or two times ridging with a cattle-drawn plow. Again, no tillage systems produced the lowest fresh root yield of only 10.66 t/ha.

Experiment 2. In Experiment 2, the results of two years were combined, as neither the fresh root yields nor the starch contents were significantly different between the first and the second year (**Table 3**). Among the various land preparation treatments, the standard practice of using a 3-disk plow followed by 7-disk plow produced the highest fresh root yield of 33.03 t/ha; this was not significantly different from twice plowing with a 7-disk plow followed by ridging, which resulted in a yield of 28.86 t/ha. The no-tillage treatment produced the lowest yield of 25.54 t/ha, while the roots also had the lowest starch contents. Overall, the land preparation methods tested had a highly significant affect on yield and a significant effect on starch content. Similar results were also reported by Tongglum *et al.* (1992). There were also highly significant differences among soil amendments in terms of fresh root yield. The application of rock phosphate + chicken manure + chemical fertilizer produced the highest fresh root yield of 30.2 t/ha. The control treatment without any of these soil amendments produced the lowest root yield of 22.5 t/ha. There was a highly significant interaction between land preparation methods and soil amendments in terms of root yield, but no interaction in terms of starch content. The starch contents of the roots significantly increased by the various tillage treatments as compared to that of plants growing under the no-tillage system.

Table 1. The effect of various methods of land preparation on the average fresh root yield and root starch content of Rayong 90, planted for three years at Rayong FCRC from 1992/93 to 1994/95.

Land preparation treatments	Fresh root yield (t/ha)	Starch content (%)
No-tillage	13.63 d	26
Two times with 7-disk plow	17.86 b	25
One time with 7-disc plow followed by animal ridging	16.86 bc	26
Two times plowing with 3-disk plow, followed by 7-disk plow	20.43 a	26
Two times of animal ridging	15.22 cd	26
One time of subsoiler followed by 7-disk plow	15.54 cd	25
Cassava harvester followed by 7-disk plow		
F-test	**	NS
cv.(%)	14.32	6.74

Table 2. The effect of various methods of land preparation on the fresh root yield and starch content of Rayong 5 at Rayong FCRC in 1995/96.

Land preparation treatments.	Fresh root yield (t/ha)	Starch content (%)
No-tillage	10.66 c	21.67
Two times with 7-disk plow	19.28 a	21.22
One time with 7-disk plow followed by animal ridging	14.46 bc	22.25
Two times plowing with 3-disk plow, followed by 7-disk plow	16.31 ab	24.27
Two times of animal ridging	16.06 ab	22.80
One time of subsoiler followed by 7-disk plow	13.63	20.29
Cassava harvester followed by 7-disk plow	15.96 ab	22.15
F-test	*	NS
cv.(%)	19.75	9.16

Table 3. The interaction between land preparation and the incorporation of soil amendments on the fresh root yield and starch content of cassava (combined analysis for two years).

	Cassava root yield (t/ha)	Starch content (%)
Year		
1 st year	27.57	24
2 nd year	28.02	26
F-test Year	NS	NS
Land preparations (LP)		
No-tillage	25.54 b	24 b
Two times plowing with 7-disk plow followed by ridging	28.86 a	26 a
One time plowing with 3-disk plow	27.08 b	25 ab
Two times plowing with 3-disk plow followed by 7-disk plow	33.03 a	25 ab
F-test LP	**	*
Soil amendments (SA)		
Control = no amendments	22.50 c	25
Chemical fertilizer 15-7-18 at 312.5 kg/ha	28.59 b	25
Rock phosphate + chicken manure at 6.25 t/ha	26.92 b	25
Rock phosphate + chicken manure + chemical fertilizer	30.20 a	25
F-test SA	**	NS
F-test Year x LP	**	NS
F-test Year x SA	**	**
F-test LP x SA	**	NS
F-test Year x LP x SA	NS	NS

Experiment 3. At the start of the experiment the soil texture was classified as loamy sand with a bulk density of 1.645 Mg/m^3, to a depth of 50 cm. **Table 4** shows the other base measurements taken before the trial. The soil was rather acid with a pH of 4.97, it had a very low organic matter (OM) content of 0.57%, while the available P was adequate and exchangeable K very low. The soil's physical and chemical characteristics indicate that the soil used in this trial was low in fertility and had poor physical properties. **Figure 1** and **2** show that in the surface soil (0-10 cm) the soil porosity was higher and the bulk density was lower than those in the no-tillage (NT) and conventional tillage (CT) plots taken at the end of the two year trial. That is probably a result of soil disturbance by the cultivation of cassava. In the NT plot certain structural parameters improved, such as an increase in soil porosity (**Figure 1**), particularly at the depth below 20 cm, as compared to the CT plot and at the start of the trial. There was also an improvement in soil bulk density; the values in the NT plots at each depth were lower than those in CT plots (**Figure 2**). This could be attributed to the *in situ* mulching of plant residues in the NT plots. Numerous studies have shown that crop residues decrease soil compactibility (Gupta *et al.*, 1987; Ohu *et al.*, 1985). In addition, in the CT plot the soil was further compacted during the cultivation practice. Another parameter that was improved was the saturated hydraulic conductivity. The results indicate that soil saturated hydraulic conductivity values in the NT plot were higher than those obtained in the CT plot at each depth interval (**Table 5**). Although at this time the

soil saturated hydraulic conductivity in the NT plot was lower than that obtained at the beginning of the experiment, in the long term this value might be improved. Probably, the soil porosity and bulk density were improved and made it possible for soil particles to produce a greater value of soil saturated hydraulic conductivity. In addition, it also could be the influence of *in situ* mulching on soil water content. Unger (1994) pointed out that a major advantage of maintaining crop residues on the surface soil is improved soil water conservation as a result of reduced runoff of surface water and improved soil conditions. Concerning soil water retention, in general, the retained soil water at the beginning of the trial seemed to be lower than those of the CT and NT plots, with the exception of the values from pF0, in particular at 0-20 cm depth (**Figures 3A-3C**). In most cases the water contents in the soil under NT and CT plots were not much different from each other at each soil water potential and depth. That might be as a result of root penetration into the subsoil of the CT and NT plots, leading to the downward movement of water.

Table 4. Soil properties at the start of the land preparation trial conducted at the JIRCAS Research Center in Klon Kaen in 2000/01 (average to 50 cm depth).

pH	4.97
Organic matter (Walkley and Black, 1934)	0.57%
Available P_2O_5 (Bray and Kurtz, 1945)	17.52 cmol(+)/kg
Exchangeable K_2O (Peech *et al.*, 1947)	21.12 cmol(+)/kg
Texture (Pipette method)	Loamy sand
Bulk density (Black, 1965)	1.645 Mg/m^3

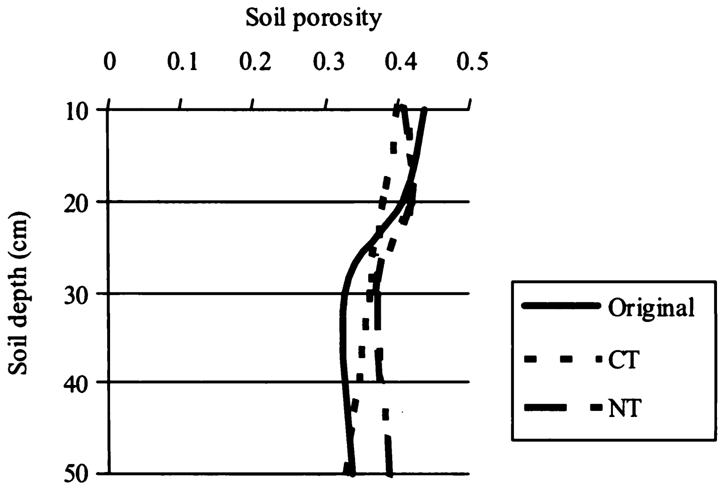

Figure 1. Effect of tillage systems on the soil porosity.

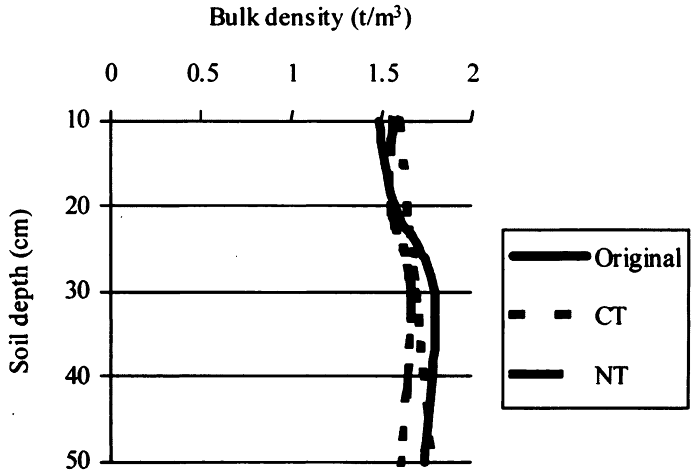

Figure 2. Effect of tillage systems on the soil bulk density (t/m³)

Table 5. Effect of tillage system on soil saturated hydraulic conductivity compared to the original soil (at the start of the experiment) at four depths at the JIRCAS Center in Khon Kaen, Thailand in 2000/01.

Soil depth (cm)	Soil saturated hydraulic conductivity (Ksat. mm./hr)		
	Original (at start)	CT	NT
0-10	139.68	13.70	20.15
10-20	29.09	10.30	13.91
20-30	2.38	4.28	15.33
30-50	3.61	0.54	1.64

As the results of both years indicate, there were no interactions between the tillage system used and the level of nitrogen application. For the first year (2000/01), the fresh root yield of cassava grown under the no-tillage system was significantly higher (59.38 t/ha) than that of cassava grown using conventional tillage (47.13 t/ha) **(Table 6)**. Considering the soil physical properties after the first year harvest, most soil parameters were improved under the no-tillage system. It was also found that the cassava fresh root yield tended to increase as the level of nitrogen application increased. The average yields were 48.94, 50.50 and 60.31 t/ha at the N rates of 0, 50 and 100 kg N/ha, respectively **(Table 6)**. In the second year (2001/2002), the two different tillage systems resulted in similar cassava fresh root yields. In the no-tillage plot the average yield was 49.13 t/ha, which was slightly lower than that obtained using conventional tillage 54.00 t/ha **(Table 7)**. As in the first year, cassava yields increased consistently but not significantly with increasing levels of N application.

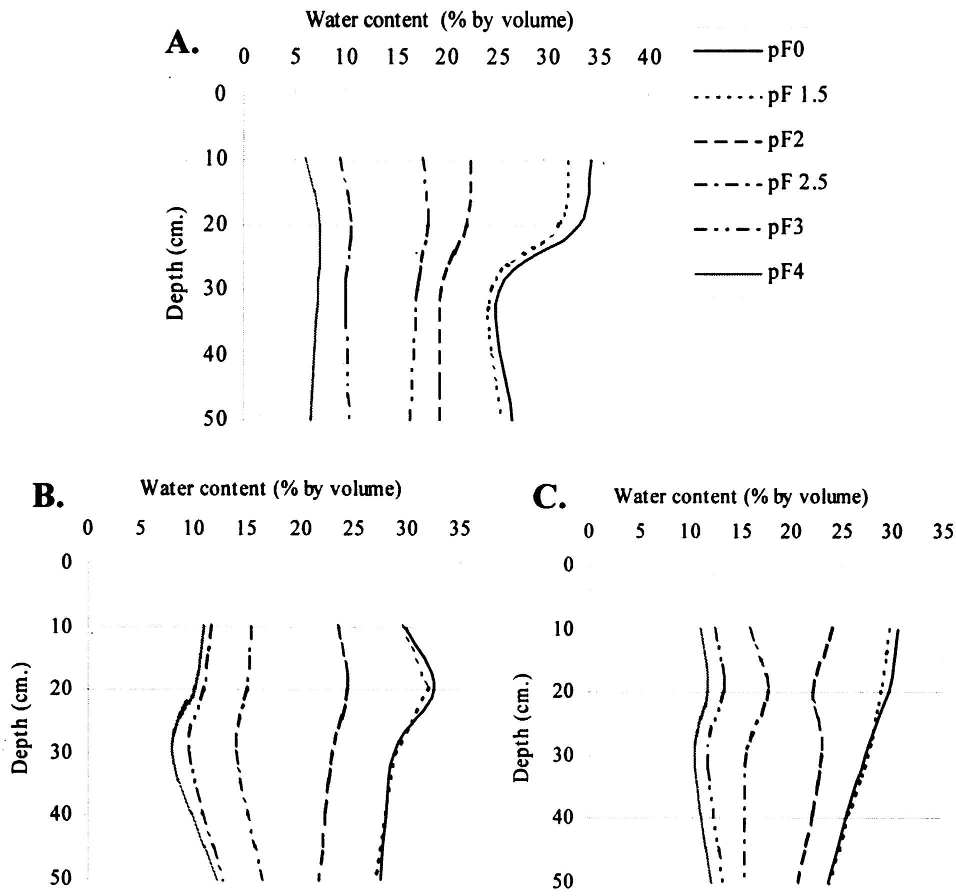

Figure 3. The relationships between soil water content and soil in depth at each soil water potential (pF): (A) the beginning of the trial, (B) under conventional tillage and (C) under no-tillage, in a land preparation trial conducted at the JIRCAS Center in Khon Kaen, Thailand in 2000/01.

Experiment 4. In Experiment 4 there were no interactions between tillage treatments and cassava varieties in terms of fresh root yield and starch content in the three sites of the experiment. In the farmer's field near Huay Pong **(Table 8),** tillage treatments had a significant effect on the fresh root yield of four cassava varieties. Using a 3-disk plow followed by 7-disk plow and up-and-down ridging produced the highest fresh root yields of 19.5 t/ha, while the no-tillage system produced the lowest fresh root yield. Among the reduced tillage treatments (T2-T5) the fresh root yields were not significantly different. Among the four varieties, KU 50 and Rayong 5 had higher yields than Rayong 72 and 90. The yields were rather low due to a very poor soil, severely deficient in Mg (personal communication), and with very low organic matter content, as well as due to lack of rain after planting and initial weed competition. Averaged over four varieties, the highest yield was obtained using a 3-disk plow followed by 7-disk-plow and up-and-down ridging, a subsoiler followed by 3-disk plow, and 3-disk plow followed by 7-disk plow and contour ridging. Ridging may have helped in early weed control. The lowest fresh root yield in the no-tillage treatment was due to flooding. There were no significant differences among treatments in terms of starch content (**Table 8**).

Table 6. Effect of tillage system and nitrogen application rate in the first year on the fresh root yield of cassava, cv. Rayong 72, grown on Satuk soil series at the JIRCAS Center in Khon Kaen, Thailand in 2000/01.

	Fresh root yield (t/ha)		
Chemical fertilizer rate (b)	Tillage system (a)		
$N-P_2O_5-K_2O$ in kg/ha	CT	NT	**Average**
0-50-50	42.75	55.13	**48.94**
50-50-50	44.94	56.06	**50.50**
100-50-50	53.69	67.00	**60.31**
Average	**47.13**	**59.38**	**53.25**
CV 21%	F (a) *	F(b) NS	F(axb) NS

Table 7. Effect of tillage system and nitrogen application rate in the second year on the fresh root yield of cassava, cv. Rayong 72, grown on Satuk soil series at the JIRCAS Center in Khon Kaen, Thailand in 2001/02.

	Fresh root yield (t/ha)		
Chemical fertilizer rate (b)	Tillage system (a)		
$N-P_2O_5-K_2O$ in kg/ha	CT	NT	**Average**
0-50-50	51.31	42.69	**47.00**
50-50-50	54.81	52.19	**53.50**
100-50-50	55.75	52.44	**54.13**
Average	**54.00**	**49.13**	**51.56**
CV 12.8%	F (a) NS	F(b) NS	F(axb) NS

At the Khaw Hin Sorn site, neither tillage treatments nor cassava varieties had significant effects on the fresh root yield (**Table 9**), but the variety of cassava had a significant effect on root starch content.

At the TTDI site, there were significant differences among tillage treatments with respect to fresh root yield (**Table 10**). Using a subsoiler followed by chisel plow produced the highest fresh root yield of 21.86 t/ha, but this yield was not significantly different from that obtained in the no-tillage treatment. Using various combinations of 3-disk and 7-disk plows produced rather low fresh root yields of about 16-18 t/ha. Among the four varieties tested, Rayong 90 produced the highest yield and KU 50 the lowest.

Table 8. Effect of various tillage treatments on the root yield and starch content of four cassava varieties[1] planted in a farmer's field in Huay Pong, Rayong, Thailand in 2001/02.

	Cassava root yield (t/ha)					Starch content (%)				
Tillage treatments	V_1	V_2	V_3	V_4	Av.	V_1	V_2	V_3	V_4	Av.
1. No tillage; Glyphosate	10.72	12.42	12.41	10.29	**11.46c**	20.4	20.7	17.6	22.0	**20.2**
2. Chisel plow; Glyphosate	12.13	13.36	12.58	10.05	**12.03bc**	23.2	20.1	17.3	23.3	**21.0**
3. Subsoiler; Glyphosate	16.82	16.77	9.97	11.25	**13.70bc**	21.3	19.4	15.6	22.5	**19.7**
4. Subsoiler+Chisel; Glyphosate	16.59	16.69	14.42	11.69	**14.85abc**	23.5	20.7	19.3	24.2	**21.9**
5. Cassava harvester; Glyphosate	12.29	19.22	14.48	12.42	**14.60abc**	21.4	18.8	17.2	22.1	**19.9**
6. 3 disk plow	13.29	15.86	14.63	10.62	**13.66bc**	23.1	20.6	19.3	22.3	**21.3**
7. Subsoiler+3 disk plow	16.40	20.08	19.35	14.45	**17.57ab**	22.0	21.2	19.7	21.9	**21.2**
8. 3 disk+7 disk plow	13.41	14.14	10.65	9.51	**11.93bc**	23.2	20.0	17.1	23.8	**21.0**
9. 3 disk+7 disk+contour ridges	21.43	17.14	15.86	15.44	**17.47ab**	20.0	19.7	17.1	22.9	**19.9**
10. 3 disk+7 disk+up/down ridges	19.40	22.92	18.75	16.93	**19.50a**	19.9	18.2	16.6	20.0	**18.7**
Average	**15.27ab**	**16.86a**	**14.31b**	**12.26c**	**14.68**	**21.8a**	**19.9b**	**17.7c**	**22.5a**	**20.5**
CV (%)					27.57					7.7
Tillage treatment (T)					*					NS
Variety (V)					**					**
TxV					NS					NS

[1] V_1 = KU 50; V_2 = Rayong 5; V_3 = Rayong 72; V_4 = Rayong 90

Table 9. Effect of various tillage treatments on the root yield and starch content of four cassava varieties[1] planted in a farmer's field in Khaw Hin Sorn, Chachoengsao,Thailand in 2001/02.

	Cassava root yield (t/ha)					Starch content (%)				
Tillage treatments	V_1	V_2	V_3	V_4	Av.	V_1	V_2	V_3	V_4	Av.
1. No tillage; Glyphosate	23.45	19.53	20.54	22.27	**21.45**	19.8	17.5	13.9	21.2	**18.1**
2. Chisel plow; Glyphosate	18.06	25.10	18.75	20.35	**20.56**	19.7	16.8	14.1	20.8	**17.8**
3. Subsoiler; Glyphosate	22.17	17.14	17.01	20.49	**19.20**	20.9	17.8	14.9	21.6	**18.8**
4. Subsoiler+Chisel; Glyphosate	20.03	19.48	18.89	17.90	**19.07**	20.2	18.3	16.3	23.2	**19.5**
5. Cassava harvester; Glyphosate	20.31	18.89	16.06	18.98	**18.56**	20.3	16.8	14.9	22.6	**18.6**
6. 3 disk plow	20.69	18.49	21.22	14.83	**18.81**	20.1	16.8	14.8	20.9	**18.2**
7. Subsoiler+3 disk plow	23.43	24.57	23.40	27.43	**24.71**	21.6	18.1	14.4	22.3	**19.1**
8. 3 disk+7 disk plow	22.81	23.96	19.13	19.18	**21.27**	20.2	17.5	14.4	22.0	**18.5**
9. 3 disk+7 disk+contour ridges	25.42	23.02	25.90	25.17	**24.88**	21.7	18.6	13.8	21.7	**18.9**
10. 3 disk+7 disk+up/down ridges	21.67	22.57	22.50	26.28	**23.25**	21.3	18.2	13.9	21.6	**18.8**
Average	**21.80**	**21.28**	**20.35**	**21.29**	**21.18**	**20.6b**	**17.6c**	**14.5d**	**21.8a**	**18.6**
CV (%)					14.72					5.65
Tillage treatment (T)					NS					NS
Variety (V)					NS					**
TxV					NS					NS

[1] V_1 = KU 50; V_2 = Rayong 5; V_3 = Rayong 72; V_4 = Rayong 90

Table 10. Effect of various tillage treatments on the root yield and starch content of four cassava varieties[1)] planted in TTDI, Huay Bong, Nakhon Ratchasima Thailand in 2001/02.

Tillage treatments	Cassava root yield (t/ha)					Starch content (%)				
	V_1	V_2	V_3	V_4	Av.	V_1	V_2	V_3	V_4	Av.
1. No tillage; Glyphosate	14.14	21.80	19.97	23.72	**19.91ab**	22.0	25.8	25.0	28.3	**25.3**
2. Chisel plow; Glyphosate	15.77	18.11	16.80	20.44	**17.78bc**	21.8	26.0	26.9	25.4	**25.0**
3. Subsoiler; Glyphosate	14.03	16.19	15.16	19.87	**16.31c**	24.3	25.8	25.8	24.9	**25.2**
4. Subsoiler+Chisel; Glyphosate	20.36	20.94	22.21	21.95	**21.86a**	26.1	27.2	26.2	30.4	**27.5**
5. Cassava harvester; Glyphosate	11.74	17.50	17.66	17.42	**16.08c**	25.5	26.1	25.6	27.9	**26.3**
6. 3 disk plow	17.03	20.39	17.45	17.13	**18.00bc**	23.7	25.0	27.2	21.0	**24.2**
7. Subsoiler+3 disk plow	16.95	15.10	19.51	14.82	**16.59bc**	24.0	26.9	27.2	28.6	**26.7**
8. 3 disk+7 disk plow	19.95	15.26	17.37	20.02	**18.15bc**	23.4	26.5	25.3	25.6	**25.2**
9. 3 disk+7 disk+contour ridges	16.09	19.11	17.94	20.15	**18.19bc**	24.9	26.5	24.3	29.3	**26.2**
10. 3 disk+7 disk+up/down ridges	14.75	18.16	17.45	19.71	**17.52bc**	25.5	24.9	27.8	29.4	**26.9**
Average	**16.08a**	**18.46a**	**18.15a**	**19.52a**	**18.05**	**24.1b**	**26.1a**	**26.1a**	**27.1a**	**25.9**
CV (%)					20.67					11.1
Tillage treatment (T)					*					NS
Variety (V)					**					**
TxV					NS					NS

[1)] V_1 = KU 50; V_2 = Rayong 5; V_3 = Rayong 72; V_4 = Rayong 90

CONCLUSIONS

The standard practice of using a 3-disk plow followed by 7-disk plow, with or without ridging generally resulted in the highest fresh root yields. There were no significant interactions between the tillage treatments and cassava varieties in terms of both fresh root yield and root starch content. No-tillage systems generally produced low cassava yields but seemed to have improved the soil's physical conditions as compared to conventional tillage; the porosity and soil saturated hydraulic conductivity increased in the no-tillage plot and the bulk density was reduced. Fresh root yields tended to increase with increasing levels of applied N.

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PLANT PROTECTION PROBLEMS IN CASSAVA IN INDIA

S. Edison[1]

ABSTRACT

Cassava is grown in India for both food and industrial purposes. Like all other crops, cassava is also prone to be infected by several pathogens. Among the various diseases of cassava that limit production, Indian Cassava Mosaic Disease (ICMD), root rot, *Phoma* and brown leaf spot are the most important.

ICMD is widespread in almost all cassava growing areas of India and causes yield losses of up to 88% in susceptible varieties and up to 50% in field tolerant varieties. The rate of spread and degeneration of cassava due to ICMD varies among varieties. Even in field tolerant varieties, entire plant populations may degenerate within three to four years. ICMD is caused by *Indian cassava mosaic begomovirus* which is serologically different from other cassava viruses, such as ACMV and EACMV. Time of infection, varietal susceptibility, climatic factors and vector population determine the disease incidence and yield loss.

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, causing up to 50% loss in certain endemic areas. Characteristic symptoms as well as morphological features of the pathogen have been described. Excessive irrigation, poor drainage and the development of a hard pan favor the occurrence of this disease. Differential reaction of cassava varieties to infection by *Phytophthora* was observed. Brown leaf spot caused by *Cercospora henningsii* is also an important disease in certain areas, causing severe defoliation. Disease intensity/incidence varies depending upon climatic factors, nutrient management and varieties. *Phoma* dieback disease is an emerging problem in certain areas where cassava cultivation is intensive. Tip drying and stunted growth leads to reduction in quantity and quality of root production. Integrated disease management options to contain the above diseases, and strategies for production of healthy planting material, are discussed.

Among the several pests which attack cassava, scale insect, spider mite, termite and whitefly are the most important ones. Scale insects (*Aonidomytilus albus*) attack the stems in the field and during storage of planting material, leading to a loss of viability of the planting material and poor establishment. The insect perpetuates itself through planting material, which serves as a source of multiplication and spread. The severity of attack increases during prolonged dry weather. Red spidermites (*Tetranychus cinnabarinus* and *Eutetranychus orientalis*) are important foliage feeders, which cause chlorosis, withering and drying of leaves. Severe infestations are observed during dry periods and the incidence increases year after year depending upon the climate. Climatic factors and insect population determine the extent of the outbreak. Yield losses due to the spider mites range from 17 to 33%. Termites (*Odontotermus* spp) are often a serious pest, attacking stems and sets in the field during dry periods, especially in Tamil Nadu and Andhra Pradesh. Two kinds of whitefly i.e. common whitefly, *Bemisia tabaci,* and spiral whitefly, *Aleurodicus disperses,* may cause serious infestations; the latter one has emerged as a serious problem since 1993. *Bemisia tabaci* is important as a vector of ICMD and is present throughout the year. Spiral whitefly causes yellowing, crinkling and curling and and is the cause of sooty mould. In both cases severity of the damage increases during the summer. For all these pests effective management strategies have been developed.

INTRODUCTION

Tropical root and tuber crops form and important group of crops used as secondary or subsidiary food for one fifth of the world population in tropical and sub-tropical regions;

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they are also the third most important group of foods, after cereals and pulses. Cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* (L.) Lam), aroids taro or arum (*Colocasia esculenta* (L.) Schott), tannia (*Xanthosoma sagittifolium* Schott) and elephant-foot yam (*Amorphophallus paeonifolius* (Dennst) Nicolson), (lesser yam (*Dioscorea esculenta* Burk), greater yam (*D. alata* L.), and African or white yam (*Dioscorea rotundata* Poir), country or Chinese potato (*Solenstemon rotundifolius* Poir) and yam bean (*Pachyrrihizus erosus* L.) are the important tropical root and tuber crops. These crops have a higher biological efficiency as producers of carbohydrates than the cereals. Besides, they can by used as raw materials for the production of alcohol, starch, sago flour, liquid glucose, vitamin C and many other industrial products, as well as animal feed. Hence, tropical root and tuber crops share a place with cereals as dietary staples, both in raw and processed forms. Their starches are invariably superior to the conventional sources of starch, and they are efficient biological producers of carbohydrates per unit area per unit time. In the 21st century nearly one fourth of the world population is estimated to live in severe poverty. With the burgeoning population in India we may have to import 40 million tonnes of food to meet the requirements by 2030. It is in this context that the tuber crops assume importance. Root and tuber crops, with due support of advanced technologies, will play a greater role in meeting the food requirements of the country in the coming years.

Cassava is a staple food in Kerala state and is popular as an industrial crop in Tamil Nadu, Maharashtra and Andhra Pradesh. Cassava is grown on an area of about 200 thousand ha with a production of 5.87 million tonnes. Sweet potato is largely grown in Orissa , Uttar Pradesh, Bihar, Assam and Maharashtra and the area under sweet potato is about 130 thousand ha with a production of 1.06 million tonnes (FAO, 1998). The cultivation of edible aroids, yams and Chinese potato is restricted to parts of Bihar, Orissa, Kerala, Tamil Nadu, Andhra Pradesh, Maharashtra, West Bengal and Northeast India.

Pest Complexes of Root and Tuber Crops

Like other crops, tuber crops are subjected to the depredation of a number of insect and non-insect pests. A comprehensive global account of cassava pest management was given by Anon (1978), Bellotti and Schoonhoven (1978), and Bellotti *et al.* (1999). Lal and Pillai (1982), Pillai and Palaniswami (1984), and Pillai (1994) reviewed the pests of cassava in India. Anon (1978), Sutherland (1986), Palaniswami (1988) and Jansson and Raman (1999) reviewed world sweet potato pests. Rajamma *et al.* (1993) detailed the pests attacking sweet potato in India. Pests of edible aroids, yams and Chinese potato, were comprehensively reported by Anon (1978); Mitchell and Maddison (1983) and Palaniswami (1994a). In India, about 34 species infest cassava, 78 species attack sweet potato, 46 species on edible aroids, 21 on yams and 10 on Chinese potato (Palaniswami and Rajamma, 2000). Major pests of each crop are discussed in a comprehensive manner along with its management strategies.

Disease Complexes of Root and Tuber Crops

Tropical root and tuber crops are attacked by several diseases caused by fungi, bacteria, viruses and mycoplasma-like organisms, which may cause yield reductions in the crops. In India, more than 80 diseases have been reported on these crops while the global figure is more than 200. However, many of these diseases are of minor importance or cause little damage and are limited in geographical distribution, while some are of considerable importance and cause significant damage. With the increase in the development of new varieties and with the international exchange of genetic material, the number of diseases are also on the increase, while in certain pathogens new virulent strains are also developing. As these crops are vegetatively propagated and many of the diseases are spread through the planting materials, great care should be taken during the import of planting materials from other countries so as to avoid introducing presently non-existing pathogens into the country. The most important viral disease of cassava reported in India is Cassava Mosaic, or more precisely Indian Cassava Mosaic Geminivirus (ICMV), which is transmitted by the whitefly, *Bemisia tabaci.*

Among all the diseases reported in India, only few diseases, like cassava mosaic disease, root rot of cassava, leaf blight of Colocasia and collar rot of elephant foot yam, are of major importance as they cause a considerable reduction in yield. Yield reduction of cassava mosaic disease (25-100%), leaf blight of Colocasia (25-50%), and collar rot of elephant foot yam (20-100%) may vary depending on the cultivars and influence of various weather factors.

MAJOR CASSAVA PESTS

Cassava Scale Insects

Scale insects attach to the stem in the field and during storage of planting material. The most important scale insect is the white mussel-shaped soft scale (*Aonidomytilus albus* CkII). It was first reported in Tamil Nadu. The insect sucks and desaps the stem. It multiplies rapidly covering the stem in large numbers, and it also attacks the side shoots and at times the petioles as well. In severe infestations the stem becomes weak and dry due to the prolonged infestation, resulting in the loss of viability of planting material and poor establishment of the crop. Weakening and breaking of the main stem causes profuse branching which gives a bushy appearance. The severity of attack increases during a prolonged dry season. The problem is perpetuated through planting materials which serve as the source of multiplication and spread. Eggs are laid beneath the scales. The young nymphs come out in 3-4 days after which they are active, spread out and settle. Once they start feeding they lose their legs and become sedentary. The adult produces a white waxy secretion over itself which develops into a scale. In 20-25 days the nymphs become full grown. The male is winged and the female is wingless and sedentary.

For the effective management, scale-free stems should be collected for storing and planting. Storing the stems in a horizontal position encourages multiplication of scales due to the development of higher temperature and humidity. Therefore, healthy stems are to be kept in a vertical position under shade to facilitate easy aeration and diffused day light. As a prophylactic measure the stems may be sprayed with Dimethoate (0.05%) at the time of storing. If further infestation is observed, one more spraying may be carried out. The infested stems are to be rejected and burned at time of planting. In case of acute shortage of planting material and when the scale attack is mild, then the stakes can be dipped into the above insecticidal solution for 10-15 minutes before planting.

Cassava Spidermites

Among the foliage feeding pests, the most serious ones are the spidermites. There are two distinct groups of spidermites. One group feeds on the lower surface of the leaves (*Tetranychus cinnabarinus* (Boisd.) and *T. neocaledonicus* Andre) causing elongated streaks, chlorosis, withering and drying of leaves. The other group which prefer to infest on the upper leaf surface includes *Eutetranychus orientalis* (Klien) and *Oligonychus biharensis* (Hirst); these cause depletion of chlorophyl, resulting in the characteristic bronzing and typical rusted & leathery appearance, and such leaves begin to curl from margins and later fold into one twisted roll. The teranychid mites usually infest the lower leaf surface but during epidemics may cover both sides of the leaf. The predominant species are *T. cinnabarinus* and *E. orientalis.* They appear together and multiply rapidly during dry periods. Both groups infest from the bottom leaves upwards. In periods of heavy infestation the population density ranges from 200-1000/leaf in almost all leaves. The lower surface feeding mites cause more severe leaf fall than other groups. The biology and binomics of *T. cinnabarinus* and *E. orientalis* reveal that the total life cycle from egg to adult ranges from 11-20 and 10-14 days, respectively. The spidermites' incidence may increase year after year depending on climatic conditions. Rainfall is the most limiting factor. Heavy rainfall accompanied by wind is harmful to mites, while a fall in relative humidity and an increase in temperature are highly conducive for their rapid multiplication. An outbreak can be expected during dry summers when the temperature is above 32°C and the relative humidity below 75%. The yield loss due to spidermites alone ranged from 17.8 to 33.1% in different varieties under natural infestation in Kerala. The economic threshold levels for spidermites was found to be 25% leaf infestation for Sree Vishakam and 10% for Sree Sahya and M4 varieties. Seasonal incidence of biotic agents of spidermites of cassava indicated that predators of mites had a preference for eggs and nymphs to adults. Several cassava accessions at CTCRI, *i.e.* CE-4, CE-14, CE-38 and CE-139, were found to be highly resistant to spidermites. The host plant resistance is the most satisfactory and long-term solution to control mites on cassava. Spraying Demethoate or Methyldemeton (0.05%) during severe infestation (Jan to April) is highly effective against the mites; spraying water at run-off level is also effective in reducing mite infestation. This has an added advantage of preserving the biotic agents of mites. Foliar application of urea followed by spraying Dimethoate at 0.05% in severe situations was recommended as an IPM approach against spidermite outbreaks.

Cassava Whiteflies

Bemisia tabaci (Genn.) is the common whitefly on cassava. It is more important as a vector of CMD than as a pest and is abundant throughout the year. An aphelinid nymphal-pupal parasitoid *Encarsia flava* (6.8 to 30%) was found to be an effective biological control agent for white flies in the field.

Spiral whitefly, *Aleurodicus disperses* Russel, was found to seriously infest cassava since 1993. It is highly polyphagous in nature and causes yellowish specks of leaves, resulting in crinkling and curling and sooty mould development. Adults are much larger than the normal whitefly, i.e. *B. tabaci* (2 mm in size). Eggs are deposited spirally on leaves and take 18-23 days to become adult. Severity of damage increases during summer.

MAJOR CASSAVA DISEASES

Cassava Mosaic Disease

Cassava mosaic disease is caused by the Indian Cassava Mosaic Geminivirus. The symptoms are chlorotic areas intermixing with normal green tissue, which gives the mosaic pattern. In severe cases leaves are reduced in size, twisted and distorted. It affects the growth of the plant, resulting in a significant reduction in plant height, stem girth, petiole length and leaf size. It causes 25-80% yield reduction depending upon the varieties.

The primary spread of the disease is through the indiscriminate use of infected planting material; the secondary spread is through the vector, the whitefly *Bemisia tabaci* G. Studies on modes of transmission indicate that the disease is not transmitted through true seeds. Sap transmission of the disease from cassava to cassava could not be achieved. However, the disease could be transmitted through sap from cassava to *Nicotiana benthamiana* and *N. glutinosa*. CMD can also be easily transmitted through grafting.

The disease causing agent (virus) was purified and found to belong to the group "Gemini" viruses. The particles measure 18-24 nm in diameter. The antisera with adequate titre strength, which can detect successfully even latent infection of the disease, have also been developed.

Symptoms of the disease are masked during dry and hot months and make it impossible to identify the diseased plants. Therefore, disease-free planting materials should be selected before the beginning of the dry/hot season.

Resistance to CMD has been studied since 1968 in the country. No cassava variety is immune to CMD. Even the related species, i.e. *M. glaziovii* is susceptible on artificial inoculation. However, a great variation in the degree of susceptibility was observed; a few field resistant/tolerant lines such as M4, H97, H165, H 2304, H1687, S1315, S1310, S2381 and S2380 were identified and recommended for cultivation.

Integrated management of CMD

This includes the following measures:

- Selection of disease-free planting material.
- Use of field tolerant varieties like H-97, H-165 and Sree Visakham.
- Selection of disease-free meristem-derived planting material, followed by clonal multiplication with periodical screening and rouging of freshly infected plants, will be useful to raise a good disease-free crop.
- Disease-free planting material can be multiplied on a large scale at higher altitude where the whitefly population is low or nil.
- Raising the plants in the nursery at closer spacing prior to transplantation into the main field is an useful step to prevent the primary spread of the disease in the main field.
- Adherence to strict sanitary practices such as timely harvest and prompt disposal of crop residues, and eradication of self-sown plants and weeds which may harbor both the disease and vectors.

Cassava Root Rot

Cassava root rot is caused by *Phytophthora drechsleri*. There are no external symptoms. Infected roots show brown discoloration of internal tissues, or are rotten and exhibit foul smell. Infected roots rot and become unfit for consumption or marketing and hence cause heavy economic losses.

The disease can be managed by providing proper drainage in the field. The infected roots should be removed from the field and burned. *Trichoderma viride* is a good biological control agent and can be released in the problem areas.

Plant Quarantine

African mealy bugs, American green mites, grasshopper, hornworm and thrips, which are serious pests in south America and Africa, have so far not gained entry into India. Mealy bugs of cassava are actually a devastating pest which has greatly affected cassava cultivation in Africa. However, it is now being contained by a massive Africa-wide biological control program.

Similarly, many serious cassava diseases, such as witches broom, super-elongation, frog skin, vein mosaic and brown streak etc. have so far not been reported in India. This warrants for strict surveillance and quarantine measures to prevent their introduction. The diseases given below, need special attention.

Name of the disease		***Causative agent***
African Cassava Mosaic	-	African cassava mosaic virus - Uganda strain
East African Cassava Mosaic	-	East African cassava mosaic virus
Cassava Common Mosaic	-	Cassava common mosaic virus
Cassava Brown Streak	-	Cassava brown streak virus
Cassava Vein Mosaic	-	Cassava vein mosaic virus
Witches Broom	-	Mycoplasma-like organisms

FUTURE OUTLOOK

In the developing countries, tropical root and tuber crops have received far less attention with respect to research and development than other crops. Most of the basic and applied research in the area of crop protection of root and tuber crops have been conducted in the developed countries. Considerably more attention has to be given to IPM/IDM of tropical tuber crops in developing countries.

Effective plant quarantine is the first line of defence against the introduction of pests and diseases. It is obviously an important component of IPM/IDM. It requires coordination at national and international levels. With efficient and vigilant quarantine, the introduction and spread of exotic pests which are of serious nature can be avoided or greatly curtailed.

In addition to the tactical approaches (biological control, host plant resistance, chemical control and systems entomology) associated with IPM for cassava, the following areas of research are also needed.

- Use of flow cytometry in determining the DNA content of insect cells in order to differentiate biotypes, sub species and the genetic make-up of populations
- Use of NMR and mass spectrometry for identification of chemicals in insects and plants affecting behaviour or survival
- Genetic engineering of microbes and its applications
- Application of artificial intelligence and expert systems.

Use of fungicides to control the fungal diseases or insecticides to keep off the vectors, are generally not practical due to economic considerations; however, fungicides can be economically used for the treatment of planting materials such as stem cuttings before planting. It is therefore necessary to use new technologies integrating flexible combinations with minimum use of pesticides. Such technologies may include use of host plant resistance, selection of disease-free planting material, field sanitation, improved cultural practices that reduce disease vulnerability, biological control, and developing disease diagnostic kits for major viruses. Many of the virus diseases need to be studied systematically for better understanding and formulation of an effective integrated disease management.

MECHANIZATION POSSIBILITIES FOR CASSAVA PRODUCTION IN MALAYSIA

H. Md. Akhir and A.B. Sukra[1]

ABSTRACT

This paper looks at the needs and potential for mechanized operations in the production of cassava on mineral soils in Malaysia. It briefly explains the planning considerations and the availability of machines for these operations. Almost all field operations in the production of cassava on mineral soil can be mechanized; however, a few operations may still need to be done manually. The scale of production determines the extent of mechanization to be adopted. Careful planning is required because mechanized production involves a large amount of capital. Planning should involve establishing a suitable schedule to carry out field operations and selecting the appropriate machines. Local environmental and topographical factors at the farm also need to be considered in the planning of mechanized cassava production.

INTRODUCTION

One of the major sources of starch is cassava (*Manihot esculenta* Crantz). Cassava starch is widely used in Malaysia in various industries such as food processing, textiles and paper production. It is also used in the production of certain chemicals such as acetone, alcohol and acetic acid. Cassava is also used in the livestock feed industry. The demand for cassava starch is growing rapidly; it was estimated at 90,000 tonnes (valued at US$ 14 million) in 1996, and has been increasing at a rate of about 27.8% per year over the last ten years (Tan, 1998). Technologies for growing cassava also have been well established (Tan and Chan, 1994). Even though cassava is an important crop for the starch industry, the area cultivated in Malaysia has sharply decreased, from 20,000 ha in 1988 to about 2,000 ha in 1997 (Anon, 2000; Tan, 2000), and has remained at this level since then. This decline has been attributed to scarcity of land and labor.

Machines for field operations for cassava, such as for land preparation, planting, fertilizer application, weed control, harvesting and transportation have been developed and reported (Sukra and Tan, 1994). In Malaysia mechanization for cassava is currently limited to land preparation, herbicide spraying and digging of roots. Mechanization for the other operations is needed for more cost-effective commercial production of the crop in view of labor shortages. The traditional method of production is too labor intensive. It requires about 81 man-days/ha **(Table 1)**.

Considerations for Mechanized Cassava Production

Planning for mechanized production of cassava is different from that of manual production. A large amount of capital is required in mechanized production. Also attention need to be given at the planning stage to several important aspects, such as terrain, infrastructure, soil type, rainfall, labor quality and capital.

Soil and terrain

For ease of mechanized operations, areas with a loam type of soil should be selected, while heavy clays should be avoided. Also, field plots should not have slopes of more than 8%, nor should they be laid on low-lying and flood-prone areas. Plots may need to be graded to ensure good drainage. If cassava needs to be planted on slopes then

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it would be advisable that the plots be laid across the slope, or slightly inclined to the contours so as to minimize soil erosion in the plots.

Table 1. Labor utilization for traditional cassava production.

	Labor utilization per hectare	
Field operation	Man-days	% of total
Land preparation*	-	-
Harvesting of stems	1	1.2
Preparing stem cuttings	1	1.2
Planting	9	11.2
Weed control		
Pre-emergent spraying	1	1.2
Hand weeding at 2-3 months	10	12.3
Pre-harvest spraying	2	2.5
Fertilizer application	5	6.2
Harvesting a 30 t/ha yield	50	61.7
Clearing fields	2	2.5
Total	81	100

*This operation is contracted out and done using 4-wheeled tractors
Source: *Adapted from Chan et al., 1983.*

Rainfall distribution pattern

Generally, it is difficult for tractors to work in wet sticky soils. Hence the interplay between soil texture and rainfall distribution pattern in any production area will determine the number of workdays available throughout the year. This parameter influences the formulation of cropping schedules, and hence the capacity and number of machines required in any mechanized cassava production that would determine its economic viability. It is best if field operations could be undertaken all year round so as to maximize the use of each machine, thereby requiring less machines for the whole farm. Areas with low but adequate amount of rainfall that is well distributed throughout the year are suitable for mechanized cassava production. On the other hand, areas with very high rainfall throughout the year are not suitable. Areas with a long wet period would require a larger number of machines for each farm as compared to those with no specific wet period.

Machinery for Field Operations

Based on our studies, we are of the opinion that it is possible to mechanize fully the production of cassava roots. The machines considered suitable for the various field operations are listed in **Table 2**. Most of the machines are imported, while a few have been developed locally. The majority of these machines have been tested on local loam soils. The optimum machinery for collecting and handling of harvested roots in the field, prior to being transported to the factory, still needs to be developed further.

Land preparation

Initial land clearing, land levelling and the construction of field roads and drains can be done using standard machines or tractor implements such as bulldozer, motor grader, digger-shovel/back hoe, and rotary disk trencher.

Table 2. Machines which may be used for different operations in the production of cassava on mineral soils.

Field operation	Prime mover*	Implement/machine*
Primary tillage	Tractor 4W**	- Disk plow - Moldboard plow
Secondary tillage	Tractor 4W**	- Rotary tiller - Disk harrow
Other operations (as needed)	Tractor 4W**	- Cambridge roller - Ridger - Rotary ditcher - Subsoiler - Mole drain plow** - Dump rake** - Spring tine
Stem harvesting	Manual	- Machete
	Tractor 4W	- Stem harvester**
Stem gathering, stacking	Tractor 4W and manual	- Trailer
Making stem cutting	Engine	- MARDI stem cutter[1]
	Manual	- Machete
	Manual	- Hand saw
	Engine	- Chain saw
Transport to field	Tractor 4W	- Trailer
Planting	Tractor 4W	- Modified 'API' planter[2](1/2/3 rows) - 'GMD' planter** - 'BONEL' automatic planter** - 'Whole stem planter** - 'Nigeria' automatic planter** - 'Cuban planter**
Fertilizer application	Tractor 4W	- Simultaneous with above planters - Spinner/bander
Pre-emergence herbicide spraying	Tractor 4W/2W[3] /Motorcycle[4]	- Boom sprayer-hydraulic or DA****
	Manual	- Manual knapsack sprayer - CDA sprayer - Motorized knapsack sprayer - Portable motorized sprayer
Post-emergence berbicide spraying	Tractor 2W	- High clearance CDA sprayer[3] - Portable motorized sprayer + long hose
	Tractor 4W	- Boom sprayer + long hose - Manual knapsack sprayer - Motorized knapsack sprayer
Inter-row weeding	Tractor 4W	- Duck foot spring tines - Inter-row rotary tiller** - 'Hammer' flail pulverizer - Rotary slasher - Oil palm bunch mulcher
Root digging	Tractor 4W	- MARDI 1-row digger[5] - 1-row elevator digger: 'API'/'Righter'[6] / 'GMD'** - CIAT ½ row digger
	Manual	- IITA-MARDI lever[7]

Table 2 (Continued)

Field operation	Prime mover*	Implement/machine*
Root gathering	Tractor 4W	- MARDI collection trailer c/w crane - Front-end loader - 'GMD' pickup loader**
Complete harvester	Self-propelled	- Combine harvester 'Righter'**
De-stumping	Manual	- De-stumping axe or machete
Transportation to factory	Tractor 4W	- Trailer

Notes:
* = Each tractor or implement is of various capacities.
** = Performance of this machine has not been tested locally.
*** = 4W or 2W refers to four-wheeled or two-wheeled.
**** = CDA refers to controlled droplet applicator.

Sources:
[1] Sukra *et al.,* 1993
[2] Sukra *et al.,* 1990
[3] Anas, A.N., Agric. Engin. Div., MARDI, Serdang, *pers. comm.*, 1990.
[4] Anas, 1990
[5] Sukra, 1994
[6] Kemp, 1978
[7] Sukra, 1986

Soil cultivation

To control weeds, prior to soil tillage operations the ground cover ought to be sprayed with a suitable herbicide using a tractor-mounted boom sprayer. The implements to be chosen for cultivating the soil depend on the soil texture, soil moisture status, ground slope, grass cover and other factors. Primary cultivation can be done using a disk plow or moldboard plow. Secondary soil cultivation can be done using a disk harrow or rotary tiller. Cambridge roller can be used for breaking large soil clods or for compaction of over-loosened soil. On low ground areas with possibility of flooding during heavy rains, planting on wide beds or high ridges is recommended. Wide beds can be constructed using ridger or furrower implements. However, it is better if such areas are provided with sufficient drainage to prevent flooding.

Harvesting stems for cuttings

Before the mature crops are harvested, good stems are collected for use as cuttings in the next crop season. The stems are cut and gathered manually and kept in standing stacks. While tractor-drawn trailers may be used in transporting the cut and gathered stems, no fully mechanized means have been found for the cassava stem harvesting operation.

Preparing cassava stem cuttings

Cassava is planted from stem cuttings of about 20 cm in length. A large amount of cuttings are required (about 10,000 cuttings/ha). For mechanized planting, the cuttings used need to be uniform in length, size and shape with their ends being cut cleanly. The preparation of stem cuttings could be done manually using simple tools such as hacksaw or a motorized small chain saw. A prototype engine-driven cassava stem-cutting machine has been developed at MARDI. The machine's quality of work was satisfactory. It was capable of preparing up to 3,300 cuttings/hour. One worker was required to operate the machine. The prototype machine developed in 1993 was estimated to cost about US$1,316 per unit (Sukra *et al.,* 1992).

Planting and fertilizing

An imported semi-mechanical single-row planter for cassava has been modified and tested by MARDI (Sukra *et al.*, 1990). The modified planter performed satisfactorily. However, its performance was affected adversely by sticky soil conditions as well as by very fine or very chunky soil tilth. Long or large-sized stem cuttings (more than 25 cm) are not suitable for use with the planter. Compared to manual planting, the planter reduced the planting time by about 70%. The planter could be attached to the tractor singly or in a gang of three. The single row planter has a work rate of 0.18 ha/hour and uses one operator. A fertilizer hopper attached to the machine applies granular fertilizer along the planted row.

Weed control

Pre-emergence herbicide spraying needs to be done immediately after planting. A mixture of two herbicides can be used for that purpose. Two liters of Alachlor or Metolachlor + 2 kg Fluometuron can be applied on a hectare planting area. This mixed herbicide can be spread using a tractor-mounted boom sprayer immediately after the planting operation. With good land preparation practice, the pre-emergent sprays would be adequate till the crop ground cover is complete. If the crop ground cover is not too good at about two months after planting or if the weed infestation is high, an inter-row cultivator or spring tine cultivator can be used for weeding in between the rows of young cassava plants. Alternatively, at three months after planting, a contact herbicide can also be sprayed in between planting rows using CDA (controlled droplet application) applicators attached to a power-tiller mounted on a high-clearance tool bar (Anas, 1990).

Pre-harvesting tops removal

Before the cassava roots are harvested mechanically, the part of the cassava plant that is above the ground need to be removed so as not to hinder the progress of the tractor with harvester (digger). A tractor-mounted rotary pulverizer or shredder implement could be used for this purpose.

Cassava root digging

Two types of root diggers have been evaluated at MARDI, i.e. the MARDI root digger and API root digger-elevator. The MARDI root digger is a tractor-mounted implement with field capacity in the range of 0.13-0.18 ha/hour, and field efficiency of 80-92% (Sukra, 1986). The API root digger-elevator is a semi-mounted tractor implement that digs, elevates and shakes the root clumps free of soil clods, and deposits them on the ground ready for manual picking and gathering. Compared with the traditional method, the implement could give 92- 95% saving in labor requirement for the root digging operation (Sukra, 1994).

Root gathering and transporting

Root gathering still need to be done manually, unless the scale of production warrants the use of a cassava combine harvester. However, the operation could be partly mechanized by using a tractor mounted collecting bucket *cum* loader. Under this method, the clumps of roots would be manually picked from the ground and thrown on to the collecting bucket, which is mounted in front of the tractor. Once full, the bucket could be raised and the content loaded on a lorry or a tractor-drawn trailer that travels along the root picking team.

CONCLUSIONS

Mechanized production of cassava roots is possible on mineral soils. Most of the machines needed for it are known or available in the market. However, a few field operations still need to be done manually. A suitably developed mechanized production system has the potential to reduce the manpower requirement and operational cost. The most suitable combination of machines for any particular production farm need to be determined on a case-by-case basis, due to the number of factors that affect the performance and economic viability of mechanized operations. Local factors such as rainfall and soil physical conditions need to be taken into consideration when planning such an operation.

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MECHANIZATION OF CASSAVA PRODUCTION IN COLOMBIA

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ABSTRACT

Advances obtained in Colombia in recent years in the development of cassava varieties with high yielding potential have helped to improve the competitiveness of the crop, and are facilitating its insertion in different markets, especially those related to the production of balanced feed for animals, as well as other industrial uses such us starch and adhesives.

To compete in these markets, production costs for cassava have to be maintained as low as possible. The cassava crop demands a high quantity of hand labor, especially in the activities of planting and harvesting. In countries such us Brazil and Thailand, important advances have been made in the development of mechanized systems for cassava production. In Colombia, CLAYUCA has been working to adapt some mechanical planters and harvesters for cassava that were originally developed in Brazil.

The two cassava planter prototypes that CLAYUCA has tested in Colombia have the capacity to plant two or three rows. The three-row model can plant 9.2 ha per day using four workers (3 planting and 1 tractor driver); the two-row model can plant 6.2 ha per day using three workers (2 planters and 1 tractor driver). There are eight working hours per day. These results compare very favorably with the results obtained with traditional cassava planting systems, in which the planting of one hectare requires at least 7 man-days. These two models of mechanical planters are a viable alternative for cassava farmers, but the minimum area needed to recover the investment costs is 30 ha. The two-row prototype was considered a best option considering that it allows variations in the distance between rows, distance between plants, the length of the stake as well as the depth of planting. One of the main advantages of the use of mechanical planters is the fact that the planting material can be harvested right before planting, thus improving the quality and avoiding the need to store stems for long periods.

For the harvesters, the two models tested by CLAYUCA can harvest 1.2 tonnes per man per day, which is very good compared with traditional harvesting systems in which at least 20 to 25 man-days/ha are required to harvest around 12 to 15 tonnes. The use of the semi-mechanized system, in which the roots are pulled out of the soil, and the workers later detach the roots from the stem, allows to increase the efficiency from around 500 kg to nearly 1 tonne of roots harvested per person per day.

In the Valle del Cauca region of Colombia, the introduction of mechanized planting is allowing farmers to reduce production costs of planting to up to 15.6% in comparison to traditional manual planting. With respect to harvest, the introduction of the harvesting machine is allowing reductions in production costs of around 18.5%. The combination of both practices is giving a total reduction in direct costs of nearly 20%.

INTRODUCTION

With the current trend towards economic globalization, agricultural sectors in developing countries such us Colombia, have to face strong competition from imported agricultural products, coming from developed countries in which a complex scheme of subsidies is used to support agricultural activities. Consumers have the choice of using alternative, imported, cheaper products, thus creating marketing problems for local farmers.

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Under these conditions, farmers critically need to have access to cost-reducing technologies that help them to enhance and maintain competitiveness for the crops they produce.

Cassava in Colombia is a good example to illustrate this situation. During the last five years, with the steady growth presented by the poultry and animal balanced feeds sectors, a great demand has appeared for cassava as a source of energy in the balanced feeds. To be able to enter these growing markets, cassava has to compete with imported cereals, mainly maize, which is now reaching annual volumes of importation of around 2 million tonnes per year. Although some progress has been made in recent years with the development of new, higher yielding varieties of cassava, this is not enough to achieve a significant reduction of production costs and a greater competitiveness.

For cassava to be able to compete in growing markets such as the animal feed sector, production costs should be kept as low as possible. One of the most important components in the production costs of cassava is the high labor requirement, especially during planting and harvesting. In some countries such as Brazil, there have been important advances in the development of mechanized systems for cassava planting and harvesting, that have allowed farmers to reduce production costs. This paper reports on the preliminary experiences obtained in Colombia with the adaptation and evaluation of Brazilian prototype machinery for cassava planting and harvesting, under the specific conditions of some of the most important Colombian cassava growing regions.

The data presented in this paper were obtained during the implementation of a project financed by the Colombian Ministry of Agriculture and Rural Development, MARD. The grant was given to CLAYUCA (Latin American and Caribbean Consortium to Support Cassava Research and Development) and the experimental work, conducted in three of the main cassava growing regions of Colombia, served as the basis for two students of the Universidad del Valle to obtain their Bachelors Degree in Agricultural Engineering.

To facilitate the implementation of the project, CLAYUCA imported from Brazil two prototypes for cassava planting and two prototypes for cassava harvesting.

A. MECHANIZED PLANTING OF CASSAVA

Prototypes for Mechanized Planting

1. Cassava Planter Model PC-20 (two rows)

The main technical characteristics of this prototype are (**Photo 1**):

- Distance between planting rows: adjustable from 85 to 95 cm
- Distance between plants in the row: adjustable from 40 to 100 cm
- Tractor potency requirements: 60-70 HP
- Hydraulic lifting system
- Automatic cutting of the stakes (saw controlled by the tire of the tractor)
- Storage capacity for chemical fertilizer: 150 kg
- Capacity for storage of cassava stems (2 sides): 1.5 m^3
- Planting depth control: available
- Output: 5 to 7 ha/day
- Labor requirement: two people plus tractor driver.

2. ***Cassava planter Model PMT-3 (three rows)***

The main technical characteristics of this prototype are (**Photo 2**):

- Distance between planting rows: fixed, 1.0 meter
- Distance between plants in the row: fixed, 90 cm
- Tractor potency requirements: 60-70 HP
- Hydraulic lifting system
- Automatic cutting of the stakes (jaws system, cutting by pressure on the stem)
- Storage capacity for chemical fertilizer: 150 kg
- Capacity for storage of cassava stems (2 sides): 1.5 m^3
- Planting depth control: absent
- Output: 8 to 10 ha/day
- Labor requirement 3 people plus tractor driver.

Parameters Evaluated

The principal parameters evaluated during this project were:

Soil conditions

1. Chemical and physical characterization of the soils in the three regions in which the research was conducted
2. Moisture content and apparent density (to determine the degree of compaction of the soils)

Prototype operational performance

The variables measured to determine the performance of the two prototypes were:

1. Uniformity in depth of planting
2. Uniformity in size of the cassava stakes planted
3. Uniformity in plant spacing
4. Mechanical damage of the cassava stakes
5. Field performance
6. Labor costs

Results and Discussion

Tables 1 and **2** present the results obtained during the experimental work. Data presented for each site is the average of three repetitions. In each case, the parameter is expressed in terms of percentage, which indicates the results obtained measured against the condition predetermined for operation of the machine. For example, if the desired size of the stake is 20 cm, and the prototype is adjusted to produce stakes with this length, the result of the uniformity of size parameter indicates the efficiency of the machine to produce and plant stakes with this size.

Uniformity in spacing: This parameter depends on the mechanism of the prototype for feeding the cassava stems from which each stake is cut. It is also influenced by the degree of preparation of the soil. In general, it was observed that the two-row prototype performed better, with values around 92%. The advantage of this prototype is that it includes a device to discard those stakes that do not meet the pre-determined length of stake. Another advantage of this machine is that it allows the use of different planting distances. The three-row prototype does not include the device to control the length of the stake. All the stakes are cut the same size. In general, performance of this prototype was inferior, with values around 80% (**Photo 3**).

Table 1. Evaluation of the two-row cassava planter, model PC-20.

Parameter	Site 1	Site 2	Site 3	Average	Manual planting
Uniformity in spacing (%)	91.3	92.6	94.3	92.7	97.7
Uniformity in size of stakes (%)	98.0	97.3	98.0	97.7	98.3
Uniformity in planting depth (%)	94.5	96.6	96.6	95.9	
Mechanical damage of the stakes (%)	10.0	10.0	9.6	10.0	0
Performance (ha/hour)	0.42	0.39	0.38	0.39	0.02
Performance (ha/day)[1)]	6.72	6.24	6.08	6.34	0.32[2)]

[1)] Assuming 8 hours of work; includes only the workers operating the machine
[2)] In the case of manual planting , the performance value is estimated assuming the same number of workers that operate the planting machine

Table 2. Evaluation of the three-row cassava planter, model PCT-3.

Parameter	Site 1	Site 2	Site 3	Average	Manual planting
Uniformity in spacing (%)	74.0	77.0	87.3	79.4	98.1
Uniformity in size of stakes (%)	96.1	96.1	95.6	95.9	98.6
Uniformity in planting depth (%)	95.6	96.6	97.6	96.6	
Mechanical damage of the stakes (%)	36.6	25.0	22.3	27.9	0.0
Performance (ha/hour)	0.37	0.42	0.36	0.38	0.02
Performance (ha/day)[1)]	8.88	10.08	8.64	9.20	0.48[2)]

[1)] and [2)] as under Table 1

Uniformity in size of stakes: This parameter is independent of the stage of preparation of the soil but plays a very important role in assuring high germination percentages. It is well known that the length of the stake and the number of nodes have a clear effect on germination of cassava stakes. The two-row prototype gave a good performance of 97.7% when used to produce stakes with length of 15 cm (**Photo 4**). With the three-row prototype the results were slightly lower, around 95.9%, and the size of the stake obtained was only 11 cm, which could be too short if the variety planted does not have a large number of nodes.

Uniformity in planting depth: This parameter did not present great differences between the two prototypes. The values obtained were around 96% for both machines. This parameter is important for its influence on the germination percentage. The depth of planting of the cassava stake is highly influenced by the type of preparation of the soil. If the area to be planted is not well prepared, the machine will be subjected to variations in the regulation of the depth of planting. This effect is minimized with the two-row planter, as this machine has a device to control the depth at which the stake is released (**Photo 5**).

Mechanical damage to the stake: Each of the two prototypes evaluated presented different degrees of damage to the cassava stakes. The differences occur as a consequence of the cutting device that each machine has. In the case of the two-row prototype, the cutting system is based on circular saws that function with the power take-off device of the tractor. The damage to the stake with this device is minimum, less than 10%. The three-row prototype gave a lower performance with respect to this parameter as the mechanical damage of the stake was around 28%. This is because the device for cutting the stakes is based on a jaws system that applies pressure on the stem to cut off the stakes with the desired length.

Efficiency of Performances: This parameter indicates the capacity of the prototypes to perform the task of planting the cassava stakes at the given distance between rows and between plants. The efficiency of the machine is affected by parameters such us soil conditions (land preparation and moisture content), capacity of the tractor, and abilities of the workers performing the task. **Tables 1** and **2** present the values obtained. The two-row prototype gave an output of 6.3 ha per day or roughly 0.8 ha per hour, using two persons and a working day of 8 hours. In the case of the three-row prototype, the output was 9.2 ha per day of 8 hours, using 3 workers. This corresponds to approximately 1.15 ha per hour. In both cases, this does not take into account the tractor driver. With the traditional planting system, by hand, a total of six workers are needed to plant one hectare in one day.

Economic impact: The two prototypes evaluated did not present significant differences in performance, although the economic importance of using them is very high. **Tables 3, 4** and **5** present the values calculated for the total cost of the planting operation using the two planters as well as with the traditional system, and its share of the total cost of production of one hectare of cassava.

Table 3. Costs of planting one hectare of cassava using the traditional method of manual planting in the Valle del Cauca, Colombia, in 2000.

Activity	Unit	Amount	Unit value (US$)	Total value (US$)
Cutting of stakes	Man-day	2	4.60	9.20
Treatment of stakes (chemicals)				6.10
Treatment of stakes	Man-day	0.5	4.60	2.30
Manual planting	Man-day	6	4.60	27.60
Re-planting	Man-day	1	4.60	4.60
Total costs of cassava planting (1 ha)				**49.80**
Totals costs of cassava production, 1 ha, US$				**566**
Percentage of total cost of production due to planting = 8.8%				
Estimated output = 1 ha/day				

The use of the two-row planter allows a reduction in the costs of planting of 51% in comparison with the traditional system. With the three-row prototype, the reduction in costs for the planting operation is of 55.6%. The three-row planter, when compared to the two-row prototype allows a further reduction of costs of 2.3 dollars per hectare.

Table 4. Costs of planting one hectare of cassava using the 2-row planter, Model PC-20, in the Valle del Cauca, Colombia, in 2000.

Activity	Unit	Amount	Unit value (US$)	Total value (US$)
Cutting and piling the stems	Man-day	3	4.60	13.80
Fixed and variable costs of planting machine	hour	1.28	4.14	5.30
Labor mechanical planting	Man-day	0.33	4.60	1.46
Labor tractor driver	Man-day	0.16	9.60	1.54
Replanting	Man-day	0.5	4.60	2.30
Total costs of cassava planting (1 ha)				**24.40**
Totals costs of cassava production, 1 ha, US$				**477**
Percentage of total cost of production due to planting = 5.1%				
Estimated output = 6.2 ha/day				

Table 5. Costs of cassava planting using the 3-row planter, Model PMT-3, in the Valle del Cauca, Colombia, in 2000.

Activity	Unit	Amount	Unit value (US$)	Total value (US$)
Cutting and piling the stems	Man-day	3	4.60	13.80
Fixed and variable costs of planting machine	hour	0.87	3.94	3.43
Labor mechanical planting	Man-day	0.33	4.60	1.52
Labor tractor driver	Man-day	0.11	9.60	1.06
Replanting	Man-day	0.5	4.60	2.30
Total costs of cassava planting (1 ha)				**22.11**
Totals costs of cassava production, 1 ha, US$				**471**
Percentage of total cost of production due to planting = 4.7%				
Estimated output = 6.2 ha/day				

B. SEMI-MECHANIZED HARVESTING OF CASSAVA

CLAYUCA has also conducted research on the adaptation and evaluation of semi-mechanized harvesting systems for cassava. This activity is important due to the excessive cost of manual harvesting, which demands approximately 25-35 man-days per hectare. CLAYUCA imported two prototypes developed in Brazil and conducted some evaluation of the performance of the prototypes under the specific conditions of some of the main cassava growing regions of Colombia.

Prototypes for Mechanized Harvesting

1. Cassava Harvester Model P 900 (two rows)

The main technical characteristics of this prototype are **(Photo 6)**:.

- Weight: 200 kg
- Output: 5 to 8 ha/day (8 hours)

- Working capacity: harvests two rows at the same time with cassava planting distances between rows of 80 to 100 cm
- Includes front cutting disk that facilitates the work
- Soil disturbance is minimum, leaving the cassava plant at the same site
- Works on soils in which it is not possible to harvest cassava manually
- Requires cutting of the cassava stems prior to the operation (at 20-40 cm height)

Parameters evaluated

The principal parameters evaluated were:

- Performance with each harvesting method (ha harvested per day)
- Root losses (% whole roots, % cut roots and % buried roots)
- Labor use (ha harvested per man per day and tonnes of roots harvested per man per day)

Results and Discussion

Table 6 presents the results obtained during the evaluation of the prototype. Values presented are the average of several repetitions and trials.

Table 6. Operating conditions of the cassava harvester Model P 900.

Parameter	Value
Operational speed	7 km/hour
Working depth	30-40 cm
Tractor power requirements	90 hp
Working width, maximum	2.4 meters
Performance	1.1 ha/hour

The main effect of the use of the harvester is the improvement in the efficiency of labor. Under the traditional system, in which the cassava roots are harvested by hand, a good performance for a worker is around 500 kg roots/day. With the use of the harvester Model P 900 CLAYUCA has been able to measure the harvest of around 1,100 kg roots/day. In more developed cassava production systems, such us those found in South Brazil, a good performance using mechanical harvesters is around 1,500 kg roots harvested/day.

Economic impact: The importance of the use of mechanical harvesters is in the reduction in the number of workers that are needed to harvest a cassava field. **Tables 7** and **8** present the results obtained during the evaluation of the prototype and its comparison with the manual harvest system. It can be observed that the introduction of the harvester prototype allows a reduction in labor cost for harvesting of 53%, which results in a reduction of 43% of the cost of harvest, and a reduction of 12% of the total production costs.

Table 7. Costs per ha of manual harvesting of cassava in the Valle del Cauca, Colombia[1)] in 2000.

Activity	Unit	Amount	Unit value (US$)	Total value (US$)
Labor (harvesters)	Man-day	30	4.60	138.00
Packing	Sacs	180	0.04	7.20
Others	Roll			2.50
Total harvest costs				**147.70**
Total costs of cassava production per ha				**566**
Harvest costs as % of total costs: 26.1				

[1)] For a production of 12 t/ha

Table 8. Costs per ha of semi-mechanized harvesting of cassava in the Calle del Cauca, Colombia in 2000.

Activity	Unit	Amount	Unit value (US$)	Total value (US$)
Labor (harvesters)	Man-day	14	4.60	64.40
Packing	Sacs	180	0.04	7.20
Fixed and variable costs of harvester (per ha)				9.50
Labor tractor driver				1.20
Others	Roll			2.50
Total harvest costs				**84.80**
Total costs of cassava production per ha				**498**
Harvest costs as % of total costs: 17.1				

The economic impact of introducing mechanized planting and harvesting of cassava can also be assessed considering the different technological options that are available for farmers to increase their productivity and competitiveness. In case of Colombia, the cassava farmers have to compete with imported cereals, mainly maize and to do that the cost per tonne of cassava has to be as low as possible to become attractive for the processing plants that transform the fresh roots into dry chips or cassava flour that is later sold to the animal feed companies. **Figure 1** presents some data obtained by CLAYUCA that compares the impact of the different technological options available to farmers. It can be seen that the cost per tonne of fresh cassava roots under traditional production systems is US$ 29.4, and that by introducing higher yielding varieties farmers are able to reduce this cost to US$ 25.4, a 13.6% reduction. However, this price is still too high for cassava processing plants. The second option available is the introduction of mechanized planting. If the farmer maintains the traditional varieties, the reduction obtained in costs is slightly lower than the reduction obtained with the improved varieties. Furthermore, the introduction of mechanized planting and harvesting, maintaining the traditional varieties, allows farmers to reduce the cost per tonne of cassava to US$ 21.2, a very significant reduction of 27.9%. At this level, cassava starts to be very competitive with imported cereals. The ideal situation is when the farmers have access to improved varieties, and mechanized planting and harvesting is introduced. This whole technology package helps farmers to bring the production cost per tonne of cassava to US$ 17.5, a very competitive price for the crop to enter different markets. It means a 40.5 % reduction in production costs compared with traditional production systems.

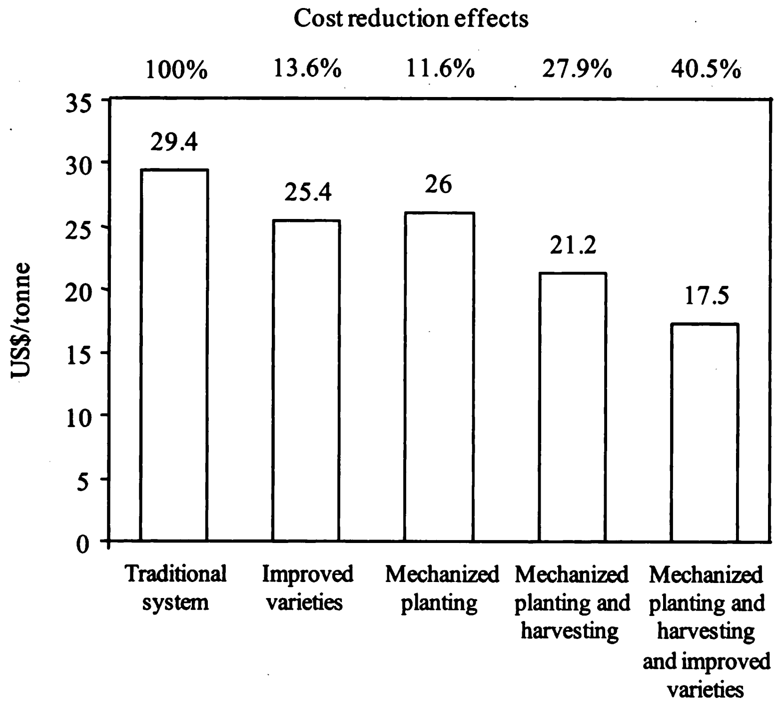

Figure 1. Cost reduction effects on cassava production due to different technology options.

CONCLUSIONS

1. The introduction of mechanized cassava planting and harvesting is a practice that has great potential to reduce the costs of labor, thus contributing to an increase in the competitiveness of the crop
2. The cost of the prototypes, around 3,500 US$ for the planter and around 1,500 US$ for the harvester, FOB Brazil, is affordable. Farmers' groups organized in the form of machinery rings can easily acquire and administrate these prototypes so that their cassava production can be done at lower costs and with improved competitiveness.
3. Operation of the planting and harvesting prototypes is simple and farmers can easily use them.
4. Farm workers that have to do the heavy work of digging cassava roots by hand, work more comfortably and improve their performance when they are allowed to use the harvester.
5. The discussion against the use of harvester prototypes arguing that it will to replace hand labor needs to be taken in the specific context. In many cases, where there is potential to stimulate commercial planting of cassava, investors will not move into

cassava production unless assured that production costs will be competitive. Mechanization of planting and harvesting becomes in these cases, a *sine qua non* condition. If the size of the unit is very small, as in the case of small-scale cassava farming systems, the adoption by farmers of mechanized planting and harvesting will be negligible.

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Photo 1. Two-row cassava planter, Model PC-20.

Photo 2. Three-row cassava planter, Model PMT-3.

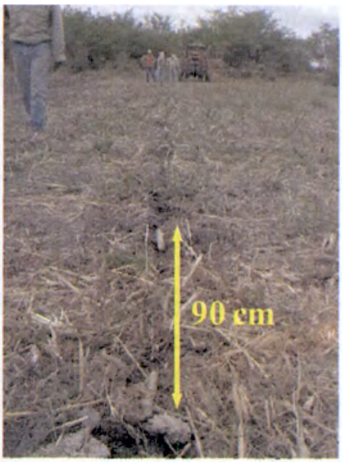


Photo 3. Distance between plants with mechanized planting.

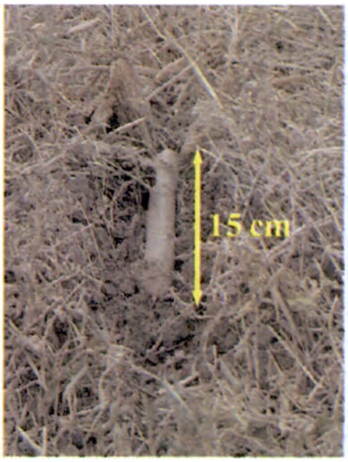


Photo 4. Distance of cassava stakes with mechanized planting.

Photo 5. Spring device to control planting depth of the cassava stake.

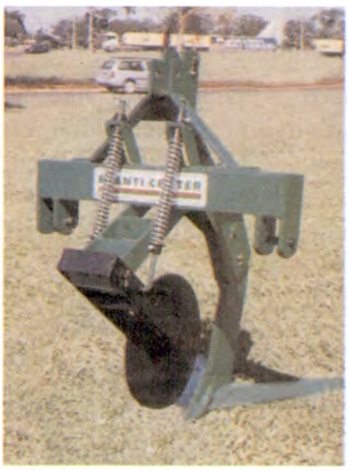


Photo 6. Cassava harvester, Model P 900.

AGRONOMIC PRACTICES FOR SUSTAINABLE CASSAVA PRODUCTION IN ASIA

Reinhardt H. Howeler[1]

ABSTRACT

The paper describes research results obtained in the development of improved cultural practices, such as time and method of planting, weed control, fertilization, intercropping and erosion control. Experiments have shown that cassava yields are seriously reduced if either low rainfall or low temperatures are limiting growth during the period of 3-5 months after planting; that planting vertically or inclined produces higher yields than planting horizontally, especially during periods of drought; that planting on ridges is better in the rainy season but planting on the flat is better in the dry season; that high and sustainable yields can be maintained either with the application of 5-10 t/ha of animal manure supplemented with 50-100 kg/ha of N and/or K_2O as chemical fertilizers (depending on soil fertility characteristics), or by the application of chemical fertilizers alone with a ratio of $N:P_2O_5:K_2O$ of 2:1:2 or 2:1:3, but not by organic or green manures alone; that intercropping with peanut generally increases total income and protects the soil from erosion; and that fertilization, intercropping, contour ridging and contour hedgerows of grasses are simple but effective ways to reduce erosion.

INTRODUCTION

Cassava is a hardy crop that grows reasonably well on poor soils and in areas with low or unpredictable rainfall. It is a popular crop among poor farmers because it requires few inputs besides labor to produce a reasonable yield. Still, to get higher yields and greater economic benefits, the crop should be well managed and some external inputs may be required. Moreover, to sustain high yields in the future, it is important to prevent soil nutrient depletion and soil losses by erosion. This can be achieved through simple agronomic or soil conservation practices.

1. Cassava-based Cropping Systems

Cassava can be planted either as a sole crop in monoculture system or intercropped with other crops. Farmers that have only small plots of land will generally prefer to intercrop cassava with other crops. In Indonesia cassava is often planted in widely-spaced rows with upland rice between rows and maize within the cassava row. After the harvest of rice and maize, a legume crop like peanut, cowpea or mungbean is planted in the space between rows in order to obtain four crops per year. In China cassava is often interplanted among recently established watermelon, while in Vietnam and China cassava is often intercropped with maize or peanut. In some parts of the Philippines cassava is interplanted among young maize plants, while in east Java of Indonesia cassava and maize are planted simultaneously. However, for commercial production of cassava for the starch or animal feed industry, such as in Thailand, China, south Vietnam and southern Sumatra of Indonesia, cassava is generally planted in monoculture. In other areas with plantation crops like rubber, coconut or cashew, cassava is often intercropped for a few years between the rows of young trees, or in case of coconut, among the old trees.

[1] CIAT, Cassava Office for Asia; Dept. Agriculture, Chatuchak, Bangkok 10900, Thailand.

Thus, there are many alternative ways of planting cassava in various intercropping systems. In most cases the cassava row spacing is widened to allow more space for the intercrop between the rows, while interplant spacing within the row is shortened to maintain a high cassava population.

Numerous experiments have been conducted to determine the best intercrops for cassava, as well as the best planting arrangements and relative time of planting (Leihner, 1983). **Tables 1** and **2** show that in north Vietnam the intercropping of cassava with one or two rows of peanut generally resulted in the highest net income. Intercropping with mungbean or soybean can be successful sometimes, but other times may result in complete crop losses due to drought or severe insect or disease problems. Peanut is a popular intercrop as it can be grown on similar acid infertile soils as cassava, it does not suffer severe pest and disease problems, and it protects the soil from rainfall splash, thus reducing erosion (**Table 1**). **Table 3** shows that when cassava was intercropped every year with four types of intercrops from 1981 to 1993 in Rayong, Thailand, the intercropping with peanut may have had a long-term beneficial effect on soil fertility as evidenced by the increases in cassava monocrop yields in 1987 and 1993 (Tongglum *et al.*, 2001).

Table 1. Effect of intercropping cassava with various grain legumes on the yield of crops, on gross and net income, as well as on dry soil loss due to erosion when grown on 10% slope at Agro-forestry College of Thai Nguyen Univ., Thai Nguyen, Vietnam in 1997.

Intercropping treatments	Yield (t/ha) cassava	Yield (t/ha) intercrop	Gross income[1)] (mil. d/ha)	Costs fert. +seed[1)] (mil. d/ha)	Net income (mil. d/ha)	Dry soil loss (t/ha)
1. Cassava monoculture	18.67	-	7.47	6.22	1.25	31.24
2. C+peanut	16.50	1.08	12.00	8.77	3.23	24.03
3. C+soybean	18.42	0.15	8.27	7.98	0.29	28.50
4. C+mungbean	20.83	0.27	10.49	7.84	2.65	28.61
5. C+black bean	17.92	0.35	9.62	7.94	1.68	28.64
6. C+cuoc bean	17.67	0.17	7.92	7.87	0.05	28.14

[1)]Prices:

cassava:	d 400/kg fresh roots		
peanut:	5000/kg dry pods	peanut seeds:	d 7000/kg dry pod
soybean:	6000/kg dry grain	soybean seeds:	7000/kg dry grain
mungbean:	8000/kg dry grain	mungbean seeds:	8000/kg dry grain
black bean:	7000/kg dry grain	black bean seeds:	7000/kg dry grain
cuoc bean:	5000/kg dry grain	cuoc bean seeds:	5000/kg dry grain

Source: *Le Sy Loi, 2000.*

2. Time of Planting and Harvest

The best time to plant cassava not only depends on the climatic conditions at time of planting but also on climatic as well as marketing conditions at time of expected harvest. In those areas where the root price depends on the starch content, farmers want to try to maximize both yield and starch content at time of harvest. However, prices also depend on market conditions and are usually highest in the off-season, i.e. when most farmers do not harvest. Thus, some farmers may want to sacrifice some yield in order to benefit from higher prices in the off-season.

Table 2. Average results of four FPR intercropping trials conducted by farmers in Tran Phu commune, Chuong My district, Ha Tay, Vietnam in 2003.

Treatments	Cassava yield (t/ha)	Intercrop yield (t/ha)	Gross income[1]	Seed costs[2]	Product. costs[2]	Net income
			('000 d/ha)			
1. Cassava monoculture	24.54	-	9,816	0	5,460	4,356
2. C+1 row peanut	21.93	1.187	14,707	480	8,115	6,592
3. C+2 rows peanut	22.52	2.000	19,008	960	8,595	10,413
4. C+2 rows mungbean	21.42	0	8,568	2000	9,635	-1,067
5. C+2 rows soybean	21.28	0.162	9,322	800	8,435	887

[1] Prices: cassava: dong 400/kg fresh roots
peanut: 5,000/kg dry pods
soybean 5,000/kg dry seed

[2] Costs: labor: dong 15,000/manday
NPK fertilizers: = 0.86 mil. dong/ha
peanut seed (80 kg/ha): 12,000 /kg = 0.96 mil dong/ha for 2 rows
mungbean seed (80 kg/ha): 25,000 /kg = 2.00 mil dong/ha for 2 rows
soybean seed (80 kg/ha) 10,000 /kg = 0.80 mil dong/ha for 2 rows
labor for cassava monoculture without fertilizers = 4.5 mil. dong/ha (300 md/ha)
labor for cassava intercropping without fertilizers = 6.675 mil.dong/ha (445 md/ha)
labor for cassava fertilizer application = 0.10 mil. dong/ha

Source: *Trinh Phuong Loan, personal communication, 2004.*

Table 3. Yield (t/ha) of cassava (C) and intercrop (INT) species in a long-term cassava intercropping trial conducted continuously at Rayong Field Crops Research Center, Thailand, from 1981 to 1993.

Intercropping patterns	1981 C	1981 INT	1986 C	1986 INT	1987 C	1988 C	1988 INT	1992 C	1992 INT	1993 C
Cassava monoculture	29.2	-	19.9	-	22.5 bc[2]	9.9	-	27.9	-	22.8
Cassava+sweet corn[1]	31.3	27.2	21.9	13.9	25.7 ab	10.2	9.8	30.7	20.1	26.2
Cassava+mungbean	24.4	0.88	17.9	0.09	21.6 c	9.1	0.33	32.9	0.23	26.4
Cassava+peanut	23.5	1.35	21.4	0.31	24.6 abc	7.3	0.22	24.9	1.94	28.3
Cassava+soybean	29.1	0.63	17.4	0.63	26.8 a	5.9	0.33	27.2	0	27.2
F-test										NS

[1] Sweet corn yield in '000 cobs/ha.
[2] Means in a column separated by DMRT at 0.05%
NS = not significantly different.
Source: *Tongglum et al., 2001.*

a. Tropical regions

In tropical regions with distinct dry and wet seasons and a mono-modal rainfall distribution, the best time to plant is early in the wet season, i.e. as soon as enough soil moisture allows for adequate germination of planted stakes. **Figure 1** shows that in Rayong, Thailand, highest yields were obtained with planting in May, at the start of the rainy season. In those areas with a bimodal rainfall distribution, such as in Kerala, India, planting at the start of the second rainy season, i.e. in Aug or Sept, will also result in high yields (George *et al.*, 2001). In the southern hemisphere the wet and dry seasons are reversed in comparison with the northern hemisphere, and the wet season generally starts in Nov-Dec and ends in April-May. In that case, highest cassava yields are obtained when planted in Dec (Wargiono *et al.*, 2001).

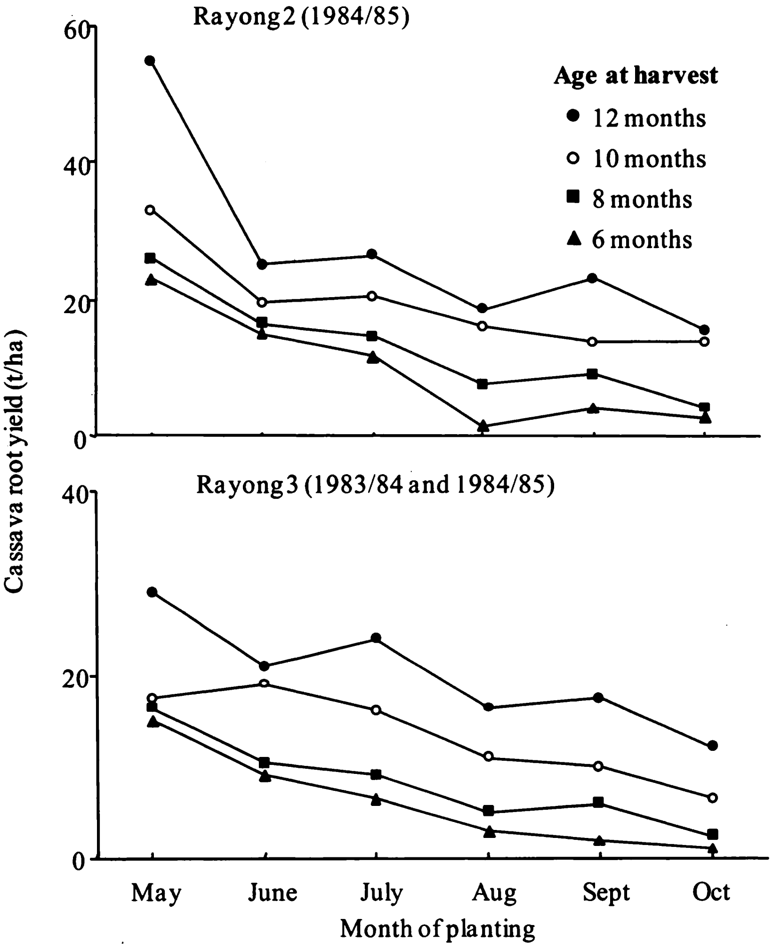


Figure 1. Effect of month of planting and age at harvest on root yields of cassava cultivars Rayong 2 and Rayong 3 planted at Rayong Field Crops Research Center, Thailand, in 1983-1985.
Source: *Tongglum et al., 2001.*

However, high yields may also be obtained when cassava is planted towards the end of the wet season. **Table 4** shows that highest yields in Rayong, Thailand were obtained when cassava was planted in Aug-Nov. In this case, plants get well established during the last months of the rainy season, grow slower during the dry season and have an additional period of fast growth during the following wet season. In this case, weed competition tends to be less severe as plant canopies are already well-established during the early part of the second wet season. **Table 5** and **Figure 2** indicate that total rainfall during the 4th to 11th month of the crop cycle was best correlated with root and starch yield when the crop was harvested at 11 months after planting (MAP), but starch content was best correlated with total rainfall during the 6th to 9th month, and was negatively correlated with rainfall during the 10th and 11th months.

Table 4. Fresh root yield (t/ha) of recommended cassava cultivars when planted in different periods at Rayong Field Crops Research Center, Thailand, 1987-1988.

	Cultivars				Average
Planting periods	Rayong 1	Rayong 3	Rayong 60	Rayong 90	
April-May	18.56	19.94	23.31	24.00	21.44 c[1)]
June-July	20.81	24.25	27.63	29.31	25.50 ab
August-Sept	22.31	24.44	32.31	27.81	26.75 a
Oct-Nov	21.81	26.62	30.19	26.06	26.19 a
Dec-Jan	19.38	20.38	29.44	23.87	23.25 bc
Feb-March	20.75	20.50	26.25	25.44	23.25 bc
Average	**20.62 d**	**22.69 c**	**28.19 a**	**26.06 b**	

[1)]Mean separation: DMRT, 0.01

Source: *Tongglum et al., 2001.*

b. Subtropical regions

Cassava is also grown in subtropical regions, such as southern China and north Vietnam. These regions are characterized by cold and dry winters (with occasional frost at higher latitudes) and hot and wet summers with relatively long daylight. **Figure 3** shows that cassava yields were little affected by date of planting when cassava was harvested at 12 months, but that yields markedly declined when planted in late summer (Aug-Nov) and harvested after 8 months in April to July. When harvested at 8 MAP, both root yields and starch content were lowest when roots were harvested during the hot months of June-July. In that case, root yields were positively and highly significantly correlated with both temperature and rainfall during the 3rd to 5th month after planting, i.e. at time of maximum growth rate of cassava (**Figure 4**), while starch content was negatively correlated with temperature and rainfall during the last month before harvest (**Figure 5**).

Figure 1 and **Table 6** indicate that root yields generally increase with increasing plant age at harvest, at least up to 18 months. Root starch content also tends to increase with plant age up to 9-10 month but may decrease sharply at the early part of the wet season as plants relocate starch from the roots to plant tops during resprouting.

It may be concluded that highest yields are generally obtained when cassava is planted as early as possible in the wet season or in early spring, while starch contents are highest when plants are harvested in the middle of the dry season. At planting time there should be enough soil moisture to get at least 80-90% germination, while soils should not be so wet as to prevent adequate aeration and root formation.

Table 5. Correlation coefficients between cassava root yield, starch content and starch yield, as well as dry soil losses due to erosion and rainfall during certain periods in the cropping cycle when cassava, cv Rayong 90, was planted at bimonthly intervals for three consecutive cropping cycles on 4.2% slope in Rayong Research Center in Thailand from 1994 to 1998.

Parameters	Correlation Coef. (r)	%P
Cassava root yield vs rainfall from the 4th-11th MAP[1)]	0.7025	0.001
Cassava root yield vs rainfall from the 3rd-11th MAP	0.6726	0.002
Cassava root yield vs rainfall from the 2nd-11th MAP	0.6005	0.008
Cassava root yield vs rainfall from the 1st-11th MAP	0.5115	0.030
Cassava root yield vs rainfall during the 1st MAP	-0.4258	0.078
Cassava root yield vs rainfall from the 1st-2nd MAP	-0.4146	0.087
Root starch content vs rainfall from the 6th-9th MAP	0.8298	0.000
Root starch content vs rainfall from the 5th-9th MAP	0.7981	0.000
Root starch content vs rainfall from the 6th-8th MAP	0.7966	0.000
Root starch content vs rainfall from the 10th-11th MAP	-0.1290	NS
Root starch content vs rainfall during the 11th MAP	-0.0772	NS
Starch yield vs rainfall from the 4th-11th MAP	0.7411	0.000
Starch yield vs rainfall from the 4th-10th MAP	0.7096	0.001
Starch yield vs rainfall from the 5th-11th MAP	0.7090	0.001
Starch yield vs rainfall from the 5th-10th MAP	0.6950	0.001
Dry soil loss (erosion) vs rainfall from 1st -3rd MAP	0.6016	0.008
Dry soil loss (erosion) vs rainfall from 1st -4th MAP	0.5515	0.018
Dry soil loss (erosion) vs rainfall from 1st -5th MAP	0.5290	0.024
Dry soil loss (erosion) vs rainfall from 1st-2nd MAP	0.5087	0.031

Note: cassava was harvested after 11 months
[1)] MAP = month after planting
Source: *Howeler, 2001.*

3. Land preparation

Most farmers prefer to plant cassava in well-prepared loose soil without any weeds. This facilitates vertical or inclined planting and reduces early weed competition. In Thailand the soil is usually prepared by hired tractor using a 3-disk plow followed by 7-disk harrow, and sometimes ridging. The contractor prefers to plow the field in straight lines parallel to roads or plot borders, irrespective of slope direction. This method results in a loose and clean soil surface and high yields, but may cause severe erosion as well as formation of a "plow sole", or compacted layer at 15-20 cm depth. This compacted subsoil impedes free drainage resulting in poor growth or root rot during the months of heavy rainfall. Moreover, the topsoil is rapidly saturated with water, which is followed by overland runoff and sometimes severe gully erosion. The regular use of a subsoiler will help to break the plow sole and improve internal drainage, which tends to improve plant growth during the height of the rainy season and increase yields (Watananonta *et al.*, 2006). The subsoiler should be followed by either a 3-disk or 7-disk plow to reduce weed competition and loosen the soil.

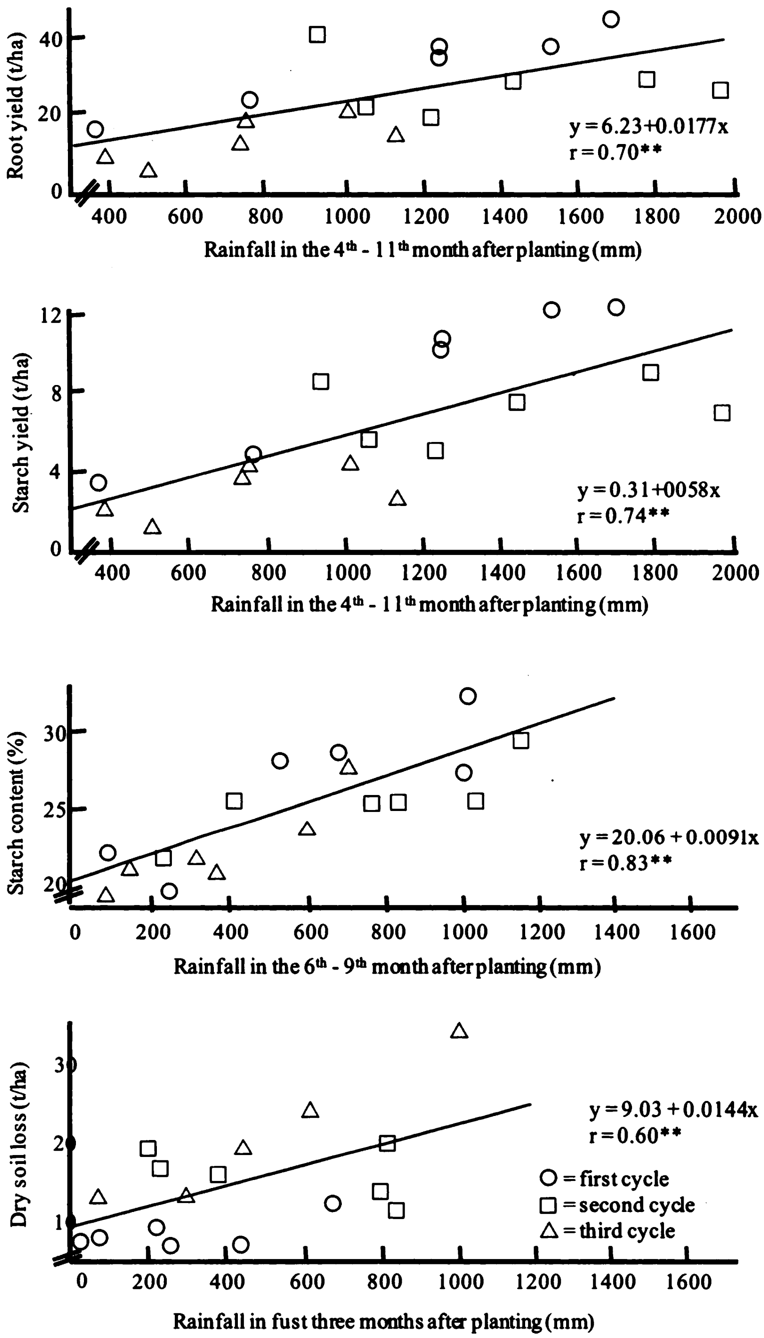


Figure 2. Linear regressions between cassava root yield, starch yield, starch content and dry soil loss due to erosion and the rainfall received during certain periods of the crop cycle when cassava, cv Rayong 90, was grown at bimonthly intervals for three complete cropping cycles on 4.2% slope at Rayong Research Center in Thailand from 1994 to 1998.
***Source:** CIAT, 1998 b.*

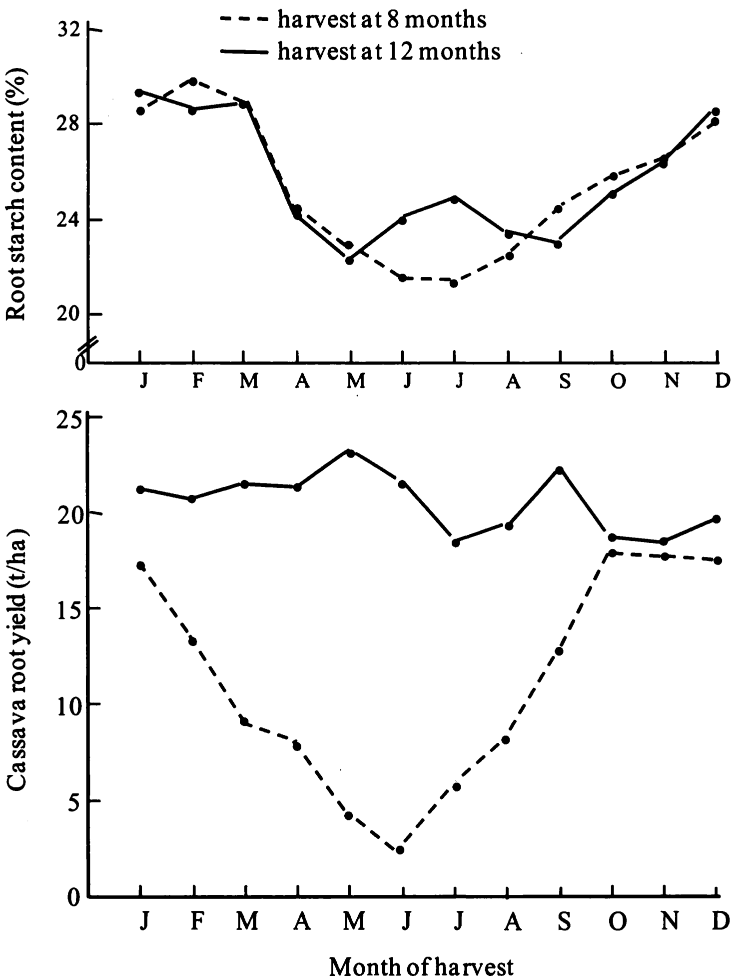


Figure 3. Cassava root starch content (top) and root yield (bottom) averaged over three varieties and three cropping cycles, when planted during different months of the year at CATAS, Danzhou, Hainan, China, and harvested after either 8 or 12 months.
Source: *Zhang Weite et al., 1998.*

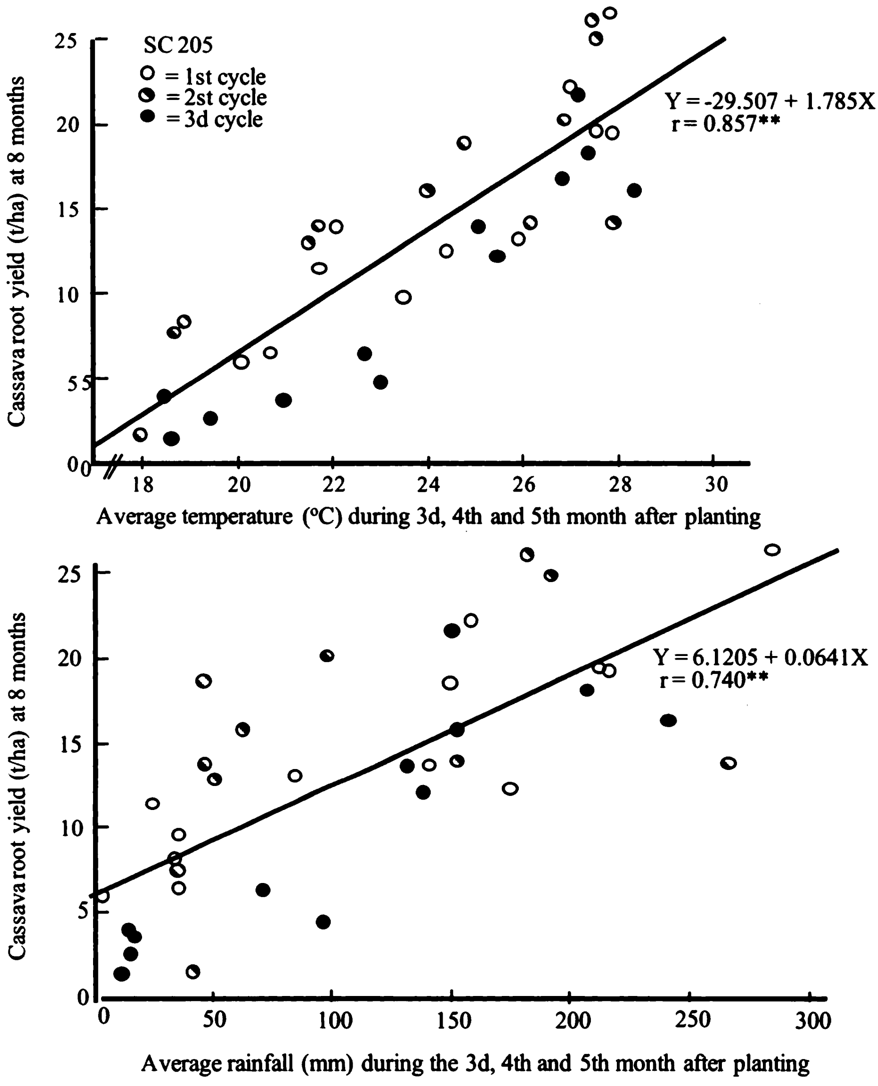
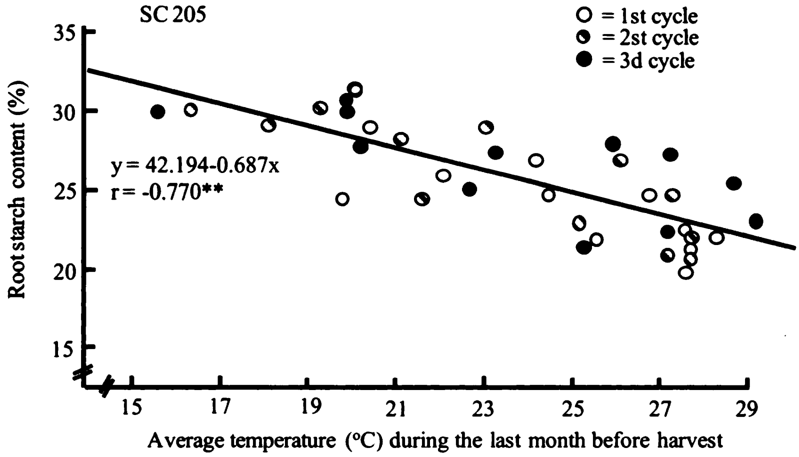


Figure 4. Linear regression between root yield of cassava, cultivar SC 205, harvested at 8 months, and the average mean temperature (top) or rainfall (bottom) during the 3d, 4th and 5th month after planting in CATAS, Danzhou, Hainan, China. Data are for 36 monthly plantings from 1990 to 1993.
Source: *Zhang Weite et al., 1998.*



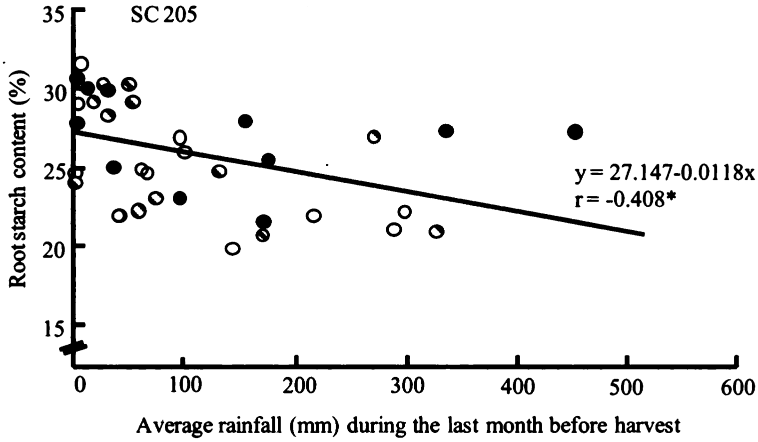


Figure 5. Linear regression between root starch content of cassava, cultivar SC 205, harvested at 8 months, and the average temperature (top) or rainfall (bottom) during the last month before harvest in CATAS, Danzhou, Hainan, China. Data are for 36 monthly plantings from 1990 to 1993.
Source: *Howeler, 2001.*

Table 7 shows that planting on top of ridges had no significant effect in root yield or starch content when planting occurred during either the rainy or dry season. However, in the dry season planting, germination was significantly better without ridges as ridging caused more rapid drying of the soil. On gentle slopes, contour ridging is an effective way to reduce run-off and erosion. However, when too much water accumulates above the ridge, this may cause water logging and lower yields, or the ridges may break causing serious gully erosion.

Table 6. Average fresh root yield of Rayong 1 as effected by age at harvest when planted at Rayong Field Crops Research Center, Thailand in 1975-1979.

Age at harvest (months)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Starch yield (t/ha)	Starch content (%)
8	16.19 f[1)]	6.44 f	2.31 f	14.3
10	23.06 e	8.31 e	4.81 e	20.9
12	31.31 d	10.69 d	5.94 d	19.0
14	37.56 c	13.06 c	7.38 c	19.6
16	41.50 b	15.00 b	8.69 b	20.9
18	45.25 a	16.44 a	9.19 a	20.3

[1)]Mean separation within each column: DMRT, 0.01
Source: *Tongglum et al., 2001.*

Table 7. Effect of stake position, stake length, and planting depth on cassava yield, planted in both the rainy and dry season at Rayong Field Crops Research Center, Thailand (Average of 3 years, 1987-1989).

	Rainy season (May-August)			Early dry season (November)		
Treatments	Plants survived ('000/ha)	Root yield (t/ha)	Starch content (%)	Plants survived ('000/ha)	Root yield (t/ha)	Starch content (%)
Method of planting						
-Ridge	14.57 a	14.98 a	16.64 a	10.69 b	14.69 a	18.63 a
-No ridge	14.43 a	13.47 a	16.66 a	12.09 a	14.96 a	18.65 a
F-test	NS[3)]	NS	NS	**	NS	NS
Stake position						
-Vertical	14.87 a	16.04 a	17.03 a	13.04 a	17.74 a	19.04 a
-Inclined	14.89 a	15.46 a	17.14 a	11.99 b	16.40 b	18.68 a
-Horizontal	13.74 b	11.08 b	15.85 b	9.31 c	10.32 c	18.17 b
F-test	**[1)]	**	**	**	**	**
Stake length (cm)						
-20	14.55 a	14.52 a	16.67 a	10.58 b	14.53 a	18.51 a
-25	14.41 a	13.54 b	16.69 a	13.02 a	15.41 a	18.87 a
F-test	NS	*[2)]	NS	**	NS	NS
Planting depth (cm)						
-5-10	14.43 a	13.90 a	16.61 a	9.74 b	13.14 b	18.21 b
-15	14.56 a	14.43 a	16.73 a	12.71 a	16.17 a	18.97 a
F-test	NS	NS	NS	**	**	**

No interaction between methods and treatments in all characters
[1)]and [2)]: Mean within a column separated by DMRT at 0.01 and 0.05 %, respectively
[3)]NS = not significantly different.
Source: *Tongglum et al., 1992.*

On smaller farms, land is generally prepared by plowing with cattle or water buffalo or by hoeing. In Indonesia, land is often prepared by plowing with cattle followed by hand-ridging with hoe. In Kerala, India, small plots are generally prepared by hoe, making individual mounds for each plant. On steep slopes in Laos and southern China, land is cleared of vegetation by machete, followed by burning; land preparation is limited to making individual holes for planting each stake horizontally. In Hainan island of China this resulted in similar yields as twice plowing and disking, but markedly reduced soil erosion (Zhang Weite *et al.*, 1998). Similarly, zero tillage and using herbicides to control weeds sometimes results in high yields in Thailand if weed growth is not aggressive (Watananonta *et al.,* 2006). However, in very weedy plots or in compacted soil, zero tillage generally resulted in lower yields and difficulty in planting, weeding and harvesting.

4. Selection and preparation of planting material

Cassava is normally planted using stem cuttings, also called "stakes" or "setts". The stems are normally cut when the mother plant is 8-12 months old. Older plants usually have longer stems and have more buds per stem, thus producing more stakes per plant. Stakes derived from the lower and middle part of the stem had significantly higher germination rates than those derived from the upper part of the stem (George *et al.*, 2001), and 15-20 cm stakes had higher germination than shorter stakes of 5-10 cm length (Chankam, 1994). Stake germination is also affected by the method and length of stem storage after cutting. **Table 8** shows that germination and plant survival decreased with increasing length of storage, but decreased faster if stems were stored in the sun in the open field, or were only covered with leaves. Varieties differ markedly in the storability of their stems, but for most varieties stems should be stored upright in the shade, and for no longer than 1½-2 months to obtain at least 80% germination; other varieties lose their germination capacity already after 3-4 weeks of storage.

Table 8. Plant survival rate (%) from stakes stored under different conditions and for various periods at Rayong Field Crops Research Center, Thailand, in 1976-1978.

Storage time	Storage method		
(days)	Under shade	In sun	Covered with leaves
0	95.6	95.3	96.5
15	93.5	93.4	91.6
30	83.4	84.3	87.9
45	80.0	55.9	58.4
60	57.5	48.9	50.0
75	49.2	31.9	43.1
90	44.9	28.9	35.9
105	43.2	21.0	22.1

Source: *Sinthuprama and Tiraporn, 1986.*

5. Planting method

If the soil is loose and friable, stakes can be planted vertically or slanted by pushing the lower part of the stake about 5-10 cm into the soil. Stakes can also be planted horizontally at 5-7 cm depth by digging individual holes, or by making a long furrow, laying the stakes down and covering with soil. The latter method is common in heavy clay soils or with zero- or minimum-tillage methods of land preparation. When the soil is well prepared and friable, planting vertically or inclined is faster than planting horizontally, but care should be taken that the eyes or buds on the stakes face upward; with horizontal planting this is of no concern.

In sandy clay loam soils in Rayong, Thailand, planting vertically or inclined produced significantly higher root yields than planting horizontally (**Table 7**); this was especially the case when stakes were planted in the early dry season (Nov), when horizontal planting resulted in slower and a significantly lower rate of germination (Tongglum *et al.*, 2001). Research conducted in two locations in China indicate that vertical planting resulted in the highest germination percentage but that inclined planting produced the highest yields (**Table 9**). Similar results were recently obtained in Cambodia (Ung Sopheap, personal communication, 2006) where inclined planting produced the highest yield; planting one stake per hill significantly increased yields as compared to the traditional practice of planting two stakes per hill, slanted in opposite directions.

Table 9. Effect of stake planting position and ridging on cassava yield and germination at 1 month in GSCRI, Nanning, Guangxi, and in CATAS, Danzhou, Hainan, China. Data are the average for SC201 and SC205 in CSCRI, and for SC205 and SC124 at CATAS.

Planting Position		GSCRI (1990-1992)		CATAS (1994)
		Germination[1] (%)	Root yield[2] (t/ha)	Root yield (t/ha)
Horizontal				
	-ridging	61.5	11.7	20.0
	-no ridging	67.4	10.9	18.6
Inclined				
	-ridging	66.4	13.0	25.3
	-no ridging	78.1	11.5	16.9
Vertical				
	-ridging	82.8	11.1	19.4
	-no ridging	85.8	11.2	18.5

[1]Average of 1991 and 1992 (no data taken in 1990)
[2]Average of 1990 and 1992 (no harvest in 1991 due to drought)
Source: *Zhang Weite et al., 1998.*

6. Application of lime and fertilizers or manures

Cassava is extremely tolerant of acid soils, growing well even at a pH as low as 4.2-4.5 and at 75-80% Al saturation (= me Al/ me Al + me Ca + me Mg + me K/100 g x 100%). In Asia there are very few soils where cassava responds to the application of lime (Susan John and Venugopal, 2006). Responses have been obtained only on the peat soils in Malaysia and on the very acid soils of the Plain of Jars in Xieng Khouang province of Laos. In most cases this is mainly a response to the application of Ca and/or Mg if dolomitic lime is applied.

While cassava can grow better than most other crops in very infertile soils, the crop does respond well to the application of chemical fertilizers or animal manures. Like any other crop, cassava extracts nutrients from the soil during plant growth and some of these are removed in the root harvest, while others may be returned to the soil in the crop residues, such as leaves and stems. **Figure 6** shows the relation between fresh root yield and the removal of N, P and K in the harvested roots, as reported in the literature. It is clear that nutrient removal increases as yields increase, but this is not a linear relationship, as the nutrient contents of the roots also tend to increase with increasing yields. Thus, nutrient removal is quite large only when yields are very high. At an average root yield of 15 t/ha, only about 30 kg N, 3.5 kg P (= 8 kg P_2O_5) and 20 kg K/ha (= 24 kg K_2O) are removed from the soil. This is much less than that removed in the harvested products of most other crops (Howeler, 1991; 2001). Nevertheless, when cassava is grown on the same land for many years, the nutrient content in the soil may be depleted, resulting in decreasing yields unless the removed nutrients are returned in the form of chemical fertilizers or manures. **Figure 7** shows how cassava in Kerala, India, responded to the application of chemical fertilizers and farm-yard (= cow) manure (FYM). Without NPK or without K, yields decreased year after year as the exchangeable K in the soil decreased below the critical level of 0.15 me/100 g. But with adequate NPK fertilizers yields could be maintained at 20-30 t/ha, while the addition of 12.5 t/ha of FYM further increased yields slightly to 25-35 t/ha. Similar results have been obtained in long-term fertility trials conducted in three locations in Thailand (Nakviroj *et al.*, 2007), in Hainan, China (Li Jun *et al.*, 2001), in Lampung, Indonesia (Wargiono *et al.*, 2001), in Serdang, Malaysia (S.K. Chan, personal communication; Howeler, 1992), and in Thai Nguyen University and in Hung Loc Agric. Research Center, Vietnam (Nguyen Huu Hy *et al.*, 2001). **Figure 8** shows the response of two cassava varieties to the annual application of various combinations of N, P and K during the 14th year of continuous monocropping in Hung Loc Center in south Vietnam. It is clear that after continuous cropping soils had become depleted mainly of K and there was a highly significant response to application of K up to 80 kg K_2O/ha. This not only increased root yields but also the root starch content. With a high rate of application of 160 kg N + 80 P_2O_5 + 160 K_2O/ha high yields of 29-32 t/ha could be maintained after 14 years of continuous cropping, as compared to 11-12 t/ha without fertilizer application. **Figure 9** shows the root yields, relative root yields and the exchangeable K and available P contents of the soil during the 14 years of cropping. With a medium level of fertilization of 80 kg N + 40 P_2O_5 + 80 K_2O/ha yields increased over the years from about 15 t/ha to about 27 t/ha, while without fertilizers or with only N and P application yields declined from about 12 to 10 t/ha. While there was no significant response to fertilizer application during the first five years of cropping, after that the response to K application became more pronounced year after year. This is due to a gradual decrease in the exchangeable soil K content, which dropped below the critical level of 0.15 me/100 g during the 7th year of cropping. Even after 14 years of continuous cropping there was only a minor response to the application of P as the available P content remained above the critical level of 5 ppm P over all these years.

Thus, in most soils in Asia, cassava responds mainly to the application of K>N>P, but in various locations in southern China and in Malang, Indonesia the initial response was mainly to N>K>P. The rates of NPK recommended in various locations, soils and cropping systems are shown in **Table 10**.

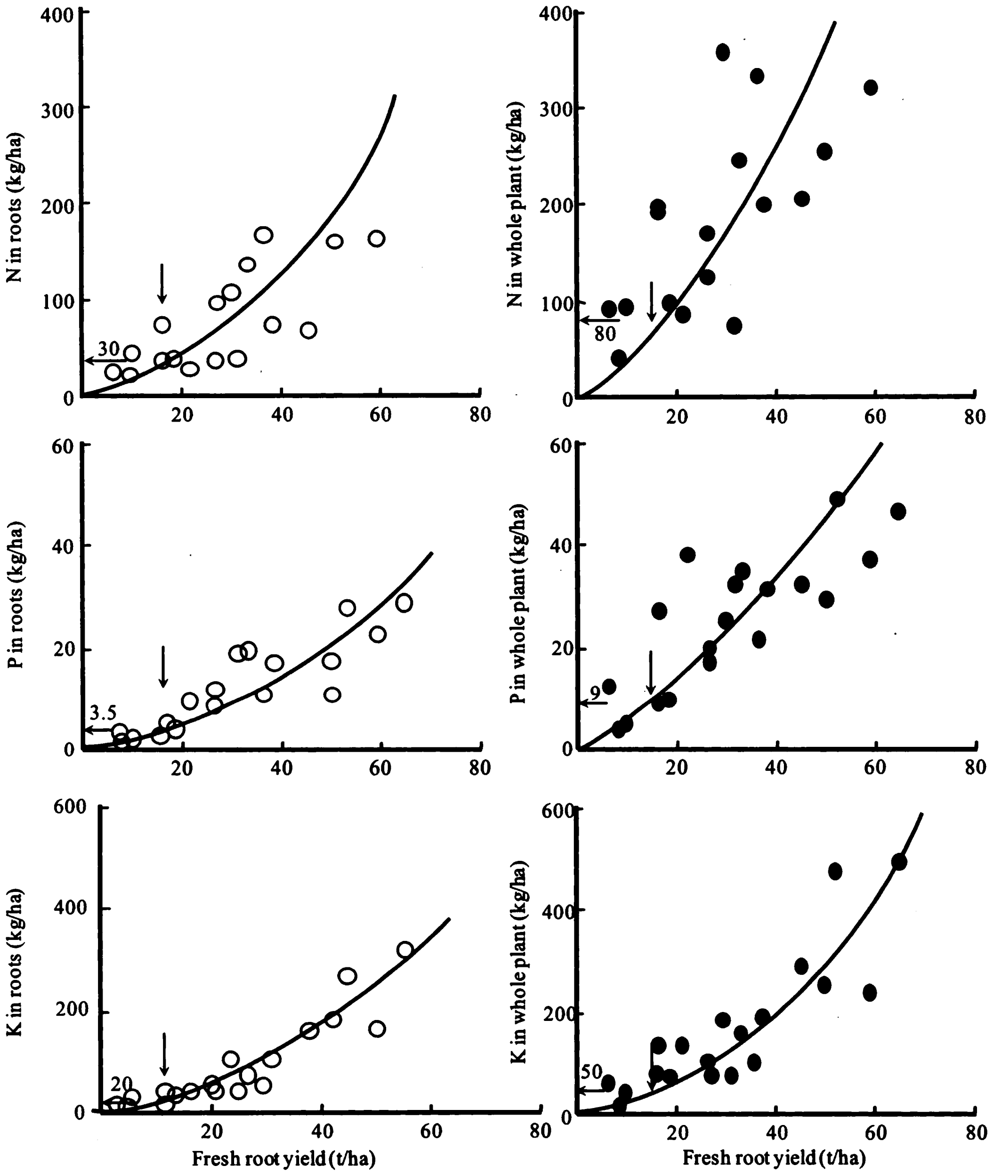


Figure 6. Relation between the amounts of N, P and K in cassava roots (left)or in the whole plant (right) and the fresh root yield, as reported by various sources in the literature. Arrows indicate the approximate nutrient removal corresponding to a fresh root yield of 15 t/ha. ***Source:*** *Howeler, 2001; 2002.*

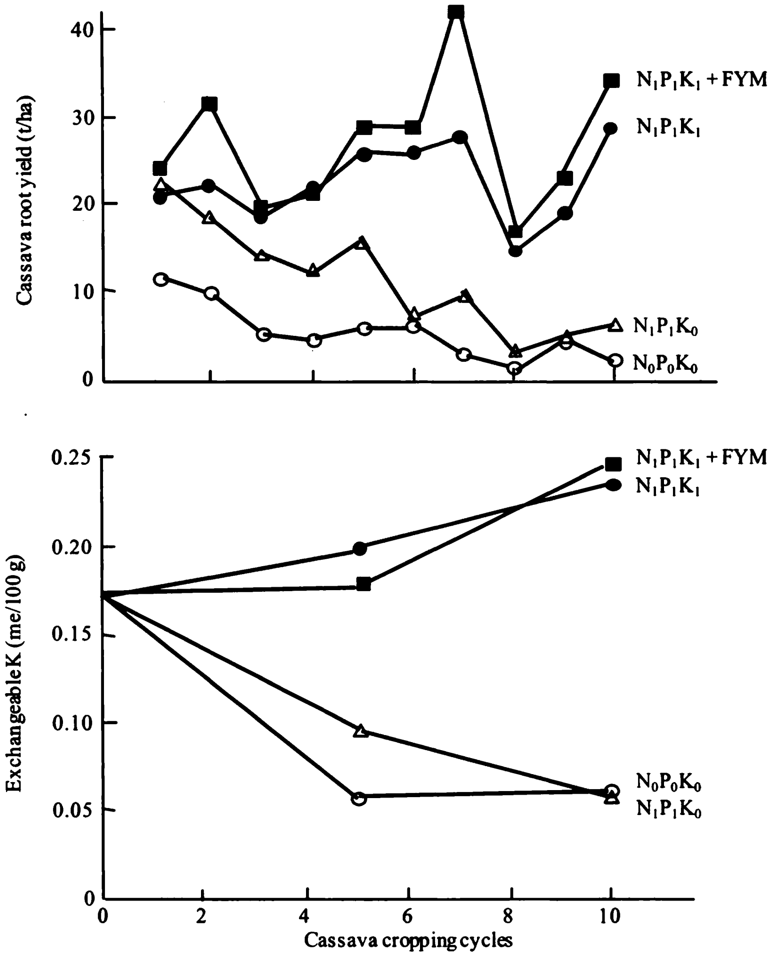


Figure 7. Cassava yield (top) and the exchangeable K content of the soil (bottom) during 10 years of continuous cropping with various NPK treatments in Trivandrum, Kerala, India.
***Source:** Kabeerathumma et al., 1990.*

Animal manures are a good source of N, P and K as well as secondary- (Ca, Mg, S) and micro-nutrients (B, Cu, Fe, Mn, Zn). They are often times the only source of nutrients available for poor farmers. However, animal manures have very low levels of N, P and K as compared to chemical fertilizers (**Table 11**) and they tend to be too low in N and K as compared to P to be suitable for most cassava soils. **Tables 12** and **13** indicate that cassava yields are generally highest with either a well-balanced application of NPK fertilizers or a combination of a medium level (5/ha) of FYM or compost supplemented with N, or N and K depending on the fertility status of the soil. This combination of manure and chemical fertilizers, or chemical fertilizers alone, generally results in a higher net income than applying only organic manures. Similar results were also reported by Susan John *et al.* (2005) for two long-term experiments conducted at CTCRI in Kerala, India.

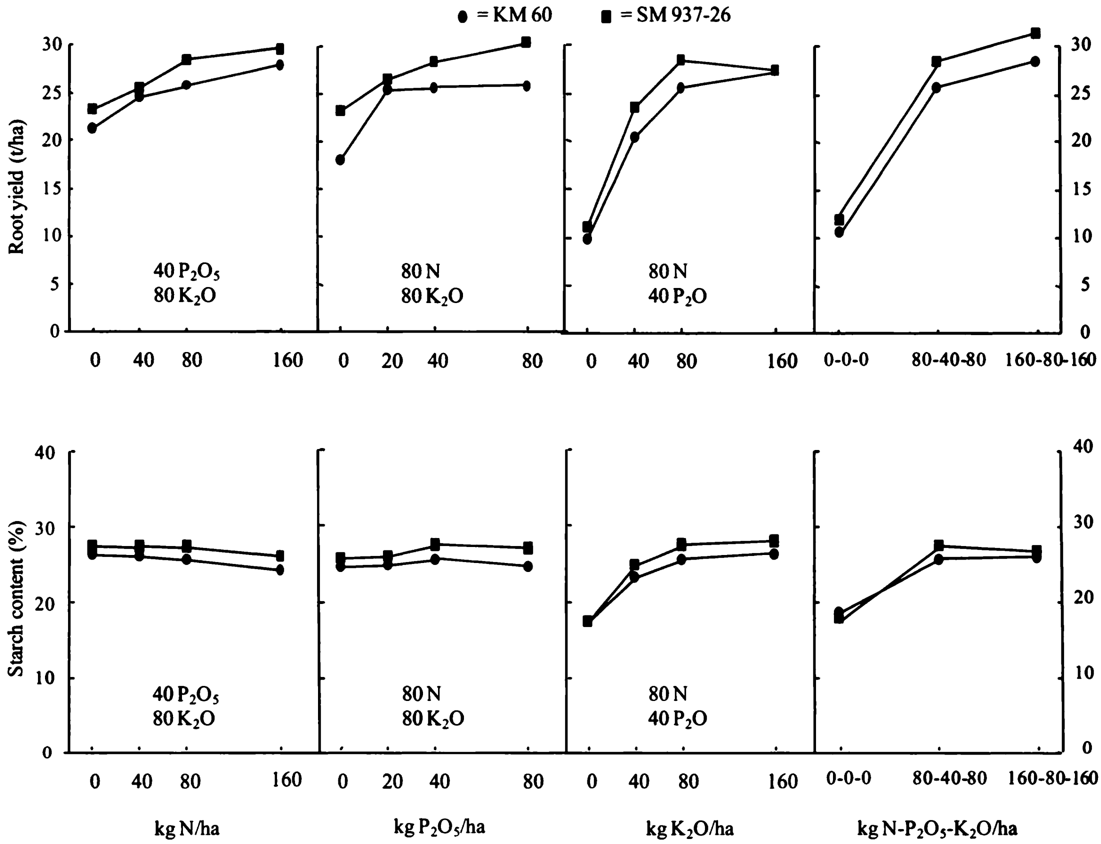


Figure 8. Effect of annual applications of various levels of N, P and K on the root yield and starch content of two cassava varieties grown at Hung Loc Agric. Research Center in Thong Nhat, Dong Nai, Vietnam in 2003/04 (14th year).

Source: *Nguyen Huu Hy, personal communication, 2004.*

Research on the best time and method of fertilizer application usually indicates that best responses are obtained when all fertilizers are either applied at time of planting or at one month after planting. Alternatively, all of the P and half of the N and K are applied at planting and the remaining N and K applied at 2-3 months after planting. Highly soluble fertilizers like urea, TSP, SSP, SP-36 and KCl, or any of the compound fertilizers, should be band or spot applied at 5-10 cm from the stake, while less soluble fertilizers like basic slag, rock phosphates, lime, gypsum and animal manures should be broadcast and incorporated into the soil before planting.

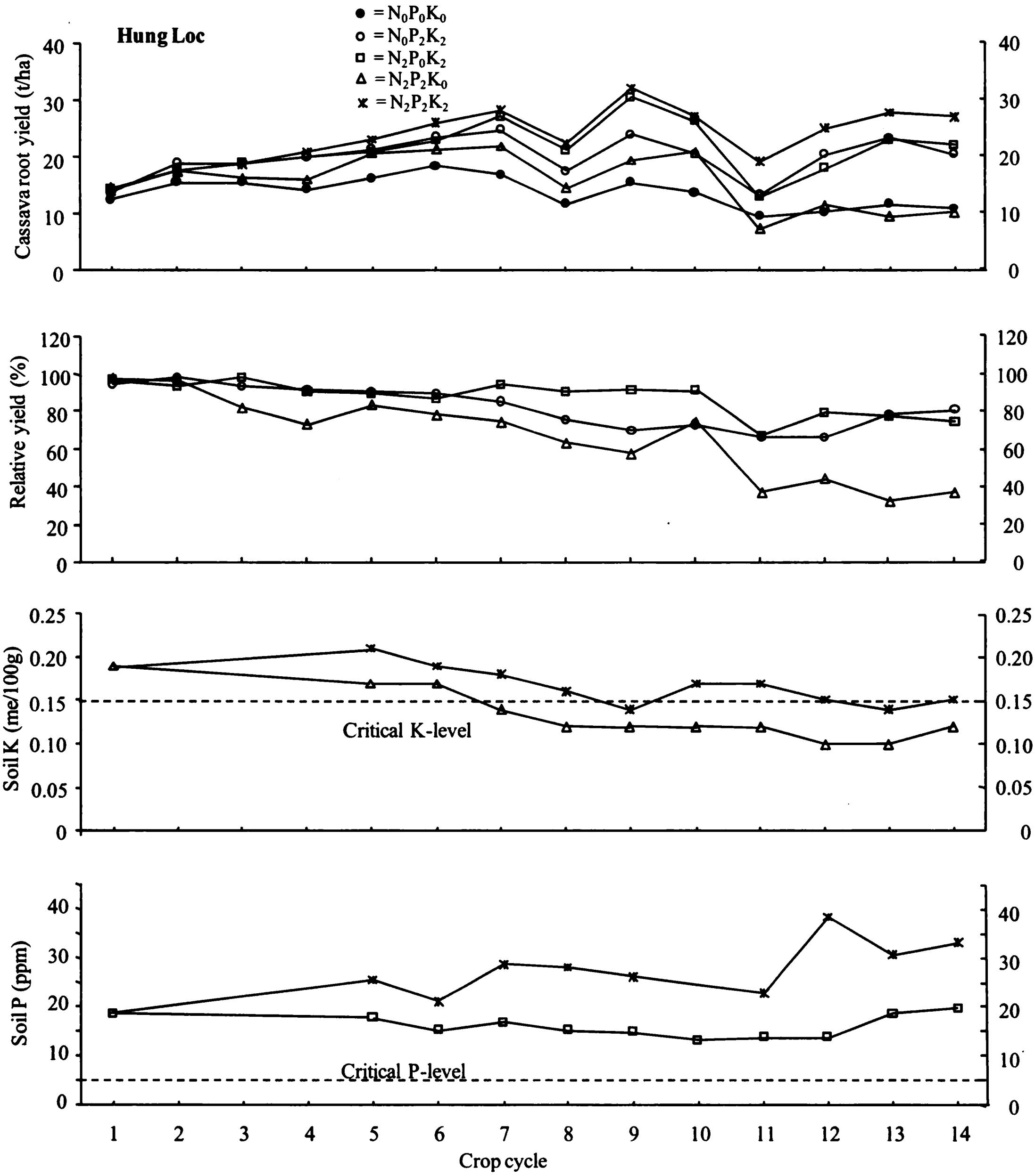


Figure 9. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during fourteen years of continuous cropping in Hung Loc Agric. Research Center, Dong Nai, Vietnam.
Source: *Nguyen Huu Hy, personal communication, 2004.*

Table 10. Optimum fertilizer applications for cassava production in various locations, soils and systems in Asia.

Location/Soil/System	$N: P_2O_5: K_2O$ (kg/ha)	Reference
in Nanning, Guangxi, China	100:50:100	Zhang Weite *et al.*, 1998
in CATAS, Danzhou, Hainan, China	200:100:200	Zhang Weite *et al.*, 1998
in CTCRI, Thiruvananthapuram, Kerala, India	100:50:100	Susan John *et al.*, 1998
for cassava monocrop in Tamanbogo, Lampung, Indonesia	90:25:45	Wargiono *et al.*, 2001
in intercropped cassava in Tamanbogo, Lampung, Indonesia	90:50:90	Wargiono *et al.*, 2001
in ViSCA, Baybay, Leyte, Philippines	60:90:60	Evangelio and Ladera, 1998
in Ubay, Bohol, Philippines	120:60:120	Evangelio *et al.*, 1995
in La Granja, Negros Occidental, Philippines	100:50:100	Evangelio *et al.*, 1995
in Hung Loc Center, Dong Nai, Vietnam	80:40:80	Nguyen Huu Hy *et al.*, 1998
at Thai Nguyen Univ., Thai Nguyen, Vietnam	160:80:160	Nguyen Huu Hy *et al.*, 1998
on mineral soils at MARDI in Serdang, Malaysia	60:30:160	Chan, 1980
on peat soils in Johor, Maysia	50:30:40	Tan, 2001
for most cassava soils in Thailand	100:50:50	Sittibusaya *et al.*, 1995
in Khon Kaen with tops incorporated	50:50:50	Tongglum *et al.*, 2001
for soils used continuous for cassava cultivation in Thailand	100-50-50	Sittibusaya *et al.*, 1995
for Quartzipsamments (sandy loam Entisols) in Thailand	50-100:0:50-100	Ho and Sittibusaya (1984)
for Paleustults (sandy loam Ultisols) in Thailand	80-100:0-30:30-50	Ho and Sittibusaya (1984)

Source: *Howeler, 2001.*

Table 11. Average nutrient contents of various manures, composts, wood ash, and chemical fertilizers.

Source of manure	Moisture (%)	N	P	K	Ca	Mg	S
		(% of dry matter)					
Cattle manure	68.2	1.85	0.81	1.69	1.54	0.62	0.29
Pig manure	60.0	2.04	1.38	1.38	-	-	-
Chicken manure	43.0	2.91	1.37	1.54	4.56	0.83	-
Sheep manure	-	3.00	0.62	2.68	1.72	0.86	0.43
Human manure	-	1.20	0.06	0.21	-	-	-
City/rural compost	-	1.16	0.37	0.90	-	-	-
Rice straw compost	73.7	1.07	0.19	0.69	-	-	-
Peanut stems + leaves compost	58.6	0.81	0.10	0.38	-	-	-
Water hyacinth	-	2.00	1.00	2.30	-	-	-
Wood ash	-	-	0.87	4.17	23.2	2.10	0.40
15-15-15	0	15	6.55	12.50	0	0	0
Urea	0	45	0	0	0	0	0
Triple superphosphate	0	0	20	0	14	0	0
Potassium chloride	0	0	0	50	0	0	0

Source: *Howeler, 2001b.*

Table 12. Effect of the application of FYM[1] and chemical fertilizers on cassava yield and economic benefit at Thai Nguyen University of Agric. and Forestry in Thai Nguyen province of Vietnam, in 2001 (2nd year).

Treatments[1]	Cassava root yield (t/ha)	Height at 8 months (cm)	Leaf life at 3 months (days)	HI	Gross income[2]	Fert. costs[2]	Product. costs[3]	Net income
					('000 dong/ha)			
1. no fertilizers, no FYM	3.25	87.1	46.5	0.39	1,625	0	2,800	-1.175
2. 5 t FYM/ha	7.79	116.6	55.2	0.49	3,895	500	3,300	0.595
3. 10 t FYM/ha	10.02	133.9	65.0	0.52	5,010	1,000	3,800	1.210
4. 15 t FYM/ha	13.11	151.8	66.1	0.52	6,555	1,500	4,300	2.255
5. 80 N+80 K_2O/ha, no FYM	15.47	154.5	66.8	0.50	7,735	680	3,580	4.155
6. 80 N+80 K_2O/ha + 5 t FYM/ha	17.98	180.0	68.5	0.48	8,990	1,180	4,080	4.910
7. 80 N+80 K_2O/ha + 10 t FYM/ha	18.70	188.3	70.8	0.49	9,350	1,680	4,580	4.770
8. 80 N+80 K_2O/ha + 15 t FYM/ha	18.50	196.6	73.1	0.48	9,250	2,180	5,080	4.170

[1]FYM = farm yard manure (pig manure)

[2]Prices: cassava dong 500/kg fresh roots
urea (45% N) 2,100/kg
KCl (60% K_2O) 2,300/kg
manure+application 100/kg

[3]Cost of cassava cultivation: 2.8 mil. dong/ha; cost of chem. fert. application 0.10 mil. dong/ha

Source: *Nguyen The Dang, personal communication, 2002.*

Table 13. Effect of various fertilization alternatives on the yields of cassava, cv Faroka, and intercropped maize as well as gross and net income when grown in Jatikerto Station in Malang, East Java, Indonesia, in 2005/06. (2nd year)

Treatments $N-P_2O-K_2O$ (kg/ha)	Organic (t/ha)	Maize yield[2] (t/ha)	Cassava yield (t/ha)	Gross income[3]	Fertil. costs[3]	Prod. costs[4]	Net income	Farmers preference ranking
				(mil. Rp/ha)				
1. 0-0-0	0	1.10	10.96	4.72	0	4.10	0.62	
2. 135-0-0	0	1.93	35.60	13.52	0.45	7.01	6.51	2
3. 135-50-0	0	2.07	36.80	14.05	0.69	7.37	6.68	3
4. 135-50-100	0	2.10	37.47	14.30	1.27	8.02	6.28	4
5. 0-0-0	10 cattle manure	1.66	26.53	10.32	2.00	7.65	2.67	
6. 0-0-0	10 compost	1.63	22.67	9.05	1.00	6.27	2.78	
7. 135-0-0	5 cattle manure	2.26	35.63	13.89	1.45	8.01	5.88	1
8. 135-0-0	5 compost	1.97	39.33	14.75	0.95	7.88	6.87	5
9. 135-50-0	5 compost	1.87	39.07	14.56	1.19	8.10	6.46	
10. 135-0-0	5 sugar mud[1]	1.67	33.73	12.63	0.95	7.32	5.31	

[1] sugar mud = blotong = by-product of sugar mill

[2] maize grain yield

[3] Prices: cassava: Rp 320/kg fresh roots; KCl (60% K_2O) Rp 3,500/kg
maize 1,100/kg dry grain; cow manure 200/kg
urea (45% N) 1,500/kg; compost 100/kg
SP-36 (36% P_2O_5)) 1,700/kg; sugar mud 100/kg

[4] Costs: cassava harvest+transport 100/kg
production costs, without fertilizers or cassava harvest, estimated at Rp 3 mil/ha

Source: *Wani Hadi Utomo, personal communication, 2006.*

7. Use of green manures to improve soil fertility

Leguminous intercrops, green manures and hedgerow species (used in "alley cropping") can improve the N status of the soil through N fixation. They do not supply P and K except by recycling these nutrients from the subsoil into the top soil through leaf fall or when their plant residues are incorporated into the soil.

When green manures are planted and incorporated into the soil before planting cassava, they may significantly increase cassava yields (**Table 14**). However, in this case farmers may have to plant cassava late in the wet season after the green manure crop, or they may have to wait planting cassava until the following year. The late planting is likely to result in low cassava yields (Howeler, 1995), while few farmers can afford to leave their land one year in an unproductive green manure crop. One way to overcome this problem is to plant the green manure as an intercrop between cassava rows and to pull out and mulch the green manure at 2-3 months after planting. **Table 15** shows that *Canavalia ensiformis* (sword bean) was the most effective of four green manures tested, increasing cassava yields from 17.6 to 26.9 t/ha. Alternatively, cassava can be planted late in the wet season after incorporating the green manure and harvested after 18 months; this method resulted in very high root yields (**Table 15**), but provides an income only once every two years. Farmers could plant the green manure and cassava in alternate years on half of their fields to obtain a more steady income.

Planting hedgerows of leguminous tree species may also help to improve soil fertility, if the hedgerows are cut back regularly and the prunings used as mulch between cassava plants. Both the hedgerows, when planted along the contour, and the mulch help to reduce erosion. **Table 16** shows that hedgerows of *Gliricidia sepium* and *Leucaena leucocephala* were very effective in increasing cassava yields, especially when no fertilizers had been applied. These alley crop treatments also resulted in the highest net incomes, both with or without applied fertilizers. However, the beneficial effect of these green manuring practices may become apparent only after several years of continuous cropping.

Table 14. Cassava root yield (t/ha) as affected by the incorporation of different green manures befour planting cassava at the Agric. Development Research Center (ADRC) in Khon Kaen, Thailand.

	Crop year					
Green manure	1	2	3	4	5	Means
Cowpea	10.23	17.58	16.24	19.14	14.64	15.57
Pigeon pea	5.44	12.91	14.16	13.25	14.18	11.99
Crotalaria juncea	5.88	13.43	14.94	17.21	15.20	13.33
No green manure	4.43	13.99	14.13	12.07	13.97	11.72
F-test	**	NS	NS	NS	NS	**
CV (%)	23.6	29.7	23.9	11.5	32.7	10.7

Source: *Sittibusaya et al., 1995.*

Table 15. The effect of green manures grown as in-situ production of manure cassava grown at RFCRC in Rayong, Thailand in 1994/95/96.

Treatment	Green manures (t/ha)	Total N (kg/ha)	Cassava root yield (t/ha)
1. Cassava +Fert. 13-13-21 (156 kg/ha)	-	-	17.56
2. Cassava + Fert. 13-13-21 (469 kg/ha)	-	-	29.78
3. Cassava + *Crotalaria juncea* (cut at 2 months)	1.92	44.75	23.75
4. Cassava + *Canavalia ensiformis* (cut at 2 months)	0.94	20.13	26.94
5. Cassava + Pigeon pea ICP 8094 (cut at 2 months)	1.09	27.00	21.39
6. Cassava +*Mucuna fospeada* (cut at 2 months)	-	-	20.28
7. Cassava + cassava (pulled out at 2 months)	0.36	11.75	18.25
8. Cassava + cassava (cut at 2 months)	0.09	1.69	12.00
9. Cassava + *Crotalaria juncea* (planted at 6-7 months)	9.89	262.13	8.75
10. Cassava + *Canavalia ensiformis* (planted at 6-7 months)	1.54	36.63	22.83
11. Cassava + Pigeon pea ICP 8094 (planted at 6-7 months)	8.92	221.69	15.86
12. Cassava + *Mucuna fospeada* (planted at 6-7 months)	-	-	17.25
13. *Crotalaria juncea*-Cassava (harvest at 18 months)	1.44	39.94	46.17
14. *Canavalia ensiformis*-Cassava (harvest at 18 months)	0.93	18.38	42.98
15. Pigeon pea ICP 8094-Cassava (harvest at 18 months)	1.05	25.63	38.81
16. *Mucuna fospeada*-Cassava (harvest at 18 months)	-	-	38.86
LSD (0.010	-	-	13.45
F-test	-	-	**
CV (%)	-	-	23.88

Note: Treatments 9-12: green manures were cut at 4.5 months (at harvest of cassava)
Treatments 6, 12 and 16: Mucuna fospeada failed due to poor germination
Treatments 3-16: 156 kg/ha of 13-13-21 were applied to cassava
Treatments 1-12: cassava was harvested at 12 months
Treatments 13-16: cassava was harvested at 18 months

***Source:** Tongglum et al., 1998.*

8. Erosion control

Due to its wide plant spacing and slow initial growth, cassava may cause more serious erosion than other crops when planted on slopes without soil conservation measures (Putthacharoen *et al*., 1998). However, farmers can markedly reduce soil losses by erosion through the use of simple agronomic or soil conservation practices, such as minimum tillage, intercropping, contour ridging, closer plant spacing, fertilizer application, mulching and the planting of contour hedgerows of grasses, legumes or leguminous tree species. Numerous on-station experiments and farmer participatory research (FPR) trials have shown that on average planting contour hedgerows of vetiver grass, *Paspalum atratum*, lemon grass, *Tephrosia candida* and pineapple were most effective in reducing erosion, while closer plant spacing, fertilizer application and lemon grass or vetiver grass hedgerows were most effective in increasing cassava yields (Howeler, 2006). Once farmers see the beneficial effects of these practices in simple FPR trials on their own fields, they are willing to adopt those practices that are most suitable for their own conditions.

Table 16. Effect of planting intercrops, green manures and alley crops, with or without fertilizers, on cassava and intercrop yields, as well as on gross and net income obtained when cassava, KM 60, was grown for the 12th consecutive year at Hung Loc Agric. Research Center in Thong Nhat district, Dongnai, Vietnam in 2003/04.

	Root yield —(t/ha)—		Starch content ——(%)——		Gross income[3] —('000d/ha)—		Product. costs[4] —('000d/ha)—		Net income —('000d/ha)—	
Treatments[1]	-fert	+fert[2]	-fert	+fert	-fert	+fert	-fert	+fert	-fert	+fert
1. C monoculture	15.62	23.44	24.1	27.1	3,749	5,626	1,900	3,091	1,849	2,535
2. C+pigeon pea GM	15.66	23.02	21.4	25.0	3,758	5,525	2,800	3,991	958	1,534
3. C+*Mucuna* GM	11.25	20.44	22.6	24.7	2,700	4,906	2,800	3,991	-100	-915
4. C+peanut IC	18.12	24.75	23.3	26.4	4,349	6,585 [5]	2,800	3,991	1,549	2,594
5. C+cowpea IC	16.25	24.44	23.6	25.8	3,900	5,866	2,800	3,991	1,100	1,875
6. C+*Canavalia* GM	15.62	25.06	22.8	24.6	3,749	6,014	2,800	3,991	949	2,023
7. C+*Leucaena* AC	21.50	26.84	22.7	26.6	5,160	6,442	2,200	3,391	2,960	3,051
8. C+*Gliricidia* AC	23.58	30.96	23.7	26.4	5,659	7,430	2,200	3,391	3,459	4,039

[1] GM = green manure; IC = intercrop; AC = alley crop

[2] +fert = 80 kg N + 40 P_2O_5 + 80 K_2O/ha; -fert = no fertilizers

[3] Prices: cassava: dong 240/kg fresh roots (includes harvest + transport)
peanut 5,000/kg dry pods

[4] Costs:

land preparation	500,000 d/ha
planting (8 md)	200,000 d/ha
weeding (48 md)	1,200,000 d/ha
seed intercrops	300,000 d/ha
planting/harvest intercrops (24 md)	600,000 d/ha
urea (45% N)	2,800 d/kg
SSP (17%P_2O_5)	1,000 d/kg
KCl (60% K_2O)	2,500 d/kg
labor	25,000 d/manday
fertilizer application (5 md)	125,000 d/ha
cutting alley crops	300,000 d/ha

[5] Peanut yield is 129 kg dry pods/ha

Source: *Nguyen Huu Hy, personal communication, 2004.*

9. Weeding

Cassava is a poor competitor and may suffer serious yield losses if the crop is not adequately weeded during the early stages of plant growth. In general, the crop should be weeded 2-3 times during the first three months or until canopy closure. Weeding is most often done by hoe, by animal-drawn cultivator or hand tractor, but can also be done by a tractor-mounted cultivator or with herbicides. Weed competition can also be reduced by adequate and early application of fertilizers to speed up canopy closure, by intercropping, and by planting in the early dry season when weed growth is less vigorous (**Table 17**). When herbicides are used it is recommended to apply metholachlor at 1.5 kg a.i./ha immediately after planting, followed by 1-2 hand weedings or spot application of Paraquat or Glyphosate, using a shield over the applicator to prevent damage to the cassava plants (Tongglum *et al.*, 2001). Alternatively, Nguyen Huu Hy *et al.* (2001) showed that application of 2.4 l/ha of Dual as a pre-emergence herbicide in Vietnam increased cassava yields and net income as compared to hand weeding.

Table 17. Cassava fresh root yield and weeding costs as effected by the frequency of hand weeding when cassava cutivars Rayong 3 and Rayong 60 were planted at Rayong Field Crops Research Center in Thailand in the beginning of the rainy and dry seasons of 1991.

Treatment	Rainy season		Dry season	
	Root yield (t/ha)	Weeding cost (US$/ha)	Root yield (t/ha)	Weeding cost (US$/ha)
Varieties				
-Rayong 3	21.44 b	111	22.88 b	57
-Rayong 60	28.00 a	94	30.81 a	53
F-test	*[1]	-	*	-
Weeding times				
-No weeding	4.81 b	0	23.63	0
-1&2 months	26.69 a	77	24.88	9
-1, 2& 3 months	29.00 a	85	25.38	14
-1, 2, 3 &6 months	27.94 a	127	26.06	57
-1, 2, 3, 6 & 9 months	31.44 a	118	29.56	104
-As necessary	28.81 a	106	31.56	90
F-test	**[2]	-	NS[3]	-

[1] and [2] Mean within a column separated by DMRT at 0.05 and 0.01%, respectively.
[3] NS = not significant
Source: *Tongglum et al., 1992.*

10. Harvest

Cassava can be harvested any time, but the roots are usually harvested between 6 and 18 months. Some early-maturing varieties can be harvested at 6 MAP for direct human consumption, but most industrial varieties are harvested between 8 and 12 MAP. **Table 6** indicates that root yields nearly tripled between 8 and 18 months and that starch contents increased substantially between 8 and 10 months. Harvesting cassava after 18 months provides an income only every 1½ years, but at a considerable saving in terms of production costs. Harvesting early, at 6-8 MAP, however, allows for double cropping cassava with a subsequent short-duration crop of rice, sweet corn or mungbean.

Cassava is usually harvested by removing the tops at 20-30 cm above the ground and using the remaining stump to pull up the roots. If the soil is too hard, the roots can be lifted out of the ground with a pointed metal bar or a metal fork attached to a wooden stick used as a lever. Roots can also be dug out with pick, hoe or shovel. In areas where labor is expensive or the soil is too hard during the dry season, farmers in Thailand now use a tractor-mounted cassava harvesting tool that loosens the soil and lifts up the roots for easy gathering by hand. In Malaysia a more sophisticated cassava harvesting machine will dig the roots and deposit them in an attached wagon. After pulling up the root clumps, the individual roots are cut off from the stump and packed in baskets or sacks for transport to the house, drying floor or starch factory. To prevent spoiling, fresh roots should be processed within 2-3 days after the harvest.

CONCLUSIONS

Cassava is an easy crop to grow, and in Southeast Asia it does not suffer from any serious pests or disease problems. It can grow in poor soils and in drought-prone areas with little risk of complete crop failure. However, to obtain high and sustainable yields, the crop should be well-managed; it should be planted at an optimum time of the year, weeded 2-3 times during the first 3-4 months, and fertilized with chemical fertilizers or manures to supply adequate amounts of all nutrients required by the crop, particularly K and N. Cassava will remain a highly competitive industrial crop only if farmers obtain high yields at low production costs by the use of high-yielding varieties and good production practices.

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SUSTAINING CASSAVA FARMERS AND OUR EARTH: BACKGROUND OF THE NIPPON FOUNDATION PROJECT IN ASIA

Reinhardt H. Howeler[1]

ABSTRACT

In Asia, cassava is generally grown on gentle to steep sloping land, in areas with infertile soils and with low or unpredictable rainfall, where most other crops would not grow well. Because of its exceptional tolerance to drought, to high soil acidity and low levels of P, cassava is particularly well adapted to these marginal areas. The crop is therefore mostly grown by small-scale and poor farmers living in isolated areas with limited infrastructure. Fortunately, in Asia cassava suffers from few insect and disease problems and the crop can be grown almost continuously on the same land if soil fertility can be maintained and soil losses by erosion prevented.

During the past 30 years, research has shown that cassava will tolerate low levels of soil P, but requires relatively high inputs of N and K to maintain high yields. In general, a combination of inorganic fertilizers high in N and K and animal or green manures will give the highest yields and maintain or improve soil fertility. Also, while production of cassava tends to result in more erosion than other crops, many simple production and soil conservation practices have been identified that are highly effective in reducing erosion. However, all these practices may require some extra inputs of labor or money, while some may take a portion of the land out of production. The challenge is to develop a package of practices that fit well into the currently used production systems, that are effective in maintaining or improving the productivity of the land and which produce enough short-term financial benefits to the farmer that outway the extra inputs that may be required. The "right" combination of practices is highly site-specific, depending both on the soil and climatic conditions as well as the socio-economic circumstances in each site. These practices may also require trade-offs between short-term economic benefits and long-term sustainability. These choices can only be made by the farmers themselves. Thus, developing more sustainable practices can best be done with the full participation of farmers, while the dissemination of these improved practices can also best be done through farmer-to-farmer extension.

In 1994 the Nippon Foundation in Tokyo, Japan, agreed to fund a 5-year project that had as its main objective to develop and disseminate improved production practices that would increase cassava farmers' income while preventing soil degradation by nutrient depletion and soil erosion. To attain this objective it was proposed to develop and use a farmer participatory research (FPR) methodology, in which farmers would directly participate in the development of these practices by conducting FPR trials on their own fields. The first phase (1994-1998) was conducted in 2-3 pilot sites each in four countries, i.e. China, Indonesia, Thailand and Vietnam, in collaboration with national research and extension organizations in those countries. In 1998 a suitable FPR methodology had been developed, many improved practices had been identified by farmers, and some of these were already being adopted on a small scale.

The second phase (1999-2003) of the project aimed to develop a similar farmer participatory extension (FPE) methodology, that would enhance the dissemination and adoption of these farmer selected practices. The second phase is being conducted in over 20 sites in both Thailand and Vietnam, and in about ten sites in China, in collaboration with many research and extension organizations in those countries. Now, in the fourth year of the second phase, many sustainable production practices are already widely adopted by cassava farmers and the project is well on its way of meeting the target of benefiting at least 8000 farmers, while also protecting the soil, water and forest resources for the benefit of society at large and of future generations.

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INTRODUCTION

Cassava (*Manihot esculenta* Crantz) originated in Latin America where it has been a staple food for the native Indian population for at least 4000 years. It was introduced to Asia on several occasions by European traders during the 17^{th} and 18^{th} Century. The crop was grown mainly as a food staple, and later, in some areas, for small-scale starch extraction. After the Second World War it became an industrial crop for production of animal feed and starch, mainly in Thailand, Malaysia and on Sumatra island of Indonesia, and later also in southern China, southern Philippines, Vietnam and Tamil Nadu state of India.

Because of its exceptional tolerance to drought, high levels of Al and low levels of P, the crop is mainly grown in areas of poor soils and with low or unpredictable rainfall. In eastern Asia cassava does not suffer from major disease or pest problems, so it is an easy and low-risk crop to grow. For that reason, it is often grown by poor farmers living in isolated and mountainous areas with marginal soil and climatic conditions. In some countries like Lao PDR and East Timor it is still grown under slash-and-burn agricultural systems, while in others it is grown as a continuous crop or in rotation with other crops, either in monoculture or in intercropping systems.

Long-term Effect of Cassava Cultivation on Soil Productivity

Many governments do not promote cassava cultivation because of the general perception that cassava will degrade the soil's productivity by exhausting the nutrient supply of the soil and by erosion. Thai Phien and Nguyen Tu Siem (1996) reported that the production of upland rice and cassava in many parts of Vietnam had turned once productive land into "waste lands", that were not suitable any more for agricultural production. Similarly, Cong Doan Sat and Pol Deturck (1998) concluded that soils in south Vietnam that had been under long-term cassava cultivation had deteriorated both chemically and physically, more so than similar soils under sugarcane, cashew, rubber or forest. Unfortunately, they did not compare cassava with other annual crops like maize, peanut or soybean, which also require annual land preparation and frequent weeding. It is well-known that any time a forest is cut and burned, and the land is prepared for growing annual crops, the soil is exposed to direct sunlight and rainfall splash, which will result in a steady decrease in soil organic matter (OM) content, leaching of nutrients and enhanced soil erosion. **Figure 1** shows that the productivity of soil declined under cassava, but it declined even more rapidly under upland rice. **Figure 2** also shows how cassava yields in three soil series in Thailand declined after many years of cassava cultivation without fertilizers. The decline in yields after continuous cassava cropping is due to soil nutrient depletion and/or excessive soil and nutrient loss by erosion. The question remains whether this is more serious in cassava than in other crops, and if so, what are the best ways to prevent this and make cassava cultivation more sustainable.

Effect of Cassava Cultivation on Soil Nutrient Depletion

Cassava has a reputation to degrade soils by excessive extraction and removal of soil nutrients, to the extent that no other crops can grow on these soils after cassava. However, comparing the removal of the major nutrients N, P and K, in cassava roots with those in the harvested products of other crops, it is clear that per tonne of dry matter (DM) produced cassava extracts much less N and P, and similar amounts of K as most cereals and much less nutrients than grain legumes and tobacco (Howeler, 1991). Similarly, in a comparative study of eight different crops grown during a 22-month period in Sri Racha, Thailand, the N and P removal per hectare was much lower for cassava grown for root production than for maize, sorghum, peanut, mungbean and pineapple, while the removal of K was similar to that of most of the other crops (**Table 1**). Nutrient removal by cassava is equal or higher than other crops only when root yields are extremely high or when leaves and stems are also removed from the field.

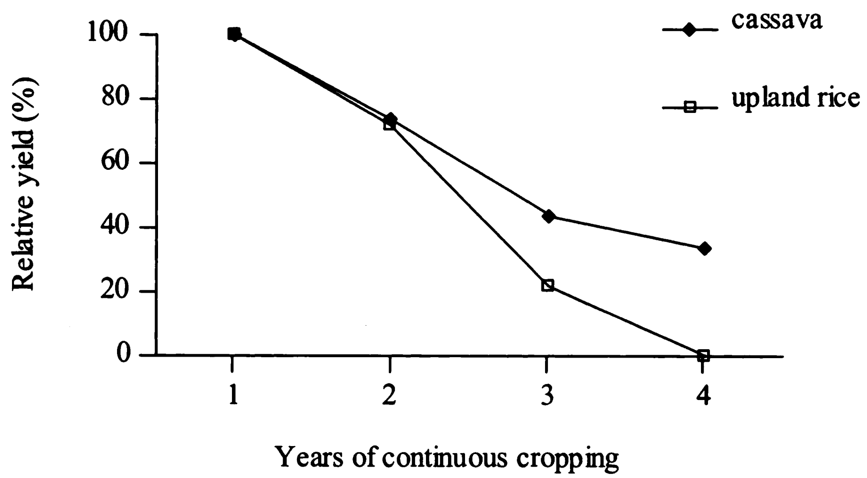

Figure 1. Yield reduction of upland rice and cassava due to fertility decline as a result of continuous cropping without fertilizer application. 100% corresponds to 18.9 t/ha of fresh cassava roots and 2.55 t/ha of rice.
***Source:** adapted from Nguyen Tu Siem, 1992.*

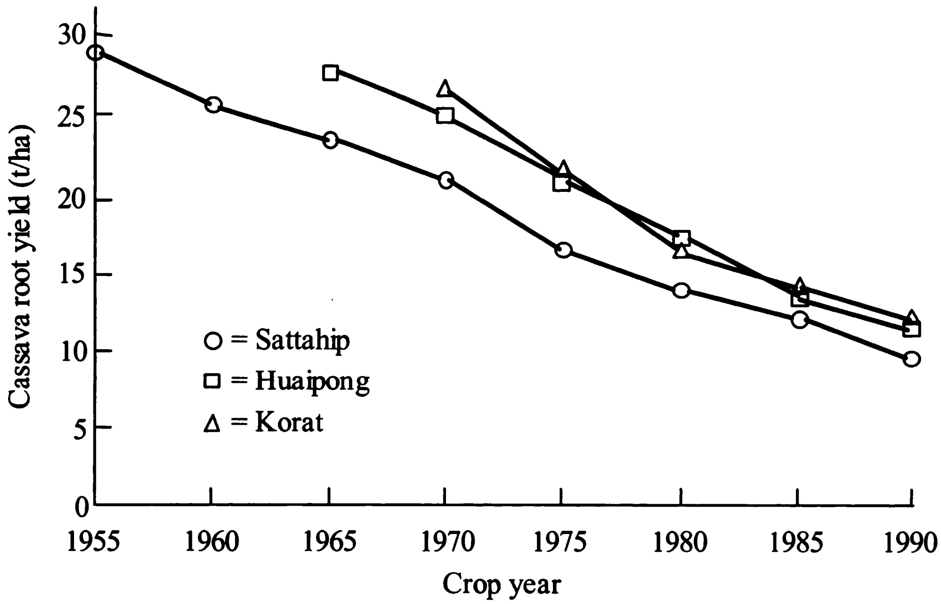

Figure 2. Decline in fresh root yields due to continuous cultivation without fertilizers in three soil series in Thailand.
***Source:** Sittibusaya, 1993; Howeler, 1995.*

Table 1. Major nutrients removed in the harvested products and returned in the non-harvested products of various crops grown during 22 months in Sri Racha, Chonburi, Thailand in 1989-1991.

Crop	No. of crop cycles	Nutrients removed (kg/ha)					Nutrients returned (kg/ha)				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
Cassava for roots	2	48	7	60	14	6	236	46	132	154	35
Cassava for forage	1	363	43	240	162	62	17	4	16	24	5
Maize	2	118	44	87	6	11	101	13	269	34	28
Sorghum	2	79	25	51	10	9	147	27	304	51	37
Peanut	2	213	19	53	6	8	133	12	183	87	28
Mungbean	3	117	15	62	9	11	54	7	66	51	14
Pineapple	1	83	15	190	51	19	160	31	176	85	24

Source: *Putthacharoen et al., 1998.*

There is no doubt, however, that cultivation of cassava, like that of any other crop, will lead to nutrient extraction and this may result in nutrient depletion if the removed nutrients are not replaced in the form of chemical fertilizers, or animal or green manures. Numerous long-term fertilizers experiments have shown that application of adequate amounts of nutrients, especially N and K, can maintain soil productivity and sustain high yields of 20-30 t/ha for more than 15-25 years of continuous cassava cultivation (Nguyen Huu Hy *et al.*, 2007; Wargiono and Ispandi, 2007, Nakviroj *et al.*, 2007). The incorporation of cassava leaves and stems into the soil after harvest, as well as the combined application of chemical fertilizers with animal manures, compost or green manure residues will generally further increase cassava yields and maintain or improve the soils' chemical and physical characteristics (Nakviroj *et al.*, 2007; Howeler, 2007)

Effect of Cassava Cultivation on Soil Erosion

Soil erosion trials conducted with twelve crops from 1943 to 1959 in Brazil indicate that castor bean, *Plaseolus* bean and cassava are the three crops causing most serious erosion and runoff (**Figure 3**). Similarly, Putthacharoen *et al.* (1998) reported that cassava grown for root production caused more than twice as much dry soil loss by erosion as mungbean, and three times more than maize, sorghum, peanut and pineapple. **(Table 2).** Howeler (1998) also reported that in Lampung, Indonesia, one crop of cassava grown in monoculture resulted in more soil loss by erosion than two successive crops of maize, peanut or soybean or a rice-soybean rotation in the same 8-month cropping season, but that intercropping cassava with upland rice, maize and soybean as well as the application of fertilizers both markedly reduced erosion (**Table 3**). Thus, there is no doubt that when cassava is grown on slopes, it may cause more erosion than other crops. This is mainly due to the crop's wide plant spacing and slow early growth, which leaves a lot of soil exposed to the direct impact of rain drops during the first three months after planting (MAP), before the crop canopy is closed.

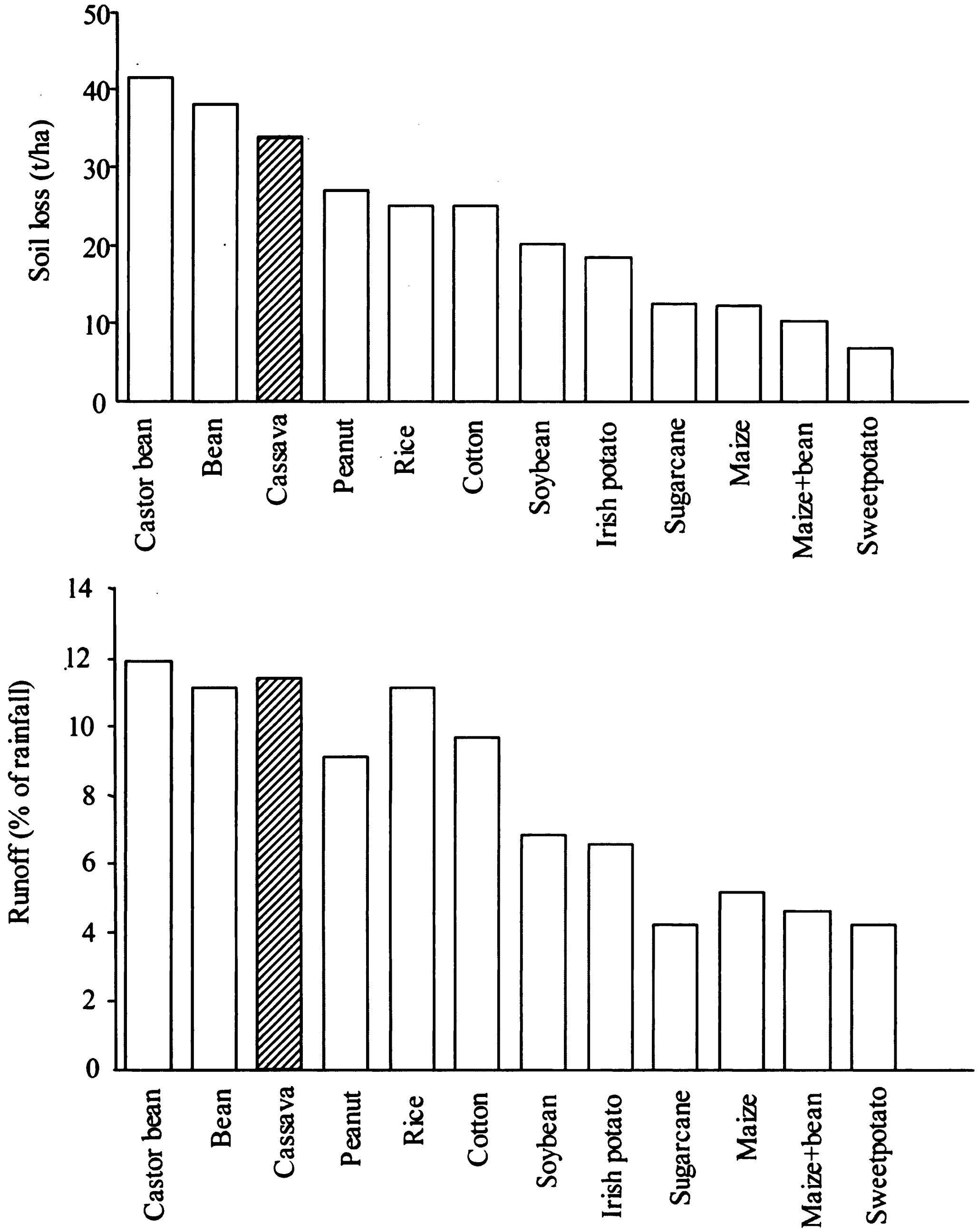

Figure 3. Effect of crops on annual soil loss by erosion (top) and on runoff (bottom). Data are average values (corrected for a standard annual rainfall of 1,300 mm) from about 48 experiments conducted from 1943 to 1959 on sandy, clayey and Terra roxa soils in Sao Paulo state of Brazil with slopes of 8.5-12.8%.
***Source:** Quintiliano et al., 1961.*

Table 2. 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)
Cassava for root production	4	142.8 a	168.5 a	311.3
Cassava for forage production	2	68.8 b	138.5 ab	207.3
Maize	5	28.5 d	35.5 cd	64.0
Sorghum	5	42.9 c	46.1 cd	89.0
Peanut	5	37.6 cd	36.2 cd	73.8
Mungbean	6	70.9 b	55.3 cd	126.2
Pineapple[1)]	2	31.4 cd	21.3 d	52.7
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.*

Table 3. Effect of various crops and cropping systems on dry soil loss due to erosion and on net income during an 8 month cropping cycle on 5% slope in Tamanbogo, Lampung, Indonesia. Data are average values for two years (1994-1996).

	Dry soils loss (t/ha)	Net income ('000 Rp/ha)
Without fertilizers		
Cassava	41.92	322
Rice-soybean	26.29	570
Maize-maize	30.64	159
With fertilizers		
Cassava	29.06	804
Rice-soybean	24.31	1,477
Maize-maize	24.98	892
Peanut-peanut	17.92	2,488
Soybean-soybean	27.61	2,031
Cassava+maize+rice-soybean	19.60	1,300

[1)] Net income = total crop value minus fertilizer costs.
***Source:** Howeler, 1998.*

Erosion is particularly serious on steep slopes, but can be equally serious on gentle slopes if they have light-textured soils with low levels of OM. The latter soils are very susceptible to gully erosion due to their low aggregate stability, and the tendency to have a hard pan in the subsoil, which inhibits internal drainage. These light-textured soils are often used for cassava production, as soil fertility may be too poor for other crops.

Numerous erosion control experiments with cassava, conducted over the past 25 years in Colombia as well as in many parts of Asia, have shown that soil losses due to erosion can be markedly reduced by several agronomic and soil conservation practices, which may also increase yields. These practices include intercropping with peanut (Le Sy Loi, 2000), no tillage, contour ridging, closer plant spacing and fertilizer application (**Figure 4**) (Howeler, 1995), as well as contour hedgerows of various grasses, pineapple and leguminous species (Nguyen Huu Hy *et al.*, 2001; Garrity *et al.*, 2000; Howeler *et al.*, 2001). Many of these practices require additional money or labor to establish, and some may initially reduce yields by taking part of the land out of production or by competition from intercrops or hedgerows. Thus, most of these practices have advantages and disadvantages and they may require trade-offs between maximizing economic benefits today and those in the future resulting from more sustainable production practices. These trade-offs can best be made by the farmers themselves. Moreover, soil conservation practices are highly site-specific, depending on the soil and climatic conditions as well as socio-economic factors. Thus, the most suitable practices for a specific location can best be developed by farmers on their own fields. And if farmers themselves select those practices they are more likely to adopt them.

The Nippon Foundation Cassava Project-First Phase (1994-1998)

In 1993 the Nippon Foundation in Tokyo, Japan, agreed to fund a 5-year project entitled "Improving the Sustainability of Cassava-based Production Systems in Asia". The main objective of this project was to enhance the adoption of soil conservation practices by those farmers growing cassava on slopes, so as to reduce soil erosion in cassava fields. The project was implemented by the CIAT Cassava Office in Asia in close collaboration with research and extension institutions in China, Indonesia, Thailand and Vietnam. It was proposed to develop the most suitable soil conservation practices together with farmers using a farmer participatory research (FPR) approach. Socio-economists and anthropologists at CIAT, in particular Jackeline Ashby and co-workers, had developed the principles and basic activities for the use of this approach (Ashby *et al.*, 1987), and had used these successfully in several farming communities in Colombia. Borrowing ideas from this and other groups with experience in farmer participatory research, a regional training course was held in Rayong, Thailand, in July, 1994, to discuss the methodologies with researchers and extensionists from the collaborating countries, in order to develop work plans with activities adapted to the specific conditions in each country.

Farmer Participatory Research (FPR)

The basic idea behind this approach is quite simple: to involve farmers directly in the development and testing of new technologies, and to let them make their own decisions about what they consider useful without making our own recommendations. The role of the researchers and extensionists changes from selecting and then recommending or transferring our selected technologies to being an equal partner with farmers in the quest for new technologies that are most useful in a particular area. Government officials become facilitators in the process of helping farmers diagnose their own problems, select some promising technologies that might solve those problems, and then help them test those technologies on their own fields in simple FPR trials. From these trials farmers select the best treatments; they may test those again before selecting the very best ones to be tried in larger areas of their production field, make some adaptations if necessary, and then adopt those practices considered most useful. **Figure 5** shows a schematic diagram of the whole process. The outstanding feature of this approach is that farmers participate in every step of the process and they make all the important decisions. While the exact execution of the activities differ somewhat from country to country, the basic approach is the same and may involve the following steps:

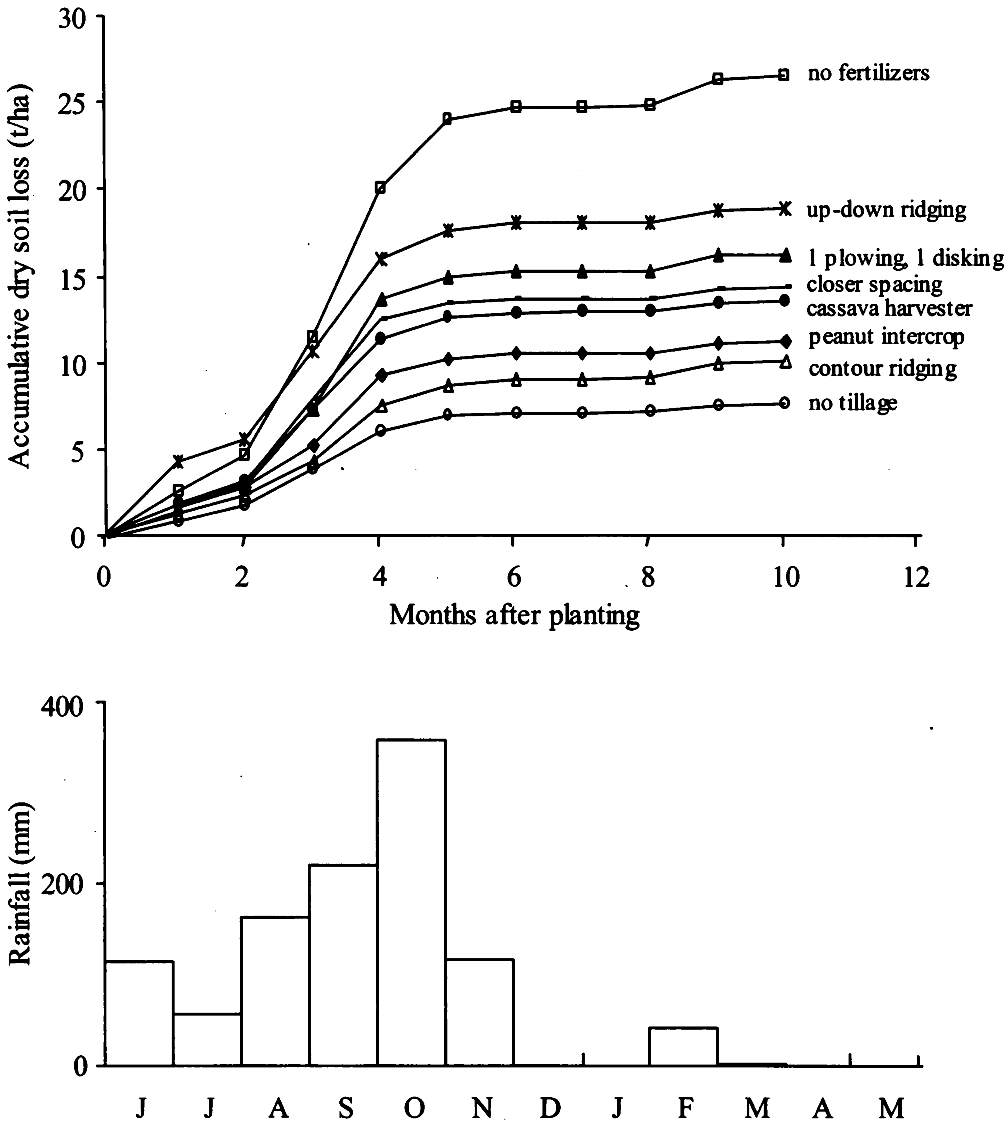

Figure 4. Effect of various crop and soil management practices on soill loss due to erosion during a 10 month cropping cycle of cassava on 4 % slope in Pluak Daeng, Rayong Thailand in 1990/01. Rainfall distribution is shown below. ***Source:*** *Anuchit Tongglum, FCRC, Rayong; Howeler, 1995.*

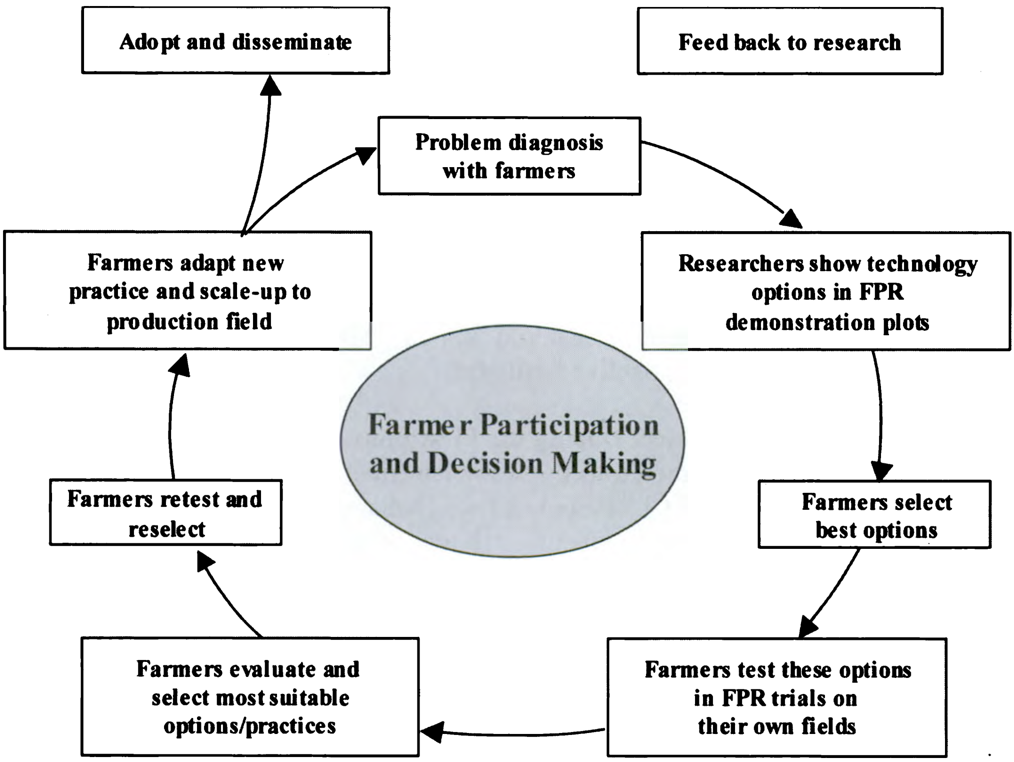

Figure 5. Farmer participatory model used for the development of sustainable cassava-based cropping systems in Asia.

1. Select suitable areas for new pilot sites.
2. Discuss the project and the FPR approach with local officials (often at the provincial, district and subdistrict levels) and village leaders.
3. Conduct Rapid Rural Appraisals (RRAs) to obtain information, and to select the most suitable sites.
4. Discuss details of the project with farmers in the selected sites and help them diagnose their own problems.
5. Take interested farmers from the pilot sites to see and evaluate demonstration plots and/or on a cross-site visit to a village that had already participated in the project and adopted some technologies.
6. Discuss with interested farmers the technology components as well as the specific treatments they want to test.
7. Help farmers set out the trails and establish the various treatments.
8. Farmers maintain their own trails while project personnel visit regularly to solve problems, give encouragement and take measurements.
9. At time of harvest, organize a field day for participating and non-participating farmers and extension workers. Usually, participating farmers and project personnel have

already harvested together the central part of each plot, leaving the harvested roots with a sign indicating the calculated yield in each plot. During the field day, farmers visit all trials and evaluate every treatment. Later in the day, the average results of each type of trial are presented and discussed, after which farmers indicate their preference for a particular treatment by raising hands.

10. The preferred treatments may be retested in FPR trials the following year or tried out in small areas of their production fields.
11. After making some adaptations, if necessary, the selected variety or practice can be scaled up to larger areas and the new technologies can be disseminated to others during field days, cross-visits or informal talks with neighbors.
12. Once a new variety or improved practice has been identified, local officials can help to obtain the necessary planting material of new varieties or hedgerow species or help farmers obtain the most effective fertilizers.

Implementation of the Project During the First Phase (1994-1998)

The first phase of the project was implemented in collaboration with research and extension organizations in China, Indonesia, Thailand and Vietnam (**Table 4**). Some institutions were involved in conducting research in order to develop new technological options or to solve specific problems identified by farmers; others were mostly involved in the setting out of demonstration plots and in the testing with farmers of selected treatments in FPR trials.

Details of the actual implementation of the project in each country have been reported by Zhang Weite *et al*, (1998), Huang Jie *et al.* (2001), Utomo *et al.* (1998; 2001), Vongkasem *et al.* (1998; 2001) and by Nguyen The Dang *et al.* (1998; 2001). **Table 5** shows the types and number of FPR trials conducted during the first phase of the project. A total of 495 trials were conducted in the four countries over a 4-year period, mostly testing new varieties and erosion control practices, but also rates of fertilization, and in Vietnam intercropping. **Table 6** shows a typical example of an FPR erosion control trial conducted by farmers in Tien Phong and Dac Son villages in Vietnam in 1997. Farmers showed a clear preference for contour hedgerows of *Tephrosia candida* or vetiver grass due to their effectiveness in reducing erosion while also increasing cassava yields and net income.

During the first phase of the project, FPR trials were conducted in 2-3 pilot sites in each country in order to try out the farmer participatory methodologies being used. Once the methodology was more or less developed and people felt comfortable with this new approach, one-week training courses were held in each country in 1997 and 1998. **Table 7** shows that a total of 127 researchers and extension workers were trained in farmer participatory methodologies, while 155 farmers participated in the conducting of FPR trials. Towards the end of the first phase of the project, some farmers in pilot sites started to adopt some of the new technologies tested in the FPR trials, including new varieties, better fertilization practices, soil conservation measures and intercropping, as indicated in **Table 8**. The table clearly shows that farmers in different countries adopted different practices depending on the particular local conditions and farmers' traditional practices.

Table 4. Institutions collaborating with CIAT in the first phase of the Nippon Foundation cassava project in Asia.

Country - Province		Institution	Research	FPR
China	- Hainan	Chinese Acad. for Tropical Agric. Sciences (CATAS)	✓	✓
	- Guangxi	Guangxi Subtropical Crops Research Institute (GSCRI)	✓	
Indonesia	- E. Java	Brawijaya University in Malang (UNIBRAW)	✓	✓
	- E. Java	Research Inst. for Legumes and Tuber Crops (RILET)		✓
	- W. Java	Central Research Inst. for Food Crops (CRIFC)	✓	
Thailand	- Rayong	Field Crops Research Institute (FCRI) of Dept. Agriculture	✓	✓
	- Bangkok	Field Crops Promotion Div. of the Dept. Agric. Extension (DOAE)		✓
	- Bangkok	Kasetsart University (KU)	✓	
Vietnam	- Thai Nguyen	Thai Nguyen Univ. of Agric. and Forestry (TGUAF)	✓	✓
	- Hanoi	National Institute for Soils and Fertilizers (NISF)		✓
	- Ho Chi Minh	Institute of Agric. Science (IAS) in south Vietnam	✓	

Table 5. Number of FPR trials conducted in the 1st phase of the Nippon Foundation cassava project in Asia.

Country	Type of FPR trial	1995	1996	1997	1998	Total
China	Varieties	15	5	4	7	**31**
	Erosion Control	12	5	4	4	**25**
	Fertilization	10	4	4	-	**18**
		37	14	12	11	**74**
Indonesia	Varieties	6	-	1	10	**24**
	Erosion Control	19	9	13	10	**57**
	Fertilization	1	-	-	10	**20**
		26	9	14	30	**101**
Thailand	Varieties	12	9	9	7	**37**
	Erosion Control	15	15	3	15	**48**
	Fertilization	5	8	-	9	**22**
		32	32	12	31	**107**
Vietnam	Varieties	7	17	25	22	**71**
	Erosion Control	16	15	15	15	**61**
	Fertilization	5	13	13	15	**46**
	Intercropping	8	11	8	8	**35**
		36	56	61	60	**213**
Total		**131**	**111**	**99**	**103**	**495**

Table 6. Average results of five FPR erosion control trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1997.

Treatments[1)]	Dry soil loss[1)] (t/ha)	Yield (t/ha) cassava	peanut[2)]	Gross income[3)]	Production costs[4)]	Net income	Farmers' prefer. (%)
				(mil. dong/ha)			
1. Farmer's practice	7.73	11.77	-	5.89	4.05	1.84	0
2. C+P, contour ridges	5.39	17.47	0.36	10.54	5.64	4.90	0
3. C+P, contour ridges, vetiver hedgerows	3.94	19.05	0.37	11.38	5.92	5.46	67
4. C+P, contour ridges, *Tephrosia* hedgerows	3.02	19.00	0.39	11.45	5.92	5.53	83
5. C+P, contour ridges, *Tephrosia*+vetiver hedgerows	2.73	17.92	0.41	11.01	5.92	5.09	3

[1)] Farmer's practice: cassava monoculture, 11.4 t/ha of FYM+68 kg N+20 P_2O_5+50 K_2O/ha; all other plots received 10 t/ha of FYM+80 kg N + 40 P_2O_5 + 80 K_2O/ha

[2)] dry pods

[3)] Prices:	cassava: dong	600/kg fresh roots
	peanut:	5,000/kg dry pods
[4)] Costs	FYM: dong	100/kg
	urea (45%N):	2,500/kg
	SSP (17% P_2O_5):	1,000/kg
	KCl (60%K_2O):	2,500/kg
	peanut seed:	6,000/kg; use 50 kg/ha
	labor:	7,500/manday
	1 US $ = 11.000 dong	

***Soure:** Nguyen The Dang et al., 2001.*

Table 7. Number of researchers/extension staff who participated in FPR training courses and number of farmers who participated in FPR trials from 1994 to 1998.

Country	Researchers and extension staff	Farmers
China	28	40
Indonesia	32	27
Philippines	2	-
Thailand	35	32
Vietnam	30	56
Total	**127**	**155**

Second Phase (1999-2003)

In 1998 the Nippon Foundation agreed to fund a second phase of the project in order to use the developed methodology to scale up to many more sites and to achieve more wide-spread adoption of soil conservation measures and other improved technologies that would benefit the cassava farmers and conserve the soil resources. The second phase of the project was entitled "Integrated Cassava-based Cropping Systems in Asia: Farming Practices to Enhance Sustainability". While the general objectives in the second phase were similar to those of the first phase, the emphasis changed from developing and implementing an FPR methodology to using that methodology in many more sites, while simultaneously developing a methodology for farmer participatory extension (FPE), so that the farmer-selected practices could be rapidly extended to more farmers in order to achieve more adoption and impact. The target during the second phase was to reach and benefit at least 8000 farmers.

Table 8. Technological components selected and adopted by participating farmers from their FPR trials conducted from 1994 to 1998 in four countries in Asia.

Technology component	China	Indonesia	Thailand	Vietnam
Varieties	SC8013***[1)] SC8634* ZM9247* OMR35-70-7*	Faroka*** 15/10* OMM90-6-72*	Kasetsart 50*** Rayong 5*** Rayong 90**	KM60*** KM94* KM95-3*** SM1717-12*
Fertilizer practices	15-5-20+Zn+ chicken manure 300kg/ha*	FYM 10 t/ha(TP)+ 90 N+36 P_2O_5+ 100 K_2O**	15-15-15 156 kg/ha***	FYM 10 t/ha (TP)+ 80 N+40 P_2O_5+ 80 K_2O**
Intercropping	monoculture(TP) C+peanut*	C+maize(TP)	monoculture(TP) C+pumpkin* C+mungbean*	monoculture(TP) C+taro(TP) C+peanut***
Soil conservation	sugarcane barrier* vetiver barrier*	*Gliricidia* barrier** *Leucaena* barrier* contour ridging**	vetiver barrier*** sugarcane barrier*	*Tephrosia* barrier*** vetiver barrier* pineapple barrier*

[1)] * = some adoption; ** = considerable adoption; *** = widespread adoption;
TP = traditional practice ; FYM = farm yard manure.

In order to concentrate the effort, the second phase is being implemented mainly in Thailand and Vietnam, with a smaller emphasis on China due to the limited number of cassava researchers in that country. As more people had already been trained in FPR methodologies in 1997 and 1998, more institutions wanted to join the project. Thus, the second phase of the project is being implemented by three research institutions in China, five research and extension institutions in Thailand, and six research institutes and universities in Vietnam (**Table 9**). **Figure 6** shows that in 2001 the project was being implemented in about nine sites in southern China, in 20 sites in eastern and central Thailand and in 21 sites in north, central and south Vietnam. Details of the implementation of the project in those countries are reported by Watananonta *et al.* (2007), Vongkasem *et al.* (2007), Nguyen The Dang (2007), Nguyen Thi Cach *et al.* (2007), Tran Thi Dung and Nguyen Thi Sam (2007), Tran Ngoc Ngoan and Howeler (2007), Li Kaimian *et al.* (2007) and Tian Yinong (2007).

Table 9. Institutions collaborating with CIAT in the second phase of the Nippon Foundation cassava project in Asia.

Country	- Province	Institution	Research	FPR	FPE
China	- Hainan	Chinese Academy for Tropical Agric. Sciences (CATAS)	✓	✓	✓
	- Guangxi	Guangxi Subtropical Crops Research Institute (GSCRI)		✓	✓
	- Yunnan	Animal Husbandry and Veterinary Station of Yunnan (AHVSY)		✓	✓
Thailand	- Rayong	Field Crops Research Institute (FCRI) of the Dept. of Agriculture (DOA)	✓	✓	✓
	- Bangkok	Field Crops Promotion Div. of the Dept. of Agric. Extension (DOAE)		✓	✓
	- Bangkok	Kasetsart University (KU)	✓		
	- Bangkok	Soil and Water Conservation Div. of the Land Development Dept. (LDD)		✓	✓
	-Korat	Thai Tapioca Development Institute (TTDI)		✓	✓
Vietnam	- Thai Nguyen	Thai Nguyen Univ. of Agric. and Forestry (TGUAF)	✓	✓	✓
	- Hanoi	National Institute for Soils and Fertilizers (NISF)		✓	✓
	- Hanoi	Root Crops Research Center of Vietnam Agric. Science Inst. (VASI)		✓	✓
	- Hue	Hue University of Agric. and Forestry (HUAF)	✓	✓	✓
	- Ho Chi Minh	Institute of Agric. Science (IAS) in south Vietnam	✓	✓	✓
	- Ho Chi Minh	Agric. and Forestry Univ. in Tu Duc		✓	✓

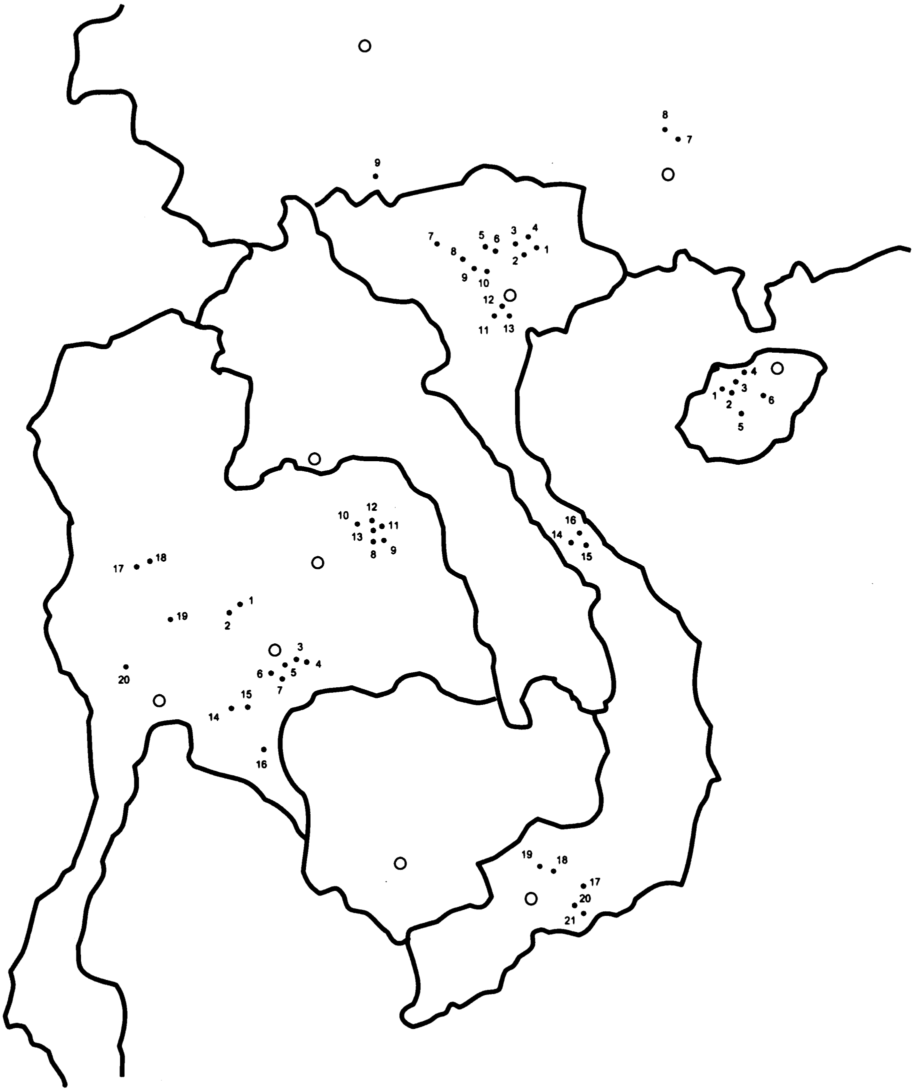

Figure 6. Location of FPR pilot sites in Thailand, Vietnam and China in 2001.

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FARMER PARTICIPATORY RESEARCH ACTIVITIES IN THE NIPPON FOUNDATION CASSAVA PROJECT IN THAILAND

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ABSTRACT

Complete canopy closure in a cassava crop takes a rather long time, especially when farmers do not apply fertilizers. This may lead to serious soil erosion when the crop is grown on slopes and result in a decline in soil fertility. Although nutrient extraction and removal by cassava tends to be less compared with many other crops, soil losses due to erosion may be higher because of the wide plant spacing used and the crop's slow initial development. Past research has shown that fertilizer application, reduced tillage, contour ridging, mulching, intercropping and the planting of contour hedgerows can greatly reduce erosion. Nevertheless, farmers seldom adopt soil conservation practices, mainly because the recommended practices are not suitable for the local conditions, they may be too costly or require too much labor, or they may be ineffective. Moreover, farmers are often not aware of the amount of soil, water and nutrients lost by erosion.

The farmer participatory research (FPR) methodology used in this project, conducted in more than 20 pilot sites in Thailand, indicate that farmers are very capable of making their own decisions, and they are willing to adopt new technologies, such as new cassava varieties, improved fertilization, use of animal or green manure, and herbicides, especially when the use of these practices lead to a higher net income. The FPR trials also showed farmers that the planting of contour hedgerows of vetiver grass, or other grasses or legumes, was very effective in reducing erosion. The use of a farmer participatory approach was very effective in developing more suitable varieties and production practices, which farmers could readily adopt and then disseminate to other farmers in neighboring communities.

The project showed that when farmers are directly involved in the development of new technologies, by planning and implementing their own trials on their own fields, this will greatly enhance the adoption and dissemination of improved technologies, which is likely to improve the farmers' living standards. This is of fundamental importance.

INTRODUCTION

In 2000, cassava (*Manihot esculenta* Crantz) was grown in Thailand in about 1.13 million hectares, the national average yield was about 16.25 t/ha, and total production was 18.75 million tonnes of fresh roots. These roots are being used for the production of about 4.66 million tonnes of dry cassava chips, pellets and starch, mainly for export, with a values of US$ 693.52 million.

Most cassava is grown by smallholders on upland areas with poor soil and low or unpredictable rainfall. In the Northeastern and the Eastern regions, cassava is grown on gentle slopes but soil erosion can be very serious. Most poor farmers do not apply fertilizers to cassava and this may lead to a decline in soil fertility, which in turn causes low yield. Past research by Kasetsart University has shown that cassava cultivation may cause twice

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as much soil erosion as the cultivation of mungbean, and three times as much as that caused by maize, sorghum and peanut (Putthacharoen, 1993; Putthacharoen *et al.*,1998).

Research on erosion control practices have shown that soil losses due to erosion can be markedly reduced by simple agronomic practices combined with soil conservation practices. This includes agronomic practices such as minimum or zero tillage, mulching, contour ridging, intercropping, fertilizer and/or manure application, and planting at higher density; and soil conservation practices such as terracing, hillside ditches and planting contour hedgerows of grasses or legumes. But these practices are seldom adopted by farmers because they may not have been appropriate for the specific circumstances of the farmers, either from an agronomic or socio-economic standpoint (Howeler, 2001).

Since 1994, the Centro Internacional de Agricutura Tropical (CIAT), the Department of Agriculture (DOA), the Department of Agricultural Extension (DOAE), the Land Development Department (LDD), Kasetsart University (KU) and the Thai Tapioca Development Institute (TTDI) have collaborated in the Nippon Foundation supported project entitled "Integrated Cassava-based Cropping Systems in Asia: Farming Practices to Enhance Sustainability". This project uses a farmer participatory research and extension approach. The farmers involved in the project were encouraged to develop technologies by themselves by conducting farmer participatory research (FPR) trials on their own fields. This enabled them to develop the most effective practices for their own conditions and disseminate these selected practices to farmers in neighboring communities.

MATERIAL AND METHODS

Project Sites

Phase 1: 1994-1998 (5 years):

To implement the project, cassava growing areas were selected that had at least 5% slope and where the farmers and local extension personnel were enthusiastic and willing to collaborate. Rapid Rural Appraisals (RRA) were conducted in each area to obtain baseline information and to select the most suitable pilot sites (Howeler, 2001; Vongkasem *et al.*, 1998). The project initially worked in only two sites (villages), one in Soeng Saang district of Nakhon Ratchasima province, and one in Wang Nam Yen district in Sra Kaew province. In 1998 this was extended to another two sites, one in Sahatsakhan district of Kalasin province and one in Sanaam Chaikhet district of Chachoengsao province.

Phase 2: 1999-2003 (5 years):

During the 2nd phase the project expanded rapidly to include over 20 sites in the following six provinces:

1. Nakhon Ratchasima province in the lower Northeast region
2. Kalasin province in the upper Northeast region
3. Prachinburi province in the Eastern region
4. Chachoengsao province in the Eastern region
5. Chaiyaphuum province in the lower Northeast region
6. Kanchanaburi province in the Western region

Collaborating Organizations:

During the 2nd phase the following institutions collaborated in the project:

1. Field Crops Research Institute of DOA
2. Rice and Field Crops Promotion Division of DOAE
3. Soil and Water Conservation Division of LDD
4. Kasetsart University (KU)
5. Thai Tapioca Development Institute (TTDI)
6. The Centro Internacional de Agricultura Tropical (CIAT)

Activities

1. Selection of project areas

The criteria of selection were the same as in Phase 1. Each year the project expanded to 1-2 new provinces by selecting appropriate pilot sites in one or more districts.

2. Training

Field staff of new sites were trained in cassava production practices and FPR and RRA methodologies.

3. Farmers meetings

Farmers from the new sites that were interested in participating in the project participated in a one-day training course with the objective of: 1. increasing the farmers' knowledge and understanding of soil conservation in cassava growing areas; 2. to discuss with farmers how to conduct, with help of researchers and extensionists, FPR trials on their own fields. These farmers then visited demonstration plots with various management practices to reduce soil erosion. Farmers were asked to score the various soil erosion control treatments, considering their likely effect on soil loss by erosion, cassava yield and net income. Farmers then selected the most suitable 4-5 soil erosion control treatments to try in FPR trials on their own fields.

4. Demonstration plots

Each year demonstration plots were established by DOA, KU, or TTDI at their research stations. These demonstrations had a large (18-24) number of treatments, including the application of chemical fertilizers or manures, green manures, closer plant spacing, intercropping with different crops and contour hedgerows of different grasses or legumes. These treatments tended to reduce soil erosion and gave farmers some ideas about alternative ways of solving erosion problems. The demonstration plots were laid out along the contour of a uniform slope; ditches were dug along the lower ends of each plot and covered with plastic to catch the soil sediments eroded from each plot. Farmers from new sites visited these demonstration plots, scored the treatments and selected those they would like to try out in FPR erosion control trials on their own fields.

5. FPR trials

After farmers decided to conduct FPR trials, researchers and extensionists helped them to decide on the best treatments, provided the necessary materials and helped them to set out the trials. During the crop season, researchers and extensionists visited the trials 1-2 times to discuss with the farmers and solve any problems.

At time of harvest, collaborating farmers and project staff harvested all the trials in the pilot site, recorded all data and calculated average results of each type of trial. Data on soil loss from every treatment was also presented to the participating farmers and others interested. The meeting then discussed the results of each trial and selected again the best treatments for next year's trials (Howeler, 2001; Watana *et al.*, 2002).

6. Scaling-up and adoption

After two years of conducting FPR trials, farmers had usually selected the most suitable treatments to try out in larger size plots (approximately 1,500-3,000 m^2) on their fields. 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.

RESULTS AND DISCUSSION

Farmer Participatory Research in the Second Phase

1. Demonstration plots

Demonstration plots were laid out at TTDI's Research and Development Center to show the effect of many alternative treatments on soil losses due to erosion, on cassava and intercrop yields and on net income. Farmers from new sites were asked to discuss and score the effectiveness of each treatment. The results indicate that farmers from different sites have different preferences, depending on the local bio-physical and socio-economic conditions, as well as on their traditional practices. Farmers usually selected 3-4 treatments that they would like to test in FPR trials on their own fields in comparison with their traditional practices.

2. FPR trials

2.1 Chayaphuum province

During the first year, 24 farmers in Khook Anu village in Naayaang Klak subdistrict of Thep Satith district were conducting FPR trials on various topics, such as soil erosion control, varieties, application of chemical fertilizers and chicken manure, planting of green manures and weed control. **Tables 1** to **6** show the average results of these trials. **Table 1** shows that farmers selected Kasetsart 50 and Rayong 5 in spite of their lower yields in the trial, because the starch and chip factories who buy the roots pay a lower price for Rayong 72, because of a generally lower starch content. Among soil erosion control practices, farmers selected vetiver grass hedgerows and contour plowing as the most suitable (**Table 2**). Especially vetiver grass hedgerows are now widely adopted in their village. **Table 3** shows that farmers preferred the use of jack bean (*Canavalia ensiformis*) as a green manure, to be plowed in the soil at 45 days after planting, after which cassava is planted immediately. Results of four FPR fertilizer trials indicate that cassava yields increased markedly with application of chemical fertilizers and chicken manure (**Table 4**) or urea (**Table 5**). Farmers preferred to apply chemical fertilizers at a rate of 156 kg/ha of 15-15-15 as this gave a rather high yield at a low cost. Application of Glyphosate following hand weeding was considered the best treatment to control weeds (**Table 6**).

2.2 Kanchanaburi province

In Nong Kae village of Thung Krabam subdistrict in Law Khwan district, 42 farmers conducted FPR trials. They conducted the same type of trials as those in Chaiyaphuum province. As a result of these FPR trials, farmers adopted vetiver grass hedgerows to control erosion (**Table 7**) and started to scale-up this year. Application of 12.5 t/ha of chicken manure resulted in the highest yield of 36.1 t/ha and a net income of \$366.11 (**Table 8**). Farmers ranked the tested varieties in the order of Rayong 72, Kasetsart 50 and Rayong 5 (**Table 9**). This village has a similar climate as the Northeastern region, which is quite suitable for planting Rayong 72.

Table 1. Results of two FPR variety trials conducted by farmers in Khook Anu village, Naayang Klak subdistrict, Thep Sathit district of Chayaphuum province in 2001/02.

Varieties	Cassava yield (t/ha)			Starch content (%)			Farmers' preference ranking
	A[1)]	B[1)]	Av.	A	B	Av.	
Kasetsart 50	19.65	13.62	16.63	<10	18	<14.0	3
Rayong 72	17.50	31.31	24.40	18	28	23.0	1 [2)]
Rayong 5	20.03	22.82	21.42	17	19	18.0	2

[1)] A = Mr. Lun; B = Mr. Chanthong

[2)] Although Rayong 72 had clearly the highest yield and starch content in these trials, farmers will continue to grow Kasetsart 50 and Rayong 5, because owners of chipping yards give a price discount for Rayong 72, claiming a low starch content.

Table 2. Average results of two FPR erosion control trials conducted by farmers in Khook Anu village, Naayang Klak subdistrict, Thep Sathit district of Chayaphuum province, in 2001/02.

Treatments	Dry soil loss (t/ha)	Yield (t/ha)		Starch content (%)	Gross income	Production costs	Net income	Farmers' preference (%)
		Cassava	Intercrop		(US$/ha)			
1. Farmers' practice	13.99	12.61	-	20.3	300.2	272.3	27.9	0
2. Contour plowing	10.16	8.41	-	20.0	200.2	272.3	-72.1	100
3. Up/down plowing	31.10	12.34	-	18.3	293.8	272.3	21.5	0
4. Mungbean intercrop	10.30	8.70	0.306	24.0	352.8	316.9	35.9	82
5. Vetiver grass hedgerows	8.03	13.02	-	22.3	310.0	287.1	22.9	100
6. Lemon grass hedgerows	4.53	15.94	-	21.0	379.5	287.1	92.4	0[2]

[1)] Prices: cassava US$ 23.81/tonne fresh roots
mungbean 0.47/kg dry grain
1US$ = 42 baht

[2)] Although lemon grass hedgerows produced the highest net income and lowest soil loss, farmers do not like this grass as it can not tolerate drought, it is difficult to find enough planting material and it is difficult to sell in large quantities.

Table 3. Average results of six FPR green manure trials conducted by farmers in Khook Anu village, Naayang Klak subdistrict, Thep Sathit district of Chayaphuum province in 2001/02.

Green manures[1)]	Cassava yield (t/ha)	Starch content (%)	Gross income[2)]	Production costs	Net income	Farmers' preference (%)
			(US $/ha)			
1. No green manure	26.14	26.3	703.3	272.3	431.0	0
2. *Crotalaria juncea*	29.87	29.4	839.2	328.0	511.2	0
3. mungbean	29.60	27.9	817.6	331.9	485.7	0
4. *Canavalia ensiformis*	30.24	30.0	864.0	302.1	561.9	100

[1)] no fertilizers were applied; green manures were planted at the same time as cassava and were weeded out by hoe at 2 MAP; farmers suggest to plant green manures either before cassava and incorporate before cassava planting, or plant GM as an intercrop at 1-1½ MAP and weed out at 2 MAP the green manure.

[2)] Prices: cassava US$ 28.57/tonne fresh roots at 30% starch

Table 4. Average results of four FPR fertilizer trials conducted by farmers in Khook Anu village, Naayang Klak subdistrict, Thep Sathit district of Chayaphuum province in 2001/02.

Fertilizer treatments	Cassava yield (t/ha)	Gross income[1)]	Production costs	Net income	Farmers' preference (%)
		———	(US$/ha)	———	
1. No fertilizers or manures	20.48	585.2	272.3	312.9	0
2. 156 kg/ha of 15-15-15	27.08	773.8	302.1	471.7	52
3. 312 kg/ha of 15-15-15	29.44	841.1	331.9	509.2	19
4. 1.56 t/ha of chicken manure (CM)	28.12	803.3	302.8	500.5	19[2)]
5. 1.56 t/ha CM+156 kg/ha 15-15-15	28.32	809.0	332.6	476.4	10[2)]

[1)] Prices: cassava US $ 28.57/tonne fresh roots at 30% starch
chicken manure 0.019/kg
15-15-15 fertilizers 0.190/kg

[2)] Chicken manure is difficult to find in the area

Table 5. Average results of five FPR fertilizer trials conducted by farmers in Khook Anu village, Naayang Klak subdistrict, Thep Sathit district of Chayaphum province in 2001/02.

Fertilizer treatments	Cassava yield (t/ha)	Starch content (%)	Gross Income[1)]	Production costs	Net income	Farmers' preference (%)
			———	(US $/ha)	———	
1. No fertilizers or manures	21.4	25.4	563.5	272.3	205.7	
2. 156 kg/ha of 15-15-15	27.0	28.8	686.4	302.0	384.4	
3. 312 kg/ha of 15-15-15	29.4	25.9	701.6	331.8	369.8	
4. 156 kg/ha of 15-15-15+ 156 kg/ha of urea	33.0	29.0	786.6	328.1	458.5	
5. 312 kg/ha of 15-15-15+ 156 kg/ha of urea	24.9	27.2	657.3	357.8	299.5	

[1)] Prices: cassava US$ 23.84/tonne fresh roots at 30% starch
15-15-15 fertilizer 0.19/kg
urea 0.16/kg
1US $ = 42 baht

Table 6. Average results of four FPR weed control trials conducted by farmers in Khook Anu village, Naayang Klak subdistrict, Thep Sathit district of Chayaphuum province in 2001/02.

Weed control treatments	Cassava yield (t/ha)	Starch content (%)	Gross income[1)]	Production costs	Net income	Farmers' preference (%)
			———	(US $/ha)	———	
1. Hand weeding (HW)	24.65	29.2	691.6	272.3	419.3	
2. HW+Glyphosate 1.5 cc/liter	29.95	28.2	827.1	290.2	536.9	
3. HW+Glyphosate 3.0 cc/liter	29.35	28.7	817.6	308.0	509.6	

[1)] Prices: cassava US$ 28.46/tonne at 30% starch with US$ 0.50 reduction for every 1% reduction in starch content.

Table 7. Average results of two FPR erosion control trials conducted by farmers in Nong Kae village, Thung Krabam subdistrict Law Khwan district, Kanchanaburi province of Thailand in 2001/02.

Treatments	Dry soil loss (t/ha)	Cassava yield (t/ha)	Starch content (%)	Gross[1)] Income	Production costs (US $/ha)	Net income
Up/down ridging	1.13	14.9	19.9	298.8	372.0	-146.4
Contour ridging	0.38	20.0	20.0	475.5	378.5	97.0
Vetiver grass hedgerows	1.10	19.2	21.2	455.9	373.0	82.9
Sugarcane hedgerows	3.71	24.2	20.2	583.0	417.3	165.7
Sweet corn intercropping	3.30	22.2	19.3	587.1	451.1	136.0

[1)] Prices: cassava US $ 23.84/tonne
sweet corn 0.02/cob
sugarcane 0.04/stem
harvesting 2.85/t
transportation 2.85/t
1US $ = 42 baht

Table 8. Average results of three FPR fertilizer and chicken manure trials conducted by farmers in Nong Kae village, Thung Krabam subdistrict of Law Khwan district, Kanchanaburi province of Thailand in 2001/02.

Fertilizer treatments	Cassava yield (t/ha)	Starch content (%)	Gross income[1)]	Production costs (US $/ha)	Net income	Farmers' preference (%)
1. No fertilizer	20.9	20.8	498.2	384.2	114.0	
2. 156.2 kg/ha of 13-13-21	18.6	20.0	442.8	403.2	39.6	
3. 312.4 kg/ha of 13-13-21	24.3	20.0	577.9	466.1	143.4	
4. 312.0 kg/ha of 15-15-15	21.4	22.0	509.5	449.6	59.9	
5. 3.12 t/ha of chicken manure	18.4	16.7	438.0	377.6	60.4	
6. 6.24 t/ha of chicken manure	23.1	21.5	550.0	405.8	144.2	
7. 9.36 t/ha of chicken manure	22.9	17.0	546.4	412.2	134.2	
8. 12.48 t/ha of chicken manure	36.1	23.0	860.7	494.6	366.1	
9. Apply fertilizer according to soil analysis	29.8	24.6	709.5	497.4	212.1	

[1)] Prices: cassava US $ 23.84/tonne fresh roots
13-13-21 fertilizer 0.20/kg
chicken manure 0.03/kg

Table 9. Results of a FPR variety trial conducted by a farmer in Nong Kae village, Thung Krabam subdistrict of Law Khwan district, Kanchanaburi province of Thailand in 2001/02.

Varieties	Cassava yield (t/ha)	Starch content (%)	Gross income	Production costs[1)] (US $/ha)	Net income	Farmers' ranking
Kasetsart 50	25.4	21.7	604.7	409.9	194.8	2
Rayong 5	29.6	14.0	705.3	433.8	271.5	3
Rayong 72	30.2	17.0	720.2	437.2	283.0	1

[1)] Price: cassava US$ 23.81/tonne fresh roots at 30% starch.

2.3 Nakhon Ratchasima province

During the 2nd phase of the project, 53 farmers in Khut Dook village, Baan Kaw subdistrict of Daan Khun Thot district, conducted FPR trials. The trials were similar to those conducted by farmers in Kanchanaburi province. After conducting trials for two years farmers adopted Rayong 90 which gave the highest root yield and net income **(Table 10)**; this is different from Chayaphuum and Kanchanaburi provinces. Farmers selected the use of 312.4 kg/ha of 16-16-8 fertilizers because it gave the highest fresh root yield; this was followed by pelleted chicken manure **(Table 11)**. With respect to weed control, application of Glyphosate resulted in higher yields and net income than the hand weeding control **(Table 12)**.

Table 10. Results of a FPR variety trial conducted by farmers in Kut Dook village, Baan Kaw subdistrict of Daan Khun Thot district, Nakhon Ratchasima province of Thailand in 2001/02.

Varieties	Cassava yield (t/ha)	Starch content (%)	Gross income[1]	Production costs[2]	Net income
			(US $/ha)		
Kasetsart 50	29.6	26.5	705.6	433.8	271.8
Rayong 5	28.3	26.5	674.2	426.4	247.8
Rayong 90	32.7	26.0	779.0	451.5	327.5
Rayong 72	28.4	23.2	676.6	427.0	249.6

[1] Prices: cassava US $ 23.84/tonne fresh roots
[2] Production costs are based on data from the office of Agricultural Economic in 2000.

Table 11. Results of a FPR fertilizer trial conducted by farmers in Kut Dook village, Baan Kaw subdistrict of Daan Khun Thot district, Nakhon Ratchasima province of Thailand in 2001/02.

Fertilizer treatments	Cassava yield (t/ha)	Starch content (%)	Gross income[1]	Production costs	Net income
			(US$/ha)		
1. No fertilizers	15.3	19.0	363.3	319.0	44.3
2. 312.5 kg/ha of 16-20-0	26.3	22.6	627.0	408.9	218.1
3. 312.5 kg/ha of 15-15-15	20.0	21.0	476.1	385.0	91.1
4. 312.5 kg/ha of 16-16-8	30.8	22.9	733.3	437.4	295.9
5. 312.5 kg/ha of 15-7-18	23.3	23.0	553.8	411.3	142.5
6. 6.25 t/ha of rice husks	20.6	18.6	490.4	376.4	114.0
7. 6.25 t/ha of cattle manure	23.8	19.0	566.6	496.5	70.1
8. 2.5 t/ha of duck manure + rice hulls	24.4	20.8	580.9	455.4	125.5
9. 2.5 t/ha of chicken manure + rice hulls	20.8	23.5	496.1	434.8	61.3
10. 625 kg/ha of pelleted chicken manure	26.6	22.2	633.3	405.4	227.9
11. 625 kg/ha of organic fertilizers	25.9	23.2	617.1	411.8	205.3

[1] Prices: cassava: US $ 23.81/tonne fresh roots
chicken manure: 0.03/kg

2.4 Prachinburi province

In Aang Thong and Khao Khaat villages in Kaeng Dinso subdistrict of Naadii district, 34 farmers conducted FPR trials. Based on the results of these FPR trials farmers preferred Rayong 72 as it was easy to take care of, followed by two breeding lines, as well as Kasetsart 50 and Rayong 5 (**Table 13**). From the FPR fertilizer trials, they preferred the use of 156 kg/ha of 15-7-18 over that of 15-15-15 as this produced the highest yield. However, no fertilizer application resulted in the highest net income (**Table 14**).

Table 12. Results of a FPR weed control trial conducted by a farmer in Kut Dook village, Baan Kaw subdistrict of Daan Khun Thot district, Nakhon Ratchasima province of Thailand in 2001/02.

Weeding treatments	Cassava yield (t/ha)	Starch content (%)	Gross income[1)]	Production costs	Net income
			——— (US $/ha) ———		
1. Hand weeding	27.4	19.2	653.2	421.3	231.9
2. Glyphosate herbicide	30.7	21.6	731.3	455.4	275.9

[1)] Prices: cassava: US $ 23.84 /tonne fresh roots.

Table 13. Average results of four FPR variety trials conducted by farmers in Kaeng Dinso subdistrict of Naadi district, Prachinburi province of Thailand in 2000/01.

Varieties	Cassava yield (t/ha)	Starch content (%)	Gross income[1)]	Production costs[2)]	Net income	Farmers' ranking
			——— (US $/ha) ———			
1. Rayong 1	7.44	17.5	124.0	180.8	-56.0	6
2. Rayong 5	10.65	22.3	201.8	193.0	8.8	5
3. Rayong 72	16.27	20.3	292.8	214.5	78.3	1
4. Kasetsart 50	12.91	20.7	234.8	201.7	33.1	4
5. CMR 36-55-166	14.06	23.4	273.8	206.0	67.8	2
6. CMR 37-18-89	14.19	22.8	272.3	206.5	65.8	3

[1)] Price: cassava: US $ 22.90/tonne fresh roots at 30% starch with US $ 0.50 reduction for every 1% reduction in starch content

[2)] Production costs: US$ 152.5/ha plus US$ 3.80/tonne for harvest and transport
1 US $ = 42 baht

Table 14. Average results of four FPR fertilizer trials conducted by farmers in Kaeng Dinso subdistrict of Naadi district, Prachinburi province of Thailand in 2000/01.

Fertilizer treatments	Cassava yield (t/ha)	Starch content (%)	Gross income[1)]	Fertilizer cost[1)]	Production costs[2)]	Net income	Farmers' ranking
			——— (US $/ha) ———				
1. No fertilizers	8.60	21.9	161.3	0	140.6	20.7	4
2. 156 kg/ha of 15-15-15	8.79	21.4	162.8	33.4	186.0	-20.7	3
3. 312 kg/ha of 15-15-15	7.10	22.7	135.9	66.9	213.0	-77.1	5
4. 156 kg/ha of 15-7-18	9.36	23.1	180.9	29.7	185.6	-4.7	1
5. 312 kg/ha of 15-7-18	9.21	22.6	175.8	59.5	213.6	-37.8	2

[1)] Prices: cassava US $ 22.80 /tonne fresh roots at 30% starch
15-15-15 0.214 /kg
15-7-18 0.191 /kg

[2)] Production costs: US$152.5/ha plus US$3.80/tonne for harvest and transport; 1US$ = 42 baht

Table 15 shows that in 2002 a total of 386 farmers participated in the project, conducting 72 FPR trials in nine pilot sites in six provinces.

Table 15. Number and area (in rai) of FPR trials conducted by farmers in various pilot sites of the Nippon Foundation project in Thailand in 2002.

					Types of FPR trials						
Province	District	Subdistrict	Village[1)]	No. of farmers	Varie-ties	Org. manures	Chem. fertil.	Chem.+org. manures	Herbi-cides	Green manures	Inter-crops
Nakhon Ratchasima	Daan Khun Thot	Baan Kaw	Khut Dook	53	1/3	1/2	1/2	-	-	-	1/2
	Thephaarak	Bueng Prue	Village 3 and 6	-	-	-	-	-	-	-	-
	Soeng Saang	Noon Sombuun	Sapphong Phoot	-	-	-	-	-	-	-	-
		Sra Takhian	Sra Takhian	-	-	-	-	-	-	-	-
	Khonburi	Tabaekbaan	Nong Phak Rai	27	1/2	1/2	1/2	-	-	-	1/5
Prachinburi	Naadii	Kaeng Dinso	Aang Thong Khaw Khaat	34	1/5	-	-	-	1/5	-	-
Kalasin	Mueang	Phuu Po	Noon Sawan	-	-	-	-	-	-	-	-
		Khamin	Khamplaafaa	-	-	-	-	-	-	-	-
	Nong Kungsri	Nong Bua	Khamsri	-	-	-	-	-	-	-	-
	Sahatsakhan	Noonburi	Noon Sawaat	-	-	-	-	-	-	-	-
		Noon Namkliang	Huay Suea Ten Paa Kluay	-	-	-	-	-	-	-	-
	Naamon	Naamon	Noon Thiang*	50	4/4	-	3/3	2/2	-	3/3	-
	Don Chaan	Dong Phayung	Noon Kokchik*	50	4/4	-	4/4	-	-	3/3	-
	Huay Phueng	Nikhom	Huay Faa*	50	4/4	-	4/4	-	-	3/3	-
Chachoengsao	Sanaam Chaikhet	Thung Phrayaa	Thaa Chiwit Mai	-	-	-	-	-	-	-	-
	Thaa Takiab	Khlong Takraw	Nong Yai	-	-	-	-	-	-	-	-
Kamphaengphet	Khanuwaralakburi	Bo Tham	Siiyaek-Ton Thoo	30	-	-	1/5	5/10	-	-	1/5
Chaiyaphuum	Thep Sathit	Naayaang Klak	Khook Anu	50	2/3	-	2/2	-	4/4	-	3/6
Kanchanaburi	Law Khwan	Thung Krabam	Nong Kae	42	2/2	2/2	2/2	-	-	2/2	2/2
Sra Kaew	Wang Sombuun	Wang Sombuun	Khlong Ruam	-	-	-	-	-	-	-	-
Total: 6	**9**	**9**	**9**	**386**	**19/27**	**4/6**	**18/19**	**7/12**	**5/9**	**11/11**	**8/20**

1) * = initiated in 2002

2) Total = 72 FPR trials; 1 ha = 6.25 rai

CONCLUSIONS

The farmer participatory research approach allows farmers to make their own decisions. They are enthusiastic to test and select the most suitable varieties and cultural practices. They not only selected vetiver grass hedgerows as the best way to control soil erosion but they also increased their cassava yields and net income by selecting the most suitable variety, such as Rayong 5, Rayong 90, Rayong 72 and Kasetsart 50. Besides those, they selected the most suitable cultural practices, such as the use of green manure, chicken manure, chemical fertilizers and weed control for their own conditions. The use of more sustainable cassava production practices is likely to improve the farmers' living standard in the near future

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FARMER PARTICIPATORY EXTENSION (FPE) METHODOLOGIES USED IN THE CASSAVA PROJECT IN THAILAND

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ABSTRACT

During the first phase (1994-1998) of the Nippon Foundation project on "Improving the Sustainability of Cassava-based Cropping Systems", two pilot sites were selected, namely Soeng Saang district, Nakhon Ratchasima province, and Wang Sombuun district, Sra Kaew province. FPR trials on methods to reduce soil erosion were conducted for three consecutive years. After narrowing down the number of suitable options, farmers in both sites finally selected and adopted the contour strip cropping of cassava with vetiver grass hedgerows. They also requested further support to extend the vetiver grass hedgerows on a larger scale to their cassava fields. In Soeng Saang district, farmers in Sappongphoot village got together to set up a Soil Conservation group. They agreed to plant vetiver grass hedgerows with a total length of 17 kilometers in the first year of 1998. Similarly, farmers in Wang Sombuun district planted vetiver grass hedgerows with a total length of about 10 kilometers. During the final year of the first phase, DOAE had extended the project to two other sites in Kalasin and Chachoengsao provinces.

In the second phase of the project (1999-2003), a total of 24 villages in 17 districts, in 8 provinces are participating in the project. To be able to scale out to so many new sites, the project used and developed several Farmer Participatory Extension (FPE) methodologies, such as cross-visits, farmer evaluation of demonstration plots, FPR trials, training courses and field days. In addition, DOAE helped farmers in 11 sites to set up "Cassava Development Villages", i.e. community-based self-help groups that help each other to develop better cassava production practices and protect the natural resources in the community. The final result is that farmers in all villages adopted vetiver grass hedgerows as the most suitable system to reduce erosion. At present, there are 865 farmers participating in the project and the total length of the vetiver grass hedgerows has grown to 130 kilometers, covering 940 ha of cassava fields. In addition, farmers also adopted new cassava varieties, such as Rayong 5, Rayong 72 and Kasetsart 50, and they are using more chemical fertilizers as well as animal manures. Recently, farmers have shown a new interest in trying out the use of green manures in their FPR trials; as a result of these trials they have now adopted the planting of *Canavalia ensiformis* as a green manure between cassava rows.

INTRODUCTION

Cassava can grow well even in low fertility soils and under relatively dry conditions. However, the rate of soil erosion in cassava fields is quite high, particularly in sloping fields with sandy soils and low organic matter content. This is due to the wide spacing of cassava planting and the slow growth rate for the first three months (Putthacharoen, 1992). The joint research of the Centro Internacional de Agricultura Tropical (CIAT), the Department of Agriculture (DOA), and Kasetsart University (KU) revealed that planting methods or planting system adjustment could reduce soil erosion (Howeler, 1987; 1994). Altogether, 24 methods (treatments) were included in the

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experiment; for instance, intercropping with some field crops, e.g. maize, groundnut, mungbean, pumpkin, water melon; the use of chemical fertilizer, manure or green manure to stimulate fast early growth; or contour strip cropping with some grasses, e.g. vetiver, ruzie grass, elephant grass and lemon grass. Each method has its own advantages and disadvantages. Some methods give extra income, but some need more management or high investment. The problem still exists on whether or not the farmers would adopt any of these methods. In 1993, CIAT, in cooperation with DOAE and DOA, established a Cassava-based Cropping System Management Project and started the farm trials using a Farmer Participatory Research (FPR) approach (Vongkasem, 1998). This methodology will enhance the farmers' awareness of soil erosion and its consequences. It also encouraged the farmers to decide which method of soil erosion prevention was most suitable and practical for their own communities. The farmers, however, did the trials by themselves under the supervision of DOAE and DOA staff. Eventually, the farmers were the ones who selected the soil conservation method that was most suitable and efficient for them.

During the first phase (1994-98), two pilot project sites were selected, namely, Soeng Saang district, Nakhon Ratchasima province, and Wang Sombuun district, Sra Kaew province. FPR trials on soil erosion control methods were conducted continuously for three years. Finally, farmers in both sites selected and adopted contour strip cropping with vetiver grass. They also requested further support to extend these vetiver hedgerows to their larger cassava fields. In Soeng Saang district, the farmers organized a group for Soil and Environmental Conservation. They agreed to plant 17 km of vetiver grass hedgerows in 1998. Similarly, farmers in Wang Sombuun district planted about 10 kilometers of vetiver grass hedgerows.

In the final year of Phase I, DOAE extended the project sites to Kalasin and Chachoengsao provinces. In Phase II (1999-present), 18 villages, in 14 districts in 8 provinces have participated in the Project. In order to extend the knowledge and understanding of soil and water conservation to more and more farmers and to achieve widespread adoption of soil erosion control practices, the project started to combine FPR trials with various Farmer Participatory Extension (FPE) activities.

FARMER PARTICIPATORY RESEARCH AND EXTENSION

Project Objectives

1. To show cassava growers the importance of soil conservation and the need to reduce soil erosion. The emphasis is placed on farmer participation in decision making and method selection.
2. To develop simple soil erosion control practices that are suitable for particular regions by conducting FPR erosion control trials with farmers.
3. To encourage and help farmers to adopt the selected practices in their cassava fields.
4. To scale-up the selected erosion control practices to more farmers and achieve widespread adoption.

Responsible Organizations

	Organization	Responsibility/Activity
1.	Centro Internacional de Agricultura Tropical (CIAT)	-Provide budget -Train staff and organize workshops -Monitoring and Evaluation
2.	Department of Agricultural Extension (DOAE)	-Facilitate project's activities in the villages -Organize farmers meetings (using farmer participatory method) and cooperate with concerning agencies in both central and regional offices. -Provide budget -Hold farmer training sessions -Monitoring and evaluation
3.	Department of Agriculture (DOA)	-Experiment to develop new options -Take part in field trials and demonstration trials -Take part in monitoring and evaluation -Take part in farmer training courses
4.	Land Development Department (LDD)	-Support knowledge on vetiver grass growing and the use of green manures -Provide vetiver tillers and green manure seeds -Set out contour lines in farmers fields for vetiver strips -Take part in monitoring and evaluation
5.	Thai Tapioca Development Institute (TTDI)	-Conduct demonstration trials -Take part in training courses -Provide training facilities -Take part in monitoring and evaluation

Farmer Participatory Research (FPR) and Extension (FPE) Methodologies

This process consists of the following steps:

1. Select pilot sites by conducting Rapid Rural Appraisals (RRAs)
2. Plant and manage demonstration plots
3. Hold farmers' meetings and organize cross-site visits
4. Conduct various types of FPR trials to increase cassava yields and/or income, such as varieties, fertilization, intercropping and erosion control
5. Training of staff
6. Extension of selected practices from farmer-to-farmer
7. Organize field days
8. Write articles in news papers; radio and TV programs
9. Print pamphlets, booklets etc.

1. Select pilot sites by conducting RRAs

The main criteria for selection of project sites are:

- Cassava is the main crop in the area and is grown on slopes with serious problems of soil erosion.

- Farmers and extensionists must be eager to work together to solve various problems.

After the pilot sites (villages) were selected, a Rapid Rural Appraisal (RRA) was conducted with the farmers to learn about the agro- and socio-economic conditions. The problems farmers encountered in cassava production were also studied.

2. Establish demonstration plots

Every year demonstration plots were laid out, usually at the TTDI Research and Training Center in Huai Bong, Nakhon Ratchasima. These demonstrations had many different treatments about ways to increase yields or reduce erosion. Farmers from new sites would visit these plots, observe the treatments and discuss and select the most suitable treatments for their own conditions. In many cases they selected vetiver grass contour hedgerows as the most suitable practice to control erosion.

3. Hold farmer's meeting and organize cross-site visits

Farmers' meetings were held in the selected villages to discuss the objectives, principles and procedures of the project. The beneficial effects of using green manures or chemical fertilizers were also discussed. The farmers then discussed and decided for themselves whether or not they wanted to participate in the project. In case farmers were not interested, the project would look for other sites.

Farmers who wanted to participate in the project were invited to join the study tour to observe the demonstration plots on soil erosion control methods. In addition, farmers from a new site would visit an "older" site. In these older sites farmers had already adopted vetiver grass hedgerows to control erosion. This was an opportunity to exchange experiences between the visitors and the hosts. The concepts of establishing a village credit fund and the administration of this fund were also discussed.

At the end of the study tour, farmers were asked whether they were interested in either conducting their own FPR trials on some selected treatments of soil erosion control, or to adopt any of the observed soil erosion control practices right away. In most cases, farmers preferred to adopt the planting of vetiver hedgerows, because they had already observed the efficiency of these hedgerows for soil erosion control under farming conditions similar to their own.

4 Conduct FPR trials on ways to increase productivity

In case farmers wanted to conduct their own FPR trails, they were provided with the necessary inputs, such as seeds of intercrops, seeds or tillers of hedgerow species, plastic sheets to cover the sediment collection ditches, and they were reimbursed for the cost of digging the sediment collection ditches. Officials from DOA and DOAE helped farmers lay out the field trials. Alternatively, if farmers wanted to adopt the planting of vetiver grass hedgerows, they would receive the necessary vetiver tillers and help from LDD in setting out contour lines.

Usually, DOAE staff would suggest farmers to conduct additional trials on new cassava varieties, chemical and organic fertilizers, and green manures. These trials provided farmers with information on how to increase cassava production efficiency and helped to attract their interest in participating in the project.

5. Training of staff

Training workshops were organized by CIAT to train the collaborating project staff of the three departments, namely DOA, DOAE, and LDD. Officials in both the central and regional offices were trained in the use of farmer participatory methodologies. Furthermore, CIAT provided additional training for the principal collaborators by sending them overseas to learn more about farmer participatory approaches and techniques.

6. Technology transfer through Farmer Participatory Extension (FPE)

In order to transfer technologies with farmers' participation, a budget was allocated to support 4-6 farmers' meetings annually. The topics included discussion on project implementation and the possible solutions for both project management and crop production. Local extension agents acted as coordinators of these discussions and could invite experts or lecturers from outside according to the farmers' needs or problems.

7. Field days

The project organized three levels of farmer field days:

7.1 Village level. This field day was held at the time of harvesting the FPR trials. After the trial plots were harvested, all data were recorded and the results were presented and discussed with the farmers. In this way, the farmers learned and obtained information to make decisions about which technologies might be suitable for their village conditions. They then discussed and planned for action in the following year.

7.2 District level. The objective of this type of field day was to disseminate technologies to nearby villages and sub-districts. On the field day, the farmers who had already conducted FPR trials shared their knowledge with other farmers. Officials from DOA, DOAE, and LDD also discussed how to increase cassava production efficiency, improving soil fertility by planting green manures, and to control erosion in various ways, including the growing of vetiver hedgerows. These field days took place in the project sites so that farmers would be able to study the real situation. This technique was quite effective as the visiting farmers were often interested in trying out the practices of soil erosion control in their own areas.

7.3 Provincial level. At this level, approximately 1,000-1,500 farmers and officials from nearby provinces were invited to visit the field day. Reporters from newspapers and television stations were also invited in order to report the project activities through the wider mass media.

8. Media production

In order to promote the project and provide information and its implementation to a wider audience, a video was made showing how to operate development work through farmers' participation. The video was distributed to many provincial offices and agencies. The Office of the Royal Development Projects Board also supported the Project by providing a booklet series, "The Factual Tips about Vetiver", for distribution to the farmers who participated in the project.

9. Additional Activities

The following additional activities were performed:

9.1 Training course for making handicrafts from vetiver leaves: The training course was aimed at offering a choice to generate income from vetiver leaves. So far, the farmers from three villages: Sapphongphoot village in Soeng Saang district, Kut Dook village in Daan Khun Thot district of Nakhon Ratchasima province, and Huai Suea Ten village in Sahatsakhan district of Kalasin province received training in the making of various handicrafts from vetiver grass. The trainers of the course were provided by the Department of Industrial Promotion.

9.2 Cassava Development Village: Since the year 2000, DOAE has adjusted the project implementation by setting up the so-called 'Cassava Development Villages'. Farmers in the target villages received training to have more knowledge and develop a clear understanding about the need to conserve soil resources in order to obtain higher yields. The construction of vetiver hedgerows across the slope and the use of green manures to increase soil fertility were demonstrated. DOAE provided the farmers with planting material of good varieties of cassava, chemical fertilizer, and vetiver plantlets on condition that they return the value of these materials to the village revolving fund after the cassava harvest. A low interest rate was agreed upon by the villagers. Futhermore, the members voted to elect the 'Fund Administration Committee', which comprised a chairman, a vice-chairman, a treasurer, and a secretary as the minimum number. Rules and regulations were discussed and voted on by the members' resolution.

RESULTS AND DISCUSSION

The implementation of the Project, "Enhancing the Adoption of Soil Erosion Control Practices in Cassava Fields" for the past eight years in an ever increasing number of sites has had a great impact on the farmers' awareness of the importance of soil erosion prevention. After testing various options to reduce soil loss, practically all farmers selected the planting of vetiver grass hedgerows across the slopes as the most suitable and effective erosion control practice. Presently, this practice has been adopted in 21 villages located in eight provinces (**Table 1**). Altogether, 865 farmers participated in the planting of vetiver hedgerows which now has a total length of 130 km in their cassava fields, planting a total of 1.3 million vetiver slips. Furthermore, farmers in a few villages adopted the planting of *Canavalia ensiformis* (sword bean) as a green manure. In addition, 21 'Cassava Development Villages' were established. At present, members of these farmers' groups have access to a revolving fund, which range in size from baht 40,000 to 380,000 per group, with a total of baht 1,475,868, to be used for the development of these communities (**Table 1**). The establishment of these groups is a way to strengthen rural communities to face new challenges in the future. Besides, DOAE tries to make use of the project sites for field visits of the farmers from nearby villages, sub-districts, districts and provinces in order to encourage further scaling-up of the project results.

Table 1. Location of pilot sites for the project "Enhancing the Adoption of Soil Erosion Control Practices in Cassava Fields", the extent of adoption of vetiver grass hedgerows, and the status of the village revolving credit funds in 2002.

Province	District[1)]	Sub-district	Village	No. of farmers	Area planted with Cassava (rai)[2)]	Area planted with Vetiver (plantlets)	Length of vetiver strip (km)	Village fund (baht)
Kalasin	Mueang	Phu Po	Noon Sawan	61	306	85,500	8.6	40,000
		Kamin	Kham Pla					
	Nong Kung Si	Nong Bua	Kham Si	67	690	111,600	11.2	85,850
	Sahatsakhan	Non Buri	Noon Sawat	63	370	86,170	8.6	75,000
		Non Nam	Huai Suea Ten	42	254	128,330	12.8	114,220
		Kliang	Pa Kluai					
	Namon	Namon	Noon Thiang	50	24	16,000	1.6	-
	Don Chan	Dong Phayung	Noon Kokchik	50	24	16,000	1.6	-
	Huay Phueng	Nikhom	Huai Fa	50	24	16,000	1.6	-
Kamphaeng Phet	Khanu Wara-laksaburi	Bo Tham	Si Yaek Ton Sai	42	170	68,000	3.0	78,288
Kanchanaburi	Lao Khwan	Thung Krabam	Nong Kae	42	170	80,000	3.0	60,000
Chaiyaphum	Thep Sathit	Na Yang Klak	Kook Anu	42	170	68,000	4.0	86,000
Chachoengsao	Sanaam Chai Khet	Thung Phraya	Tha Chiwit Mai	6	45	50,000	2.0	101,080
	Tha Takiap	Khlong Takrao	Nong Yai	42	170	100,000	5.3	83,550
Prachinburi	Na Di	Kaeng Dinso	Ang Thong	34	170	60,000	4.5	84,800
Nakhon	Daan Khun Thot	Baan Khao	Kut Dook	53	309	130,000	15.0	132,000
Ratchasima	Thepharak	Bueng Prue	village 3, 6	26	214	80,000	11.0	54,000
	Soeng Saang*	Noon Sombuun	Sapphongphoot	60	828	80,000	20.0	54,848
		Sa Takhian	Sra Takhian	-	30	20,000	2.0	0
	Khon Buri*	Map Tako En	Lam Phiak	27	24	50,000	0.0	0
Sra Kaew	Wang Sombuun	Wang Sombuun	Khlong Ruam	42	-	90,000	-	22,500
Total: 8	17	20	21	865	5,876	1,335,600	129.8	1,475,868

[1)] * Additional new sites for implementation of the project in 2002.
- data not available
[2)] 1 ha = 6.25 rai

LESSONS LEARNED

The following lessons have been learned from the Project:

1. The implementation of a project that has as its objective to enhance the conservation of soil, water and the environment, must involve the people of the whole community, or at least, it must start with some parts of the community that participate in the Project. The villagers must be aware of the seriousness of the problems that need to be solved by sharing their opinions and by making decisions together.

2. The technologies offered to the farmers must have a direct positive effect on yield and must be adapted to their way of life. For example, the adoption of vetiver grass hedgerow planting and intercropping with sword bean as a green manure is likely to improve soil fertility, which in turn may result in increased cassava yields.

3. The duration of a project is also another significant factor for its success, because the soil erosion problem does not have an immediate impact on the daily life of the farmers. Thus, farmers need some time to become aware of the problem, to test several possible solutions and to confirm the results before they decide to adopt soil conservation practices. In this case, the project should continue for at least ten years.

4. Agricultural extensionists need to change their role, from recommending certain practices to being a facilitator, to encourage members of the community to participate in analyzing their problems and search together for solutions. In many cases, they can act as the coordinator to seek help and knowledge from outside. Nevertheless, the needs must be identified by the community.

5. Various incentives or subsidies of some production inputs are necessary, particularly for the conducting of field trials, to provide vetiver slips and to help set out contour lines after farmers have decided to adopt the planting of vetiver grass contour hedgerows.

6. Farmers should be given freedom to select and modify the soil erosion prevention treatments to be tried on their own field. For example, they can test the use of other grasses or other crops as contour hedgerows, such as sugarcane or upland rice.

7. The forming of farmers' self-help groups will provide opportunities for members of the community to express their opinions and find the best ways for future development. Support from outsiders in terms of supplying planting materials, fertilizer, seeds, etc., with the condition that the users of the inputs return these to start the village revolving funds, may be a way of strengthening the development of the community and empower its members to solve their own problems.

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FARMER PARTICIPATORY RESEARCH (FPR) ON SOIL EROSION CONTROL AND FERTILIZER USE FOR CASSAVA IN VIETNAM: 1999-2002

Nguyen The Dang[1]

ABSTRACT

In Vietnam, about 75% of the total land area are uplands, and most of these have a sloping topography. Of the 263,900 ha of cassava, 216,000 ha are planted on sloping land. For that reason, in many areas the soil for planting cassava is severely eroded. Soil erosion and inadequate fertilization are the two main causes of soil degradation leading to a reduction in cassava productivity. Based on the identification of the above mentioned constraints, a series of FPR trials on soil erosion control for land management, and balanced fertilization for cassava have been conducted by farmers in Vietnam. These trials were coordinated by six institutions, namely Thai Nguyen Univ. of Agric and Forestry (TUAF), the National Inst. for Soils and Fertilizers (NISF), the Vietnam Agric. Science Inst. (VASI), Hue Univ. of Agric. and Forestry (HUAF), Thu Duc Univ. of Agric. and Forestry (TDUAF) and the Inst. of Agric. Sciences (IAS) of south Vietnam.

From 1999 to 2002, a total of 103 experiments on soil erosion control have been conducted by farmers in 24 villages in the provinces of Thai Nguyen, Tuyen Quang, Yen Bai, Phu Tho, Ha Tay, Hoa Binh, Thua Thien-Hue, Ba Ria-Vung Tau, Dong Nai and Binh Phuoc provinces. Various plant species have been used as contour hedgerows for soil erosion control in most of these experiments. Planting of these hedgerows reduced the amount of eroded soil to only 2.5 to 48.8% of that in the check plot. Contour hedgerows of vetiver grass, *Paspalum atratum,* pineapple and *Tephrosia candida* minimized the amount of eroded soil. In some experiments conducted on less than 20-25% slope, intercropping cassava with peanut and taro, combined with hedgerows and adequate fertilization were found to be the most effective means of reducing erosion.

The combined use of chemical fertilizers and organic manures, intercropping, and the planting of contour hedgerows have been very effective in controlling soil erosion, retaining water and nutrients in the soil and improving the yield of cassava. All experiments were evaluated by farmers, and they have selected and adopted the planting of hedgerows of *Paspalum atratum*, vetiver grass and *Tephrosia candida,* and are now extending these practices to other cassava areas.

From 1999 to 2002, a total of 85 FPR fertilizer trials were conducted by households in the project pilot sites in the various regions. In Son Duong district of Tuyen Quang province, fertilizer treatments of 80 kg N + 40 P_2O_5 + 80 K_2O/ha increased the cassava yield by 77 % compared to the unfertilized check plot. In Phu Tho, the application of 60-80 kg N, 50-60 kg P_2O_5 and 80 kg K_2O/ha in addition to 10 tonnes FYM/ha increased yields 19-34% compared with applying only 10 tonnes FYM. In Ha Tay, the application of 60 kg N + 40 P_2O_5 + 80 K_2O/ha resulted in a cassava yield of 32.5 t/ha, 20% higher than the farmers' practice. Fertilizer experiments in the provinces of Ba Ria-Vung Tau, Dong Nai and Binh Phuoc showed that the application of 40 kg N + 40 P_2O_5 + 40-80 K_2O/ha in addition to 5 t/ha FYM increased the yield from 43-83% compared to the check plot without fertilizer application.

During the field-days at harvest time, farmers selected above-mentioned treatments for adoption and dissemination to other cassava production areas.

INTRODUCTION

Vietnam has a total natural area of 32,924,100 ha, about 75% of which are uplands, and most of these have a sloping topography. According to statistical data, of the 263,900 ha of cassava, about 216,000 ha are planted on sloping land. For that reason, in many areas the soil used for planting cassava is severely eroded. Soil erosion and inadequate

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fertilization are the two main causes of soil degradation leading to a reduction in cassava productivity. Since the availability of land in Vietnam is very limited, the expansion of land for cassava production is impossible. Therefore, measures to control soil degradation and intensify cassava production is the main goal at present.

Based on the identification of the above mentioned contraints, with the support of the Nippon Foundation and CIAT, a series of FPR trials on soil erosion control for land management and balanced fertilization for cassava have been conducted by farmers in Vietnam. These trials were coordinated by six institutions, namely Thai Nguyen University of Agriculture and Forestry (TUAF), the National Institute for Soils and Fertilizers (NISF), the Vietnam Agricultural Science Institute (VASI), Hue University of Agriculture and Forestry (HUAF), Thu Duc University of Agriculture and Forestry (TDUAF) and the Institute of Agricultural Sciences of South Vietnam (IAS).

RESULTS

From 1999 to 2002 a total of 103 FPR trials on soil erosion control and 85 FPR fertilizer trials were conducted by households in ten provinces, i.e. Thai Nguyen, Tuyen Quang, Yen Bai, Phu Tho, Hoa Binh, Ha Tay, Thua Thien-Hue, Ba Ria-Vung Tau, Dong Nai and Binh Phuoc (**Table 1**).

Table 1. The number of FPR erosion control and fertilization trials conducted by farmers in 11 provinces in Vietnam during 1999 to 2002.

	Erosion control trials				Fertilization trials			
Province	1999	2000	2001	2002	1999	2000	2001	2002
Thai Nguyen	6	2	2	1	-	1	1	2
Tuyen Quang	1	2	4	4	-	1	4	3
Phu Tho	1	4	4	4	1	6	6	1
Yen Bai	-	-	-	2	-	-	-	-
Hoa Binh	3	4	4	4	-	3	5	-
Hay Tay	-	2	2	1	-	3	3	3
Thanh Hoa	-	-	-	1	-	-	-	-
Thua Thien-Hue	-	3	5	5	-	3	5	4
Ba Ria-Vung Tau	-	2	4	4	-	2	4	4
Dong Nai	-	-	-	-	-	4	3	3
Binh Phuoc	-	4	4	4	-	-	5	4
Total	**11**	**23**	**29**	**30**	**-**	**23**	**36**	**24**

Results of Research on Soil Erosion Control

In order to identify the most suitable experimental treatments, all farmers participating in the project have been invited to visit and evaluate FPR demonstration plots. After discussion, farmers selected mainly those treatments involving various types of contour hedgerows for their FPR trials to be conducted on their own land.

In Minh Duc commune of Pho Yen district of Thai Nguyen province, an FPR soil erosion control trial with five treatments has been conducted for two years by two households. The data in **Table 2** show that when cassava was intercropped with peanut, the amount of eroded soil was reduced to 77% compared to the farmers' traditional practice of monocropping. When hedgerows of *Tephrosia candida* and/or vetiver grass were added, erosion declined to only 40-49% of the check treatment, and most farmers selected this treatment for adoption and dissemination.

Table 2. Average results of two FPR soil erosion control trials conducted by farmers in Minh Duc commune of Pho Yen district in Thai Nguyen province of Vietnam in 1999 and 2000.

Treatments[1)]	Dry soil loss (t/ha)			Yield (t/ha) cassava		Yield (t/ha) peanut		Farmers' preference (%)	
	1999	2000	Av.	1999	2000	1999	2000	1999	2000
1. Farmer's practice	32.55	21.30	26.92	15.75	13.12	-	-	0	0
2. C+P; no hedgerows	22.84	18.51	20.67	24.88	18.68	0.21	0.31	5	50
3. C+P; vetiver grass hedgerows	11.62	10.35	10.98	27.00	20.00	0.18	0.28	90	73
4. C+P; *Tephrosia candida* hedgerows	15.32	11.22	13.27	26.25	19.87	0.16	0.27	90	67
5. C+P; *Tephrosia*+ vetiver hedgerows	12.01	9.87	10.94	28.88	21.81	0.15	0.27	100	97

[1)] Farmer's practice: 12 t/ha of FYM + 45 kg N+30 P_2O_5/ha
Treatments 2-5: 10 t/ha of FYM + 80 kg N+40 P_2O_5 + 80 K_2O/ha
Source: *Nguyen The Dang, 1999, 2000.*

In Hong Tien commune of Son Duong district of Tuyen Quang province, in addition to *Tephrosia* and vetiver grass, two species of forages, i.e. *Paspalum atratum* and *Panicum maximum,* were also used as hedgerows for erosion control. The two-year average data indicate that the eroded soil in treatment 3, 4 and 5 was only between 6 and 7% of that in the check plot without hedgerows (**Table 3**). The treatment with *Tephrosia candida* hedgerows reduced the dry soil loss to 14.1% of the check plot, and 63% of farmers during the field day selected this as the most suitable practice. The effectiveness of erosion control was actually better in those treatments with grass barriers, but only 0-17% of farmers selected any of those treatments, mainly because they were not aware of the benefit that could be obtained from grass hedgerows.

Table 3. Average results of three FPR soil erosion control trials conducted by farmers in Hong Tien commune, Son Duong district of Tuyen Quang province in 1999 and 2000.

Treatments	Dry soil loss (t/ha)	Cassava yield (t/ha)	Gross income ---(mil.	Net income dong/ha)---	Farmers' preference (%)
1. Farmer's practice (check)	106.00	26.30	13.15	11.72	0
2. C+*Tephrosia* hedgerows	15.00	28.70	14.35	12.92	63
3. C+vetiver grass hedgerows	7.10	27.00	13.50	12.07	0
4. C+*Paspalum atratum* hedgerows	7.20	31.20	15.60	14.17	17
5. C+*Panicum maximum* hedgerows	6.20	27.00	13.50	12.07	11

- NPK Hien Nong (7:4:7): 1,430 dong/kg (1,100 kg/ha)
- Cassava: 500 dong/kg
- Variety: KM 94
- Participants: 3 farmers
- Number of farmers participating in evaluation: 46

Source: *Nguyen The Dang, 2000.*

Results from an FPR trial conducted from 1996 to 2002 in Dong Rang, Hoa Binh province (**Table 4**) shows that the practice of intercropping cassava with taro or peanut, applying fertilizers and planting contour hedgerows of *Tephrosia candida* or vetiver grass markedly reduced erosion. In those treatments where cassava was intercropped with peanut, with hedgerows of *Tephrosia* or vetiver grass, the eroded soil loss decreased to only 2.2 to 4.5% of that in the treatment where cassava was intercropped with taro and grown without fertilizers or hedgerows. **Table 5** shows that both cassava and intercrop yields remained the same or increased over time; yields were higher when fertilizers were applied and contour hedgerows of either vetiver grass or *Tephrosia candida* were planted

Table 4. The effect of various treatments on dry soil loss by erosion in an FPR soil erosion control trial conducted by a farmer[1)] in Dong Rang commune, Luong Son district of Hoa Binh province from 1996 to 2002.

Treatments[2)]	Dry soil loss (t/ha)							
	1996	1997	1998	1999	2000	2001	2002	Av.
1. C+T; without NPK; without hedgerows	43.14	12.54	25.66	15.10	3.40	16.27	12.40	18.36
2. C+T; with NPK; vetiver grass hedgerows	18.67	0.00	0.00	3.30	0.12	0.25	0.00	3.19
3. C+T; with NPK; *Tephrosia* hedgerows	15.95	0.86	0.38	3.15	0.40	0.12	0.00	2.98
4. C+P; with NPK; vetiver grass hedgerows	2.39	0.00	0.10	0.30	0.06	0.00	0.00	0.41
5. C+P; with NPK; *Tephrosia* hedgerows	3.99	0.15	0.00	0.70	0.12	0.40	0.40	0.82

[1)] Farmer: Nguyen Van Tho
[2)] C = cassava; T = taro; P = peanut
NPK = 40 kg N+40 P_2O_5+80 K_2O kg/ha
Source: *Thai Phien et al., 1996-2002.*

Table 5. The effect of various treatments on the yields of cassava and intercrops in a FPR soil erosion control trial conducted by a farmer[1)] in Dong Rang commune, Luong Son district of Hoa Binh province from 1996 to 2002.

Treatments[2)]	Crop	Yield of cassava and intercrops (t/ha)							
		1996	1997	1998	1999	2000	2001	2002	Av.
1. C+T; without NPK;	C	9.00	12.50	12.10	18.05	12.58	8.91	8.75	11.70
no hedgerows	T	5.65	6.43	2.80	4.49	2.10	3.00	2.60	3.87
2. C+T; with NPK;	C	13.02	15.39	14.81	20.00	14.45	15.19	16.87	15.67
vetiver grass hedgerows	T	4.50	8.03	3.43	3.84	2.25	3.09	2.60	3.96
3. C+T; with NPK;	C	14.09	15.93	16.10	23.30	15.94	17.15	15.30	16.83
Tephrosia hedgerows	T	4.50	8.10	3.43	4.49	2.15	2.60	3.00	4.04
4. C+P; with NPK;	C	15.66	14.86	14.81	21.67	16.70	14.23	15.30	16.18
vetiver grass hedgerows	P	0.74	0.25	0.60	0.35	0.51	0.90	0.51	0.55
5. C+P; with NPK;	C	14.29	14.79	15.43	21.67	15.58	14.94	14.63	15.90
Tephrosia hedgerows	P	0.78	0.28	0.49	0.42	0.65	0.90	0.60	0.59

[1)] Farmer: Nguyen Van Tho
[2)] C = cassava; T = taro; P = peanut
NPK = 40 kg N+40 P_2O_5+80 K_2O kg/ha
Source: *Thai Phien et al., 1996-2002.*

In an FPR trial conducted on a 40% slope for eight years by seven farmers in Phuong Linh commune, Thanh Ba district of Phu Tho province, intercropping cassava with peanut and with vetiver grass hedgerows (T_6) reduced the eroded soil loss on average to 40% of that in the check plot (**Table 6**). The trapping of washed out soil and fertilizers by the hedgerows caused cassava yields in this treatment (T_6) to increase 23% as compared to the plot without hedgerows (T_3) (**Table 7**).

Table 6. The effect of various treatments on the dry soil loss (t/ha) by erosion in an FPR soil erosion control trial conducted by six farmers in Phuong Linh commune, Thranh Ba district, Phu Tho province from 1995 to 2002.

Treatments[1)]	Year									Compared to check (%)
	1995	1996	1997	1998	1999	2000	2001	2002	Av.	
1. C monocult.; with NPK; no hedgerows (check)	54.5	38.9	106.1	18.4	51.8	99.1	54.7	91.2	64.3	100
2. C+P, without NPK; no hedgerows	53.6	41.3	103.9	13.3	25.1	108.2	56.7	78.4	60.1	93
3. C+P; with NPK; no hedgerows	50.1	32.9	64.8	14.0	33.7	95.2	69.0	75.2	54.4	85
4. C+P; with NPK; *Tephrosia* hedgerows	45.3	37.9	40.1	5.3	6.2	34.2	16.3	28.0	26.7	42
5. C+P; with NPK; pineapple hedgerows	43.4	36.0	32.2	0.8	10.5	33.1	6.1	29.3	23.9	37
6. C+P; with NPK; vetiver hedgerows	42.9	36.8	32.0	3.1	8.0	39.2	14.3	28.2	25.6	40
7. C monocult.; with NPK; *Tephrosia* hedgerows	45.3	38.6	32.5	6.3	3.3	38.3	18.4	26.7	26.2	41

[1)] C = cassava; P = peanut

T_5 in 1995 had *Desmodium* hedgerows; T_4 in 2000, 2001 and 2002, and T_6 in 2001 and 2002 had cassava monoculture

NPK: 60 kg N + 40 P_2O_5 + 120 K_2O/ha; all plots received 10 t/ha of pig manure

***Source:** Thai Phien et al., 1995-2002.*

In Suoi Rao commune in Chau Duc district of Baria-Vungtau province, two FPR erosion control trials were conducted by two households, using pineapple, *Paspalum atratum* and vetiver grass as hedgerows. **Table 8** shows that the use of any one of these hedgerows reduced the amount of eroded soil. Intercropping cassava with maize also decreased erosion to only 24% of that in the check plot without intercropping. However, the maize intercrop significantly reduced cassava yields and increased costs, resulting in a lower net income. Upon assessing these experimental results, most farmers selected a treatment with either vetiver grass or *Paspalum atratum* for adoption and dissemination in sloping land.

Another experiment, using two grasses (vetiver grass and *Paspalum atratum*) and two leguminous tree species (*Leucaena leucocephala* and *Gliricidia sepium*) was conducted by three households in Dong Tam commune in Dong Phu district of Binh Phuoc province (**Table 9**). In general, treatments with contour hedgerows were quite effective in reducing erosion, with the two grass species being more effective than the leguminous trees.

Table 7. The effect of various treatments on cassava and intercrop yields (t/ha) in an FPR soil erosion control trial conducted by six farmers in Phuong Linh commune, Thanh Ba district, Phu Tho province from 1995 to 2002.

Treatments[1)]	Crop	Year 1995	1996	1997	1998	1999	2000	2001	2002	Av.
1. C monocult.; with NPK; no hedgerows (check)	C	19.04	23.77	19.17	25.75	26.30	29.00	17.80	27.10	23.49
2. C+P, without NPK;	C	18.33	15.30	23.08	18.16	11.15	17.00	28.60	21.10	19.09
no hedgerows	P	0.96	0.88	0.70	0.47	0.45	0.59	0.77	0.54	0.67
3. C+P; with NPK;	C	17.50	14.64	19.23	20.32	18.60	15.00	32.10	29.70	20.89
no hedgerows	P	1.21	1.02	0.97	0.51	0.47	0.63	0.83	0.43	0.76
4. C+P; with NPK;	C	14.81	15.14	14.67	21.60	23.80	20.00	21.40	16.10	18.44
Tephrosia hedgerows	P	1.03	0.76	0.85	0.51	0.49	-	-	-	0.73
5. C+P; with NPK;	C	17.60	21.63	19.39	23.33	24.00	20.00	16.10	18.80	20.11
pineapple hedgerows	P	0.91	0.89	0.97	0.73	0.66	0.80	0.96	0.46	0.80
6. C+P; with NPK;	C	18.11	21.96	23.71	26.52	33.80	32.00	25.00	25.30	25.80
vetiver hedgerows	P	1.38	0.94	0.85	0.38	0.37	0.62	-	-	0.76
7. C monocult.; with NPK; *Tephrosia* hedgerows	C	17.60	26.18	23.33	25.05	21.70	23.00	30.30	28.00	24.39

[1)] C = cassava; P = peanut
T_5 in 1995 had *Desmodium* hedgerows; T_4 in 2000, 2001 and 2002, and T_6 in 2001 and 2002 had cassava monoculture;
NPK: 60 kg N + 40 P_2O_5 + 120 K_2O/ha; all plots received 10 t/ha of pig manure
Source: *Thai Phien et al., 1995-2002.*

Table 8. Average results of two FPR soil erosion control trials conducted by farmers in Suoi Rao commune, Chau Duc district, Ba Ria-Vung Tau province in 2000/01 and 2001/02.

Treatments[1)]	Dry soil loss (t/ha) 2000/01	Dry soil loss (t/ha) 2001/02	Yield (t/ha) Cassava 2000/01	Cassava 2001/02	Intercrop 2000/01	Intercrop 2001/02	Farmers' preference (%) 2000/01	Farmers' preference (%) 2001/02
1. Cassava; no hedgerows	31.76	77.47	48.85	37.89	-	-	0	10
2. C; pineapple hedgerows	11.20	31.94	43.54	31.10	-	-	0	17
3. C; *Paspalum* hedgerows	15.49	21.87	40.54	34.54	-	-	71	43
4. C; vetiver hedgerows	13.15	40.43	47.16	30.99	-	-	100	43
5. C+maize intercrop	11.82	14.50	33.24	24.94	4.47	3.53	17	10

[1)] Fertilizer: 80 kg N + 40 P_2O_5 + 80 K_2O/ha
Source: *Nguyen Thi Sam et al., 2000-2002.*

Table 9. Average results of three FPR soil erosion control trials conducted by farmers in Dong Tam commune, Dong Phu district of Binh Phuoc province in 2000/01 and 2001/02.

Treatments	Dry soil loss (t/ha) 00/01	Dry soil loss (t/ha) 01/02	Cassava yield (t/ha) 00/01	Cassava yield (t/ha) 01/02	Gross income[1)] (mil. dong/ha) 00/01	Gross income[1)] (mil. dong/ha) 01/02	Net income (mil. dong/ha) 00/01	Net income (mil. dong/ha) 01/02	Farmers' preference (%) 00/01	Farmers' preference (%) 01/02
1. Cassava; no hedgerows	37.8	39.40	21.4	19.8	6.21	7.52	2.33	3.10	10	20
2. C; vetiver hedgerows	24.7	15.80	21.6	23.1	6.26	8.78	2.13	4.15	20	30
3. C; *Leucaena* hedgerows	33.6	21.80	22.0	21.8	6.38	3.28	2.25	3.66	20	0
4. C; *Gliricidia* hedgerows	34.8	28.10	23.4	21.2	6.79	8.06	2.66	3.43	25	0
5. C; *Paspalum* hedgerows	28.2	12.70	24.2	22.6	7.02	8.59	2.89	3.96	25	50

[1)] Prices: cassava dong 290/kg fresh roots in 2000/01, dong 380/kg in 2001/02.

Based on the results of these FPR trials, most farmers in Vietnam have selected vetiver grass, *Tephrosia candida* and *Paspalum atratum* as the most useful practices to be adopted in their production fields. Up to 2002, a total of 222 households have adopted the use of vegetative contour hedgerows for erosion control in 99 ha of cassava land.

Results of Research on Fertilizer Use

Based on problem identification by farmers, researchers and farmers considered low yielding varieties, degraded land, inadequate and unbalanced fertilization as the major constraints to obtaining high cassava yields. To overcome these problems a wide range of experiments regarding the use of balanced fertilization have been conducted by farmers.

In Am Thang and Hong Tien communes of Son Duong district in Tuyen Quang province, FPR trials on NPK fertilization were carried out by four households between 2000 and 2001. The results (**Table 10**) indicate that applying only 40 kg N and 40 K_2O/ha increased cassava yields by 39%, while the application of 80 kg N, 80 K_2O and 40 P_2O_5/ha (treatment 4) increased the yield by 77% compared with the check without fertilizers. On the field days at harvest, almost all farmers selected these two treatments for adoption and dissemination to other cassava production areas.

Table 10. Combined results of four FPR fertilizer trials conducted by farmers in Am Thang and Hong Tien communes of Son Duong district, Tuyen Quang province in 2000 and 2001.

Treatments[1)] (N, P and K in kg/ha)	Cassava yield (t/ha) 2000 Am Thang	Cassava yield (t/ha) 2001 Am Thang	Cassava yield (t/ha) 2001 Hong Tien	Cassava yield (t/ha) Average	Compared to check plot (%)	Farmers' preference (%) Am Thang	Farmers' preference (%) Hong Tien
1. Without fertilizer (check)	5.0	17.5	27.7	16.7	100	0	0
2. 40 N+40 K_2O	13.5	22.5	33.7	23.2	139	55	29
3. 40 N+20 P_2O_5+40 K_2O	13.8	28.7	27.7	23.4	140	4	9
4. 80 N+40 P_2O_5+80 K_2O	18.2	38.7	31.9	29.6	177	45	40

[1)] Variety: KM94

***Source:** Nguyen The Dang, 2000-2001.*

In Phuong Linh, Thong Nhat and Bao Thanh communes in Phu Tho province, ten households conducted two trials on the use of various combinations of FYM and NPK fertilizers (**Tables 11** and **12**). In Phuong Linh, applying 10 t/ha of FYM combined with 60 kg N, 40-60 P_2O_5 and 80-120 K_2O/ha increased cassava yields on average by 21-30%. In Thong Nhat and Bao Thanh, using 10 t/ha of FYM plus 80 kg N, 40 P_2O_5 and 80 K_2O/ha resulted in the highest yield, which was 19% higher than that obtained with the traditional practice of applying 10 t/ha of FYM and 500 kg/ha of 5:10:3 fertilizers.

Table 11. Average results of five FPR fertilizer trials conducted by farmers in Phuong Linh commune, Thanh Ba district, Phu Tho province from 1996 to 2002.

Treatments (N, P and K in kg/ha)	Cassava yield (t/ha) 1996	1997	1998	1999	2000	2001	2002	Av.	Compared to check (%)
1. 10 t/ha FYM (check)	15.9	15.8	16.0	13.5	17.2	18.5	15.3	16.0	100
2. 10 t/ha FYM+60 N +60 P_2O_5+120 K_2O	19.3	20.2	18.2	19.1	20.9	21.4	16.7	19.4	121
3. 10 t/ha FYM+60 N +60 P_2O_5+80 K_2O	18.7	19.3	20.7	18.7	21.3	20.7	17.5	19.6	122
4. 10 t/ha FYM+60 N +40 P_2O_5+120 K_2O	21.9	17.6	17.7	19.1	23.4	23.2	22.4	20.8	130

Source: *Thai Phien et al., 1999-2002.*

Table 12. Average results of five FPR fertilizer trials conducted by farmers in Thong Nhat and Bao Thanh communes, Phu Ninh district of Phu Tho province in 2001.

Treatments (N, P and K in kg/ha)	Cassava yield (t/ha) Thong Nhat	Bao Thanh	Average	Gross income[1)]	Product. costs	Net income
				--------(mil.dong/ha)-------		
1. 10 t/ha FYM+500 kg/ha NPK (5:10:3)	19.3	19.4	19.35	6.77	3.71	3.06
2. 10 t/ha FYM+40 N+20 P_2O_5+40 K_2O	21.0	21.8	21.40	7.49	3.58	3.91
3. 10 t/ha FYM+80 N+40 P_2O_5+80 K_2O	22.3	23.7	23.00	8.05	4.04	4.01
4. 10 t/ha FYM+80 N+40 P_2O_5+120 K_2O	22.7	21.3	22.00	7.70	4.21	3.49
5. 10 t/ha FYM+80 N+60 P_2O_5+120 K_2O	21.3	19.4	20.35	7.12	4.32	2.80

[1)] Prices:

cassava	dong	350/kg fresh roots
NPK (5:10:3)		1,200/kg
urea (45% N)		2,000/kg
SSP (17% P_2O_5)		1,000/kg
KCl (60% K_2O)		2,500/kg
FYM		100/kg

Source: *Thai Phien et al., 2001.*

Another experiment on the use of NPK fertilizers was conducted in Thanh Hoa commune in Ha Tay province. The result indicate that the application of 60 kg N, 40 P_2O_5 and 80 K_2O/ha increased the yield by 20% in comparison with the farmer's traditional practice and markedly increased the farmers' net income. After evaluation, 90% of farmers selected this treatment for adoption and expansion in the area (**Table 13**).

In Thuong Long village in Thua Thien-Hue province, a fertilizer experiment consisting of three treatments was conducted by three households in 2000. Data in **Table 14** show that using a mixture of 60 kg N, 60 P_2O_5 and 120 K_2O/ha doubled the yield and increased net income 2.4 times as compared to the check without fertilizers.

Table 13. Average results of three FPR fertilizer trials conducted by farmers in Thach Hoa commune, Thach That district, Ha Tay, Vietnam in 2000/01.

Treatments (N, P and K in kg/ha)	Cassava yield (t/ha)	Gross income[1]	Product. costs[2]	Net income	Farmers' preference (%)
		('000 dong/ha)			
1. Farmers' practice	27.1	8,130	3,308	4,822	10
2. 40 N+40 P_2O_5+0 K_2O	30.7	9,210	3,263	5,947	0
3. 40 N+0 P_2O_5+40 K_2O	29.3	8,790	3,156	5,634	0
4. 60 N+40 P_2O_5+80 K_2O	32.5	9,750	3,680	6,070	90
5. 80 N+40 P_2O_5+120 K_2O	32.3	9,690	3,938	5,752	0

[1]Prices: cassava dong 300/kg fresh roots
urea (45% N) 2,200/kg
fused Mg-phos. (15% P_2O_5) 1,000/kg
KCl (60% K_2O) 2,400/kg

Table 14. Average results of three FPR fertilizer trials conducted by farmers in Thuong Long village, Hong Ha commune, A Luoi district, Thua Thien-Hue, Vietnam in 2000.

Treatments (N, P and K in kg/ha)	Cassava root yield (t/ha)	Gross income[1]	Production costs[2]	Net income	Farmers' preference (%)
		('000 dong/ha)			
0 N+0 P+0 K	7.5	3,750	1,800	1,950	0
30 N+30 P_2O_5+90 K_2O	12.5	6,250	2,613	3,637	66
60 N+60 P_2O_5+120 K_2O	15.6	7,800	3,131	4,669	34

[1]Prices: cassava dong 500/ kg fresh roots
urea (45% N) 2,500/ kg
SSP (15% P_2O_5) 1,100/ kg
KCl (50% K_2O) 2,200/ kg
[2]Cost of cassava cultivation: 1.8 mil. dong/ha (120 mandays)
Cost of fertilizer application: 0.03 mil. dong/ha (2 mandays)

In Suoi Rao commune in Ba Ria-Vung Tau province, the application of 5 t/ha of FYM together with 40 kg N, 40 P_2O_5 and 40 K_2O/ha increased the yield by 43% compared to the check plot without fertilizers; 100% of farmers selected this treatment for adoption (**Table 15**).

In An Vien commune in Dong Nai province, and in Dong Tam commune of Binh Phuoc province, the application of 80 kg N, 40 P_2O_5 and 80 K_2O/ha increased cassava yields by 44 and 55%, respectively, while the additional application of 5 t/ha of FYM further increased yields to 62% and 83%, respectively, compared with the check without fertilizers. The majority of farmers selected either one of these treatments for adaption in their cassava production fields (**Tables 16** and **17**).

According to our surveys, until 2002 at least 157 households in the FPR pilot sites in Vietnam are applying these selected treatments to achieve a more balanced fertilization in 26 ha of cassava.

Table 15. Average results of two FPR fertilizer trials conducted by farmers in Suoi Rao village, Chau Duc district, Ba Ria-Vung Tau, Vietnam in 2000/01.

Treatments (N, P and K in kg/ha)	Cassava yield (t/ha)	Gross income[1)]	Product. costs[1)] ('000 dong/ha)	Net income	Farmers' preference (%)
0 N+0 P+0 K	38.61	11,583	5,700	5,883	0
80 N+40 P_2O_5+80 K_2O	50.21	15,063	6,535	8,528	0
40 N+40 P_2O_5+80 K_2O	49.03	14,709	6,375	8,334	50
40 N+40 P_2O_5+40 K_2O+5 t FYM/ha	55.36	16,608	7,335	9,273	100

Prices: cassava dong 300/kg; urea (45% N) 1,800/kg; SSP (17% P_2O_5) 1,000/kg; KCl (60% K_2O) 1,800/kg
FYM dong 200/kg; fertilizer applic. 40,000/ha; manure applic. 80,000/hg; labor 20,000/mday

Table 16. Average results of three FPR fertilizer trials conducted by farmers in An Vien village, Thong Nhat district, Dong Nai, Vietnam in 2000/01.

Treatments (N, P and K in kg/ha)	Cassava root yield (t/ha)	Gross income[1)]	Product. costs[1)] ('000 dong/ha)	Net income	Farmers' preference (%)
0 N+0 P+0 K	19.66	5,701	3,350	2,351	10
80 N+40 P_2O_5+80 K_2O	28.37	8,227	4,329	3,898	50
40 N+40 P_2O_5+80 K_2O +5 t FYM/ha	31.96	9,268	4,779	4,489	40

[1)] Prices: cassava dong 290/ kg fresh roots
urea 2,300/ kg
SSP 1,000/ kg
KCl 2,300/ kg
FYM 120/ kg
labor 25,000/ manday

Table 17. Average results of three FPR fertilizer trials conducted by farmers in Dong Tam village, Dong Xoai district, Binh Phuoc, Vietnam in 2000/01.

Treatments (N, P and K in kg/ha)	Cassava yield (t/ha)	Gross income[1)]	Production costs[1)] ('000 dong/ha)	Net income	Farmers' preference[2)] (%)
0 N+0 P+0 K	16.6	4,482	2,900	1,582	20
80 N+40 P_2O_5+80 K_2O	25.8	6,966	3,879	3,087	50
80 N+40 P_2O_5+80 K_2O+5t FYM/ha	30.4	8,208	4,429	3,779	30

[1)] Prices: cassava dong 270/ kg fresh roots
urea (46% N) 2300/ kg
SSP (18% P_2O_5) 1000/ kg
KCl (60% K_2O) 2300/ kg
FYM 100/ kg
[2)] Number of participating farmers: 24

CONCLUSIONS

1. The use of contour hedgerows of vetiver grass, *Paspalum atratum* and *Tephrosia candida* reduced the amount of eroded soil to 2.2 to 49% compared to the check plots without hedgerows.

2. The combined use of chemical fertilizers and organic manures, intercropping and planting of contour hedgerows have been very effective in controlling soil erosion, retaining water and nutrients in the soil, and improving the yield of cassava; this also increased the net income of farmers.

3. Applying 60-80 kg N, 40-50 P_2O_5 and 80-120 K_2O/ha increased cassava yields by 20 to 100% compared to the check plots without fertilizers.

4. After our field days at harvest time, participating farmers generally selected the above-mentioned treatments for adoption and dissemination to other cassava production areas.

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FARMER PARTICIPATORY VARIETY TRIALS CONDUCTED IN VIETNAM

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ABSTRACT

Cassava varieties, previously selected by various institutes and Universities for having high fresh root yields and starch contents, were evaluated and selected by farmers on their own fields with the help of researchers and local or provincial extentionists who participated in the Farmer Participatory Research (FPR) project to improve the sustainability of cassava production in Vietnam.

In FPR variety trials conducted in 24 locations in the north, central and southern regions of Vietnam from 1998 to 2001, 60-100% of farmers prefered KM94 cultivar. More specifically, in the north, 60-100% of farmers preferred KM94, KM60 and KM98-7, because of their high root and starch yields making them suitable for industrial usage. In the central part of the country, the new variety KM98-1 was preferred by 100% of farmers, because of high yield and low cyanogenic potential, making this variety suitable for both factory use and human consumption. Besides KM98-1, farmers also liked KM98-5, KM94 and KM99-5. In the south, 71-100% of farmers preferred KM98-5, while others also liked KM94, KM98-1, SM937-26 and KM140-2. Particularly, KM140-2 had a very high root and starch yield in 2001, higher than KM98-5. So, the promising line KM140-2 will be further tested and evaluated by farmers in different communities having different environments before being released as a new variety.

There are six steps in the process of building capacity for farmers to conduct FPR variety trials: 1. Discuss with farmers the objective of conducting these trials; 2. Study tour to visit research organizations where varieties are being developed; 3. Discuss again and decide on the activities to be undertaken; 4. FPR training; 5. Farmers establish and take care of trials on their own fields under the guidance of researchers; and 6. At time of harvest a field day is organized to evaluate the varieties and to select the most promising ones. A workshop may be organized at the research sites to discuss the results and lessons learned, to get feedback from farmers so as to further develop more suitable varieties. For research and sustainable development of high yielding cassava cultivars, the participation of farmers in varietal evaluation and selection is an essential part of the process, while it empowers farmers to contribute to their own and their community's development.

INTRODUCTION

Vietnam produces annually more than 2 million tonnes of cassava fresh roots and is ranked 13th in terms of cassava production in the world. In Vietnam, cassava has great potential, both for domestic consumption and for export. In the early part of the 21st Century, cassava is changing from being a food crop to a cash crop, and both the farmers and the Vietnam government are showing more interest in the crop. There are seven main exported products of cassava, including starch and modified-starch (Pham Van Bien *et al.*, 2001).

Most cassava in Vietnam is produced by smalholder farmers. As such, research on breeding and selection of cassava varieties that have high starch yield is important to enhance the adoption of good varieties and sustainable development. The Farmer

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Participatory Research (FPR) methodology can be used to meet the needs of farmers. Farmers conduct trials by themselves, while researchers help and give advice. When farmers participate in cassava varietal evaluation, they will ask many questions and select those varieties that are well adapted in their own fields. What and how to manage, monitor and evaluate for high yield and income? What are the benefits in term of selection and evaluation of the cassava breeding methodology? How can they apply the methodology in their field? ... No researchers can answer these questions as well as farmers, who have lived a long time in their regions. In Vietnam, farmers themselves will decide which new cassava varieties should be expanded in the different regions.

In this paper we present the results of Farmer Participatory Research on cassava variety trails in three regions of Vietnam. It was found that in the north, 60-100% of farmers at the project sites prefered KM94, KM60 and KM98-7. In the central part of the country, the new variety KM98-1 was preferred by 100% of farmers. Besides KM98-1, farmers there also liked KM98-5 and KM94. In the south, 60-71% of the farmers preferred KM98-5, KM94, KM98-1, SM937-26 and KM140-2.

The process of building capacity for farmers to conduct FPR variety trials includes six steps, in which the level of participation of farmers increases from low to high. From our results and discussions about this paper, we concluded that the FPR project, funded by the Nippon Foundation and coordinated by Reinhardt Howeler and other CIAT scientists, has been very usefull for developing and disseminating high yielding cassava varieties and more sustainable production practices in Vietnam.

OBJECTIVES.

To select cassava varieties with high fresh root yield and high starch content by farmers on their own fields with the help of researchers and local or provincial extensionists in three regions: north, central and south Vietnam.

To improve farmers' capacity to select and develop new cassava varieties.

METHODOLOGY.

- Establish groups of farmers interested in cassava varietal evaluation
- Farmers and researchers together discuss and plan the research
- Visit demonstration plots and train farmers and local extensionists
- Set up FPR trials by farmers with the help of researchers
- Monitor and evaluate at field days/workshop to select the most promising varieties.
- Expand new varieties selected by farmers to different areas

RESULTS AND DISCUSSION.

FPR variety trials were conducted in 24 locations in the north, central and southern regions of Vietnam from 1999 to 2002.

1. FPR cassava trials in the north of Vietnam

In north Vietnam these trials were conducted by researchers of the Root Crops Research Center of the Vietnam Agricultural Sciences Institute (VASI) together with farmers in Thach That district of Ha Tay province, and by researchers of Thai Nguyen University of Agriculture and Forestry (TUAF) in 2000 and 2001. **Figure 1** and **Table 1** show the results. So far, farmers in Ha Tay province have selected eight varieties, i.e KM94, KM60, KM98-7, KM21-10, SM2220-11, OMR38-71-12, OMR37-52-6 and OMR37-52-8.

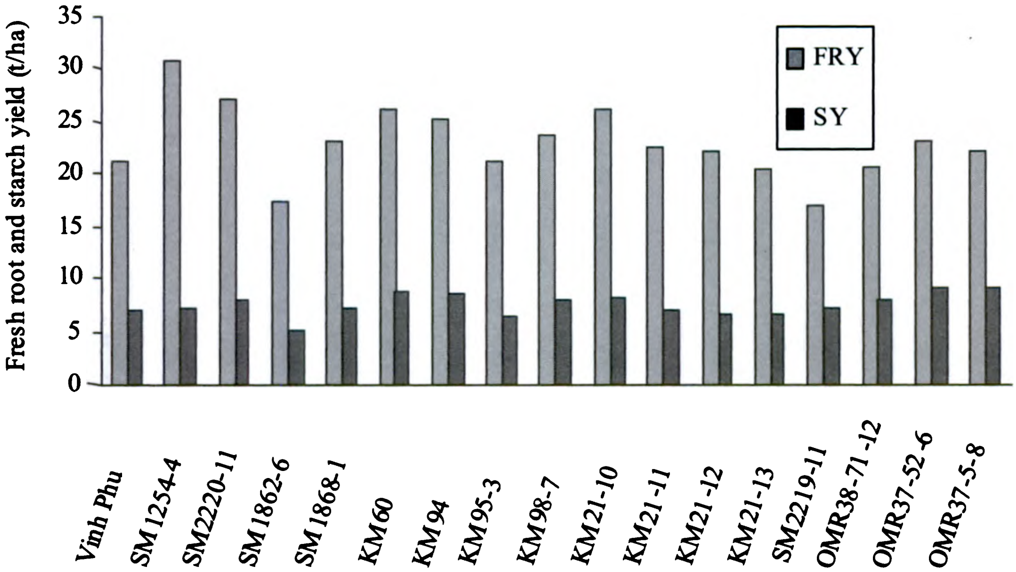


Figure 1. Average fresh root and starch yields of cassava varieties tested in Hatay and Thai Nguyen provinces in north Vietnam. from 1999 to 2001

OMR37-52-6, OMR37-52-8, KM60 and KM94 produced the highest starch yield (SY): 9.2, 9.1, 8.7 and 8.4 t/ha, and the highest fresh root yield (FRY): 23.1, 22.2, 26.3 and 25.3 t/ha, respectively. These were followed by KM21-10, SM2220-11 and KM98-7, which had starch yields ranging from 8.0 to 8.3 t/ha and fresh root yields from 23.6 to 27.2 t/ha. Expecially, KM94 and SM2220-11 had high starch yields of 9.6 and 9.2 t/ha, and fresh root yields of 31.2 and 32.3 t/ha, respectively, in 1999. Some other varieties also produced high starch yields, like KM98-7; KM60, OMR37-52-6 and OMR37-52-8, which produced 10.1, 9.7, 9.2 and 9.1 t/ha, respectively in Thai Nguyen province in 2001 (**Table 1**). Thus, these eight varieties will be introduced to FPR trials in others locations.

Subsequently, KM94, KM98-7 and KM60 were further tested in FPR trials and were preferred by 65-100% of farmers in north Vietnam (**Figure 2** and **Table 2**). A total of 12 varieties have been tested in FPR trials in 12 communes, including some new lines as well as local varieties (Xanh Vinh Phu and SC 205 = bamboo leaf) from 2000 to 2002. The results in **Figure 2** and **Table 2** show that most of the farmers preferred the high yielding cultivars such as KM60, KM98-7 and KM94, which produced on average 30.9, 30.3 and 29.2 t/ha, respectively, in 10-12 locations. These varieties have about 50% higher fresh root yields than the local varieties. Farmers also like some of the newest varieties that were introduced in the trial in 2002: SM215-4-5, KM108-2 and KM104-4. Those had root yields ranging from 32.0 to 37.8 t/ha. In particular, the fresh root yield of KM94 reached 42.8 t/ha in Thach Hoa commune in 2000, and 40 t/ha in Van Yen district in 2001. KM60

Table 1. Average fresh root yield (FRY) and starch yield (SY) of various cassava varieties grown in variety trials conducted by VASI in Ha Tay and by Thai Nguyen University in Thai Nguyen from 1999 to 2001.

	Ha Tay									Thai Nguyen			Average	
	Root yield (t/ha)			Starch yield (t/ha)			Harvest index (HI)			FRY	SY	HI	FRY	SY
Varieties	1999	2000	2001	1999	2000	2001	1999	2000	2001	2001				
Xanh Vinh Phu	-	-	19.6	-	-	5.6	-	-	0.62	23.2	8.6	0.56	21.4	7.1
SM1254-4	33.3	28.0	-	7.8	6.9	-	0.68	0.72	-	-	-	-	30.7	7.4
SM2220-11*	32.3	22.1	-	9.2	6.7	-	0.58	0.57	-	-	-	-	27.2*	8.0*
SM1862-6	17.3	-	-	5.1	-	-	0.58	-	-	-	-	-	17.3	5.1
SM1868-1	21.5	24.5	-	6.5	8.0	-	0.56	0.57	-	-	-	-	23.0	7.3
KM60*	28.7	-	-	7.7	-	-	0.64	-	-	23.8	9.7	0.57	26.3*	8.7*
KM94*	31.2	27.2	22.9	9.6	8.8	7.2	0.58	0.69	0.60	19.8	8.1	0.56	25.3*	8.4*
KM95-3*	23.8	21.5	23.1	6.4	6.3	6.6	0.54	0.54	0.62	16.9	6.3	0.49	21.3*	6.4*
KM98-7*	-	22.2	22.7	-	6.7	7.2	-	0.57	0.68	25.8	10.1	0.63	23.6*	8.0*
KM21-10*	-	-	26.3	-	-	8.3	-	-	0.68	-	-	-	26.3*	8.3*
KM21-11	-	-	22.5	-	-	7.1	-	-	0.68	-	-	-	22.5	7.1
KM21-12	-	-	22.3	-	-	6.8	-	-	0.63	-	-	-	22.3	6.8
KM21-13	-	-	20.5	-	-	6.7	-	-	0.59	-	-	-	20.5	6.7
SM2219-11	-	-	-	-	-	-	-	-	-	17.1	7.2	0.48	17.1	7.2
OMR38-71-12	-	-	-	-	-	-	-	-	-	20.8	8.0	0.58	20.8*	8.0*
OMR 37-52-6*	-	-	-	-	-	-	-	-	-	23.1	9.2	0.61	23.1*	9.2*
OMR 37-52-8*	-	-	-	-	-	-	-	-	-	22.2	9.1	0.60	22.2*	9.1*

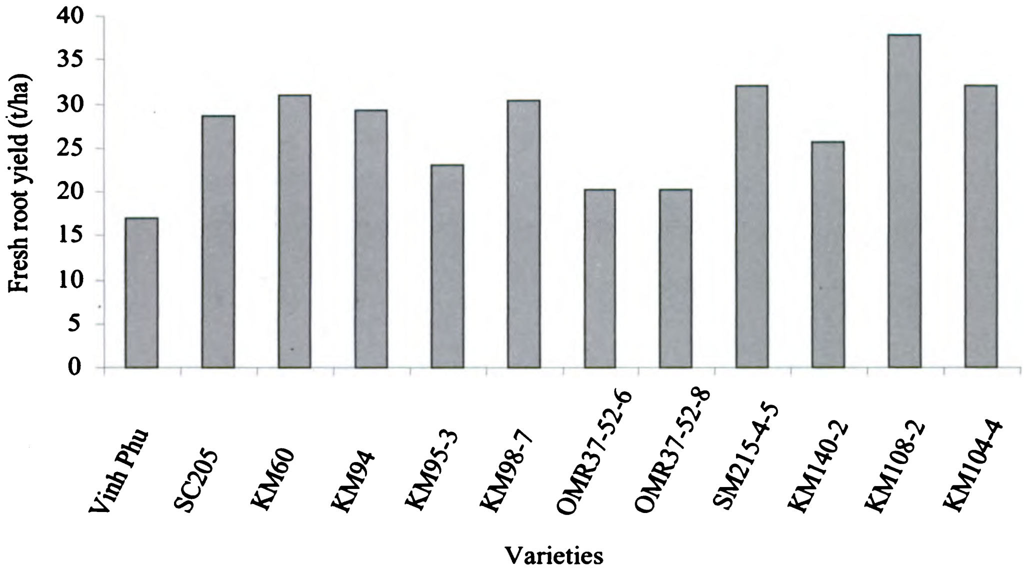


Figure 2. Average fresh root yields of cassava varieties tested in FPR trials conducted in 12 locations in north Vietnam from 2000 to 2002.

produced 37.4 t/ha in Thach Hoa in 2000 and KM 98-7 yielded 33.3 t/ha in Pho Yen district of Thai Nguyen province in 2001.

2. FPR cassava variety trials in the central part of Vietnam

Hue University of Agriculture and Forestry (HUAF) evaluated and selected good cassava cultivars with farmer participation in Hong Ha, Thuong Long and Huong Van communes in Thua Thien Hue province in the central part of Vietnam. Researchers at the University discussed with participating farmers how to conduct FPR cassava trials and organized field days/workshops in the field. Farmers selected the best varieties and decided which ones should be expanded. The results are presented in **Figure 3** and **Table 3**. The following varieties produced both high fresh root yield (FRY) and starch yield (SY): KM98-1, KM94, SM1447-7, SM937-26, KM108-2 and KM140-2. KM98-1 had an average FRY of 31.2 t/ha and SY of 8.6 t/ha, while KM94 had a FRY of 27.5 and SY of 8.1 t/ha. These two varieties have been tested by farmers for many years from 1998-2002. In 2002 farmers also liked some of the new varieties like KM108-2 and KM140-2. In particular, in 2000/01 KM98-1 reached FRY of 34.8 t/ha and SY of 8.8 t/ha on fallow soils in upland areas; this variety was preferred by 100% of farmers, because of its high yield and low cyanogenic potential, making this variety very suitable for both factory use and human consumption of minority people living in upland areas. Thus, KM98-1 and KM94 were selected for adoption and dissemination by farmers in Central Vietnam. And farmers are showing much interest in the new varieties KM108-2 and KM140-2 in the region. But, those new varieties should be evaluated for a few more years in different environments before being released.

Table 2. Fresh root yields of various cassava varieties grown in FPR trials conducted by farmers in 12 locations in north, Vietnam from 2000 to 2002.

	Thach Hoa		Tran Phu		Tien Phong	Thong Nhat			Thuong Am	Son La	Pho Yen	Am Yhang	Hong Tien	Van Yen	Minh Duc	Bao Than	Av.	Farmers' preference
Varieties	'00	'02	'00	'01	'00	'00	'01	'02	'00	'00	'01	'01	'01	'01	'02	'02		
Xanh Vinh Phu	17.0	18.5	-	24.2	22.8	14.0	12.0	12.0	13.2	-	18.7	12.5	25.5	-	11.5	20.0	17.1	20-30
SC205 (La Tre)	-	-	26.4	-	30.1	18.0	23.0	23.0	-	22.	-	-	-	24.9	-	-	28.5	25-35
KM60*	37.4		30.3	28.4	26.9	20.0	25.0	-	19.8	30.	-	25.0	28.6	37.0	-	-	30.9*	65-100
KM94*	42.8	31.7	33.3	27.6	29.8	22.5	26.5	26.5	21.0	32.	23.7	26.0	33.8	40.0	21.0	28.7	29.2*	71-100
KM95-3	32.9	-	21.3	26.3	30.5	14.0	14.0	14.0	19.8	24.	25.0	22.0	23.6	-	30.0	-	22.9	0
KM98-7*	-	-	31.2	30.1	31.9	24.0	20.0	20.0	26.4	-	33.3	25.0	25.1	-	25.0	-	30.3*	70 -100
OMR37-52-6	-	-	-	-	-	-	-	18.0	-	-	25.3	-	24.4	-	13.5	-	20.3	0
OMR37-52-8	-	-	-	-	-	-	-	18.0	-	-	23.7	-	22.7	-	16.5	-	20.2	0
SM215-4-5*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32.0	32.0*	100
KM140-2	-	25.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25.6	0
KM108-2*	-	37.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37.8*	100
KM104-4*	-	32.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32.0*	100

Table 3. Fresh root yield (FRY) and starch yield (SY) of cassava varieties grown in FPR trials conducted by farmers in three locations in Thua Thien-Hue province from 1999 to 2002.

Locations	Hong Ha				Thuong Long		Huong Van			Average		Farmers' preference (%)	Potential usage
	1999/'00		2000/'01		2001/'02		2002						
Varities	FRY	SY	FRY	SY	FRY	SY	HCN	FRY	SY	FRY	SY		
Nep (local)	26.9	8.0	15.6	5.0	17.9	5.3	85	16.6	4.2	19.3	5.6	50-67	food
Xanh Vinh Phu	28.3	8.5	24.2	7.4	21.7	5.7	110	21.5	5.8	23.9	6.9	35-37	food, feed
KM94*	29.2	8.8	24.9	7.9	28.0	8.0	202	27.8	7.7	27.5	8.1*	40-91	starch
KM98-1*	31.8	9.5	34.8	8.8	29.1	8.2	115	28.9	7.8	31.2	8.6 *	100	food, feed, starch
SM1447-7*	32.1	8.2	-	-	24.0	7.2	135	-	-	28.1	7.7 *	37-51	feed, starch
SM937-26*	-	-	30.3	9.2	26.4	7.3	165	25.5	6.8	27.4	7.8 *	37-67	feed, starch
KM98-5	-	-	-	-	29.0	8.1	177	23.4	6.1	26.2	7.1	36-50	feed, starch
KM21-12	-	-	-	-	-	-	-	26.1	6.7	26.1	6.7	0	feed, starch
KM111-1	-	-	-	-	-	-	-	21.2	5.1	21.2	5.1	0	feed, starch
KM108-2*	-	-	-	-	-	-	-	29.3	7.9	29.3	7.9*	60-85	feed, starch
KM140-2*	-	-	-	-	-	-	-	29.6	7.6	29.6	7.6*	60-85	feed, starch
KM98-7	-	-	-	-	-	-	-	26.7	6.8	26.7	6.8	30	feed, starch

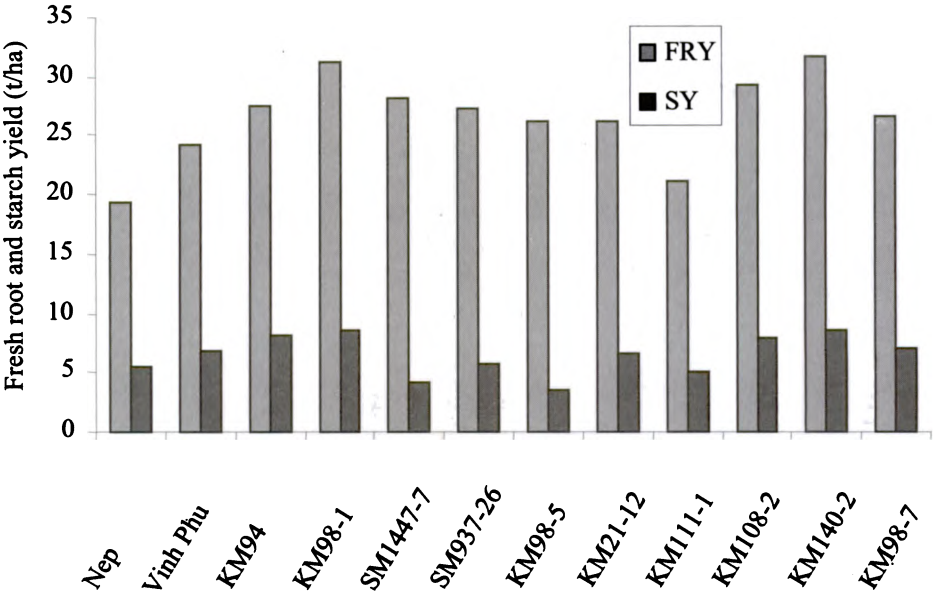


Figure 3. Average fresh root and starch yields of cassava vatieties tested in FPR trials conducted in three locations in the central part of Vietnam from 1999 to 2002.

3. FPR cassava variety trials in the south of Vietnam

Researchers at Hung Loc Agricultural Research Center (HARC) of the Institute of Agricultural Sciences (IAS) of South Vietnam have been very successful in the breeding and selection of new cassava varieties. HARC helped to set up FPR trials in various communities in south Vietnam.

From 1999-2000, HARC researchers selected some good varieties with high starch and fresh root yields and introduced these for evaluation by farmers (**Figure 4** and **Table 4**). These are KM94, KM98-5, KM98-6, KM98-1, KM98-2, KM60, SM937-26 and KM98-4, which produced on average 11.1, 11.4, 11.0, 9.8, 9.9, 9.5, 9.5 and 9.1 tonnes of starch/ha and fresh root yields of 40.9, 38.6, 36.8, 34.9, 33.2, 32.3, 34.1 and 42.5 t/ha, respectively.

These varieties were subsequently evaluated in FPR trials by farmers in nine locations in south Vietnam from 2000-2002. The results are presented in **Figure 5** and **Tables 5** and **6**. The data show that 71-100% or 60-100% of farmers preferred KM98-5 and KM98-1, because KM98-5 had a high SY of 10.7 and high FRY of 42.3 t/ha, while reaching 54.7 t/ha FRY and 14.3 t/ha SY in An Vien commune in 2000 (**Table 5**); these results for KM98-5 were repeated in 2001 (**Table 6**). **Tables 5** and **6** show that KM98-1 had similarly high yields, followed by KM94 and KM60. Some good new varieties are KM140-2, KM140-4 and KM108-2 recently evaluated and selected by 50-66% of farmers at 7 locations in the South (**Table 6**). In particular, KM 140-2 reached a SY of 12.4 t/ha and a fresh root yield of 45.3 t/ha in 2001/02 in An Vien commune.

So, in general, KM98-5, KM94 and KM98-1 have been preferred by farmers in south Vietnam. And KM140-2 and KM140-4 are promising cultivars that will be further tested in more locations with different environments before being released.

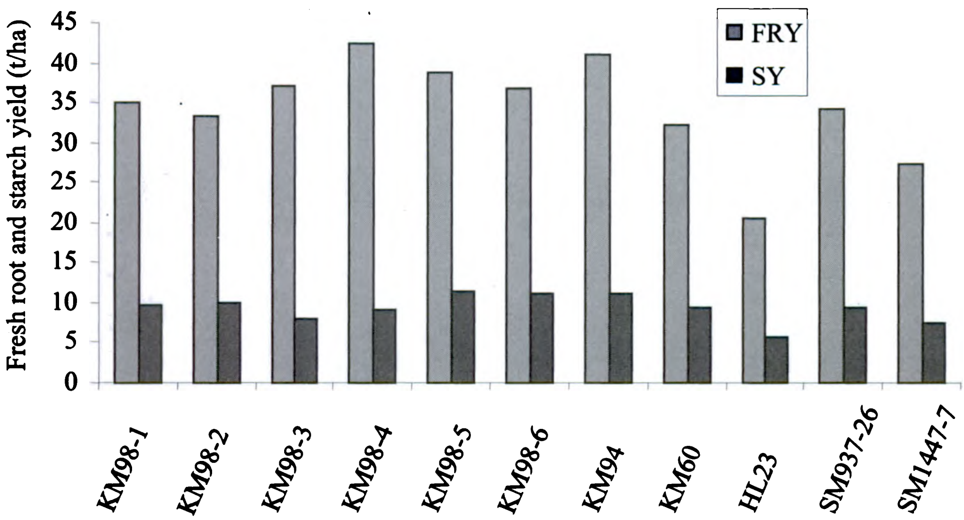


Figure 4. Average fresh root and starch yields of cassava varieties tested by farmers and Hung Loc researchers in south Vietnam in 1999/00 and 2000/01.

Table 4. Results of cassava variety trials conducted by researchers at Hung Loc Agric. Research Center in Dong Nai province, south Vietnam, in 1999 and 2000.

Varieties	1999			2000			Average	
	Root yield (t/ha)	Starch yield (t/ha)	Harvest index	Root yield (t/ha)	Starch yield (t/ha)	Harvest index	Root yield (t/ha)	Starch yield (t/ha)
KM98-1*	43.1	12.4	0.74	26.6	7.2	0.79	**34.9**	**9.8***
KM98-2*	39.6	12.1	0.59	26.7	7.7	0.71	**33.2**	**9.9***
KM98-3	36.9	11.5	0.59	-	-	-	36.9	8.1
KM98-4*	42.5	9.1	0.58	-	-	-	**42.5**	**9.1***
KM98-5*	46.0	13.0	0.58	31.2	9.8	0.70	**38.6**	**11.4***
KM98-6*	46.9	13.7	0.58	26.7	8.2	0.71	**36.8**	**11.0***
KM94 (Control*)	48.5	12.3	0.57	33.2	9.9	0.67	**40.9**	**11.1***
KM60 (Control*)	38.0	11.3	0.59	26.5	7.6	0.70	**32.3**	**9.5***
HL23 (Control*)	25.4	7.0	0.45	15.3	4.3	0.63	20.4	5.7
SM937-26*	-	-	-	34.1	9.5	0.71	**34.1**	**9.5***
SM1447-7	-	-	-	27.2	7.5	0.71	27.2	7.5

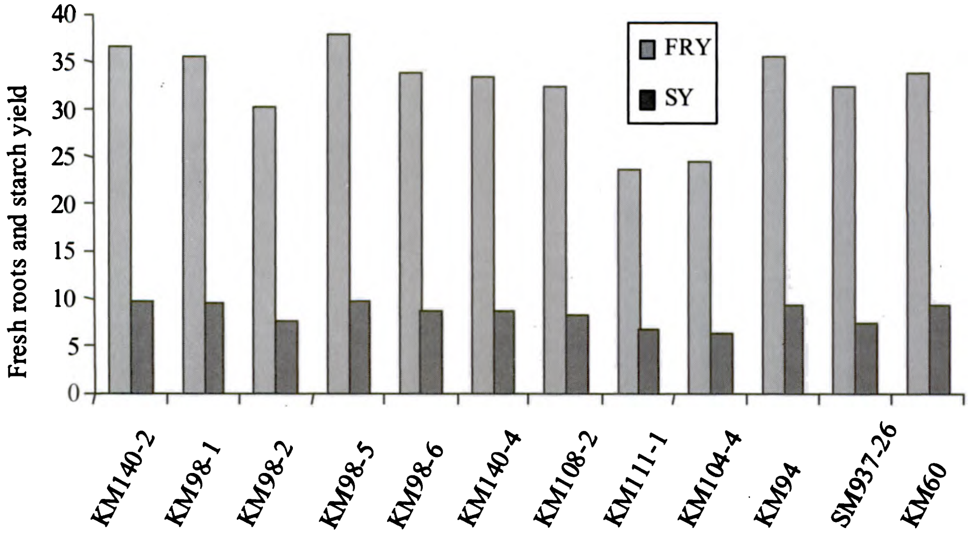


Figure 5. Average fresh root and starch yields of cassava varieties tested in FPR trials conducted in nine locations in south Vietnam from 2000 to 2002.

We may ask the question: what are the most suitable cassava varieties for all of Vietnam? There are seven varieties that have been tested and selected in many locations in Vietnam. Of these, KM60 and KM94 have been widely disseminated during the past 5-7 years in our country. They have become the check varieties with which to compare the new ones. **Figure 6** shows that for the whole of Vietnam KM98-1 and KM98-5 have produced the highest FRY and may be considered equal in starch yield with the two check varieties. Presently, KM94, KM60, KM98-1 and KM98-5 are widely disseminated. And recently, KM140-2 has become a very promising clone.

Table 7 shows the average farmers' preference for cassava varieties evaluated in FPR trials in 24 locations in Vietnam from 1999 to 2002. Most farmers liked KM98-1, KM94, KM140-2 and KM108-2. Those varieties were preferred by 72.5 to 80.3% of farmers who conducted and evaluated these trials; these were followed by KM98-5, KM98-7, KM60 and SM937-26. It has recently been estimated that the total area of new varieties in Vietnam has reached about 90,000 ha in 2002.

FARMER CAPACITY BUILDING THROUGH FARMER PARTICIPATORY RESEARCH (FPR) ABOUT SELECTION AND DEVELOPMENT OF NEW CASSAVA VARIETIES

Farmer capacity building is a process through which farmers and researchers help each other in order to improve their knowledge and management skill by conducting cassava research for sustainable development.

Table 5. Fresh root and starch yields (t/ha) of cassava varieties tested in FPR trials conducted by farmers in four locations in south Vietnam in 2000.

	An Vien		Hill 61		Phuoc Long		Thu Duc		Average		Farmers' preference
Varieties	FRY	SY	FRY	SY	FRY	SY	FRY	SY	FRY	SY	(%)
KM98-5	54.7	14.3	36.9	10.0	29.0	7.7	48.7	-	**42.3**	**10.7**	71 - 100
KM98-1	47.3	12.8	38.9	10.7	28.3	7.5	42.3	-	**39.2**	**10.3**	71 - 100
SM937-26	45.0	12.7	33.7	9.3	-	-	38.8	-	39.2	7.3	0
KM98-6	43.1	11.0	33.9	8.8	24.7	5.9	-	-	33.9	8.6	0
KM98-2	33.6	8.6	31.9	8.5	25.1	5.8	-	-	30.2	7.6	0
KM94 (Control)	40.9	11.3	36.6	10.2	26.1	7.1	57.6	-	**40.3**	**9.5**	65 - 100
KM 60 (Control)	34.2	8.6	33.7	9.5	-	-	-	-	**34.0**	**9.1**	30 - 50

Table 6. Fresh root and starch yields (t/ha) of cassava varieties tested in FPR trials conducted by farmers in seven locations in south Vietnam in 2001 and 2002.

	An Vien (2001)		Hill 61 (2001)		Hung Thinh (2001)		Truong Hoa (2001)		Dong Tam (2002)		Minh Lap (2002)		Suoi Rao (2002)		Average		Farmers' preference
Varieties	FRY	SY	FRY	SY	FRY	SY	FRY	SY	FRY	SY	FRY	SY	FRY	SY	FRY	SY	(%)
KM140-2*	45.3	12.4	34.4	9.0	38.7	9.5	30.7	8.9	-	-	-	-	33.5	9.1	36.5	9.8*	60 - 85
KM98-5*	48.7	12.8	29.7	7.9	35.2	7.1	-	-	28.1	-	29.6		30.6	8.3	33.7	9.0*	60 - 85
KM98-1*	43.2	10.4	28.7	7.3	33.7	8.0	-	-	29.5	-	26.4		29.9	7.9	31.9	8.4	50
KM140-4	-	-	32.9	8.6	37.2	9.0	28.8	7.9	-	-	-	-	34.8	9.4	33.4	8.7*	50 - 66
KM108-2*	39.2	8.5	35.6	10.0	27.1	6.9	-	-	-	-	-	-	28.1	7.4	32.5	8.2	50
KM111-1	23.3	9.6	17.7	4.4	28.3	6.7	22.2	6.3	-	-	-	-	27.4	7.2	23.8	6.8	0
KM104-4	-	-	17.4	4.7	22.8	5.9	-	-	-	-	-	-	33.2	8.7	24.5	6.4	0
KM94 (Control)	38.5	8.8	30.9	8.4	33.2	8.4	27.7	8.2	24.2	-	23.3	-	35.9	9.9	30.5	8.7*	50
SM937-26	-	-	-	-	-	-	-	-	27.1	-	24.4	-	-	-	25.8	-	-

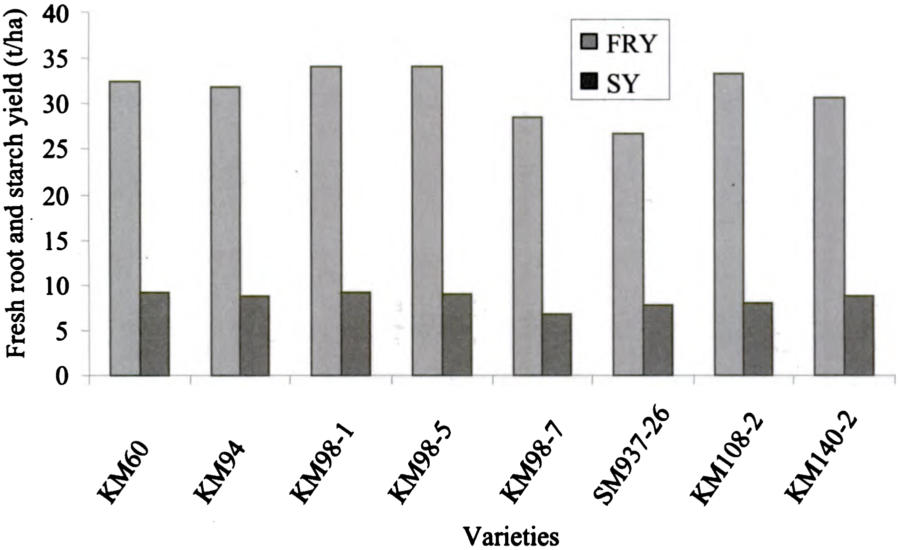


Figure 6. Average fresh root and starch yields of cassava varieties tested in FPR trials conducted in 24 locations in Vietnam from 1999 to 2002.

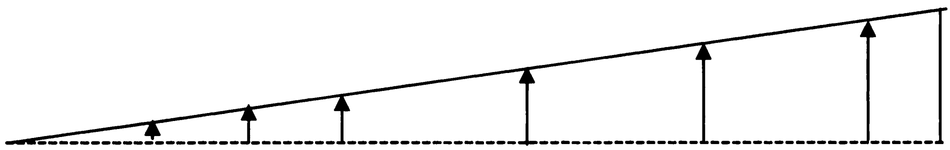
Table 7. Average farmers' preference for cassava varieties tested in FPR trial in 24 locations in Vietnam from 1999 to 2002.

Varity	Farmers' preference (%)
KM98-1	80.3
KM108-2	73.9
KM94	73.8
KM140-2	72.5
KM98-5	67.0
KM98-7	66.7
KM60	61.3
SM937-26	52.3

The process of capacity building for farmers to conduct FPR cassava variety trials includes the following steps (**Figure 7**):

1. Objective understanding (Passive participation)
2. Study tour/visit experiments (Information supplying-Some participation)
3. Discuss and farmers decide about activities (Partial participation)
4. Implementation planning and Training (Equal participation)
5. Setting out and taking care of trials by farmers with help of researchers (Active participation)

6. Evaluation and selection of promising varieties at field day/workshop in the commune (Participatory activity)



Steps in capacity building for Farmer Participatory Research

Figure 7. Extent of farmer participation during the various steps of FPR varietal evaluation.

Farmers decide which cassava varieties to expand in their fields. So farmers should clearly understand the objectives of conducting these trials and the steps in the process of conducting research.

Farmers receive information in order to clearly understand the research objectives. So, we organize a study tour to visit research trials where varieties are being developed so they can select those that seem most suitable.

The FPR program's activities are important for conducting the trials in their fields. Researchers facilitate the discussion with farmers to decide on the activities to be undertaken. They know what should be done in participatory cassava research, such as following the experiment's lay-out plan, fertilizer application, weeding etc.

Before farmers can set up and conduct trials by themselves, they need to be trained in the process of doing varietal evaluation trials. Researchers train farmers and village extensionists, who can then advice farmers and monitor the cassava variety trials.

For active participation in research, farmers are asked to take care of their trials on their own fields under the guidance of researchers or extensionists. After the training course, farmers carry out the implementation plan by themselves, such as fertilizer application, weeding, and hilling up...on time

At time of harvest, a field day is organized to evaluate the varieties and to select the most promising ones. A workshop may be organized at the research sites to discuss the results and the lessons learned, to get feedback from farmers, so as to further develop more suitable varieties. For research on sustainable development of high yielding cassava varieties, the participation of farmers in variety evaluation and selection is an essential part of the process, while it empowers farmers to contribute to their own and their community's development.

CONCLUSIONS

In the north of Vietnam: Cassava varieties selected for having high fresh root yields and starch content by farmers in 12 locations in Thai Nguyen, Tuyen Quang, Phu Tho, Ha Tay and Hoa Binh provinces include KM94, KM60, KM98-7, KM21-10, SM2220-11, OMR38-71-12, OMR37-52-6 and OMR37-52-8. Of these, KM94, KM98-7 and KM60 were preferred by 65-100% of farmers and were further disseminated.

In the central part of Vietnam: Cassava varieties were first evaluated by researchers in HUAF and the best were introduced to farmers for testing on their own fields. KM98-1 was the variety preferred by 100% of farmers, because of high yield and low cyanogenic potential, making this variety suitable for both factory use and human consumption. Besides KM98-1, farmers also liked KM98-5 and KM94, while they have also become interested in KM108-2 and KM140-2.

In the south of Vietnam: KM98-5, KM94 and KM98-1 were the preferred varieties; these were further expanded by farmers in the south. KM140-2 and KM140-4 are promising cultivars that will be further tested in more locations with different environments.

In Vietnam as a whole, most farmers like KM98-1, KM94, KM140-2 and KM108-2. These varieties were preferred by 72-80% of farmers, followed by KM98-5, KM98-7, KM60 and SM937-26. The areas planted with KM94 and KM60 have expanded rapidly every year, followed by KM98-1 and KM98-5. Recently, KM140-2 has been introduced as a new promising clone.

2. PRINCIPLES OF FARMER PARTICIPATORY RESEARCH

- Farmers and researchers should work together as both have useful and complementary skills and knowledge
- The FPR trials should be simple and with relatively few treatments (3-5) so that farmers can easily monitor and evaluate the various treatments
- Give farmers the opportunity to make their own evaluations and selections
- Train farmers in simple analytical skills
- Build farmer's self-confidence in research as it empowers farmers to contribute to their own and their community's development.

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FARMER PARTICIPATORY RESEARCH (FPR) TRIALS ON CASSAVA INTERCROPPING SYSTEMS IN VIETNAM

Tran Thi Dung[1] *and Nguyen Thi Sam*[1]

ABSTRACT

Farmers in Vietnam practiced intercropping before the FPR project. However, they have increased the area of cassava intercropped as a result of the project. A total of 44 FPR intercropping trials were conducted by farmers on their own fields from 1999 to 2001. The results show that intercropping cassava with peanut, black or red bean (actually cowpea) or mungbean increased their net income, improved the soil, and reduced weeds and soil losses by erosion as compared to the monocropping system. As a result of these trials intercropping with peanut has been more widely adopted by farmers in Vietnam.

INTRODUCTION

Intercropping with food crops and grain legumes is a common practice in tropical cropping systems. Since cassava is widely spaced and it takes several months to completely cover the soil, intercropping during the early stage of crop development generally results in the highest land use efficiency, less erosion and higher total income. Estimates indicate that at least one-third of cassava grown worldwide is intercropped (Cock, 1985). Intercropping cassava tends to minimize the risk of crop failure. It generally does not affect the total crop value as the reduced yield of the main crop is compensated by the yield of the intercrops. In sloping areas, intercropping reduces nutrient loss and maintains soil fertility. Biological nitrogen fixation is an important N resource for cassava intercropped with legumes, and the incorporation of the residues of the intercrops may result in an increase in soil organic matter. Therefore, Vietnamese farmers have readily adopted cassava intercropping as a useful production system (**Table 1**).

RESULTS OF FPR TRAILS IN VIETNAM

A. In the North

Intercropping cassava with peanut is more common in north Vietnam, as it is beneficial and easy to adopt. After several years of conducting FPR intercropping trails using various crop species and systems, farmers were most interested in intercropping cassava with peanut in two rows, planted at the same time as cassava. Results confirm that intercropping cassava with peanut was able to maintain cassava yields (Nguyen Hue *et al.*, 2001; Nguyen The Dang *et al.*, 2001), while cassava and peanut planted at the same time (Vu Thi Luu *et al.*, 2001) and in two rows of intercrops (Trinh Phuong Loan *et al.*, 2001) were considered the best system.

Tables 2 to **8** show that in Ha Tay, Phu Tho, Tuyen Quang and Yen Bai provinces of north Vietnam intercropping with one or two rows of peanut between cassava rows was optimum, both in terms of the yields of cassava and peanut, and in increasing the net income. This practice has now been widely adopted by farmers.

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Table 1. Number of FPR intercropping trials conducted by farmers in various sites in Vietnam from 1999 to 2001, and the number of households adopting this technology.

Village, district, province	Number of FPR intercropping trials			Adoption (No. of farmers)	
	1999	2000	2001	2000	2001
Tran Phu, Chuong My, Ha Tay	-	3	3	5	60
Thach Hoa, Thach That, Ha Tay	-	-	3	-	-
Dac Son, Pho Yen, Thai Nguyen	-	-	-	-	8
Tiẹn Phong, Pho Yen, Thai Nguyen	-	-	4	37	40
Minh Duc, Pho Yen, Thai Nguyen	-	-	3	-	25
An Thang, Son Duong, Tuyen Quang	-	-	2	-	-
Hong Tien, Son Duong, Tuyen Quang	-	-	1	-	-
Yen Hung, Van Yen, Yen Bai	-	-	1	-	-
Dong Rang, Luong Son, Hoa Binh	-	-	2	-	45
Thong Nhat, Phu Ninh, Phu Tho	-	-	2	-	-
Hong Ha, A Luoi, Thua Thien Hue	-	2	3	-	5
Thuong Long, Nam Dong, Thua Thien Hue	-	-	2	-	-
An Vien, Thong Nhat, Dong Nai	3	3	-	-	5
Dong Tam, Dong Xoai, Binh Phuoc	-	2	-	-	5
Minh Lap, Dong Xoai, Binh Phuoc	-	-	-	-	5
Suoi Rao, Chau Duc, Ba Ria-Vungtau	-	2	2	-	-
Son Binh, Chau Duc, Ba Ria-Vungtau	-	-	1	-	-
Total	**3**	**12**	**29**	**42**	**198**

1. In Ha Tay province:

Table 2. Average results of three FPR intercropping trials conducted by farmers in Tran Phu commune, Chuong My district in Ha Tay province in 2000/01.

Treatments	Cassava yield (t/ha)	Intercrop yield (t/ha)	Gross income[2)]	Product. costs[3)]	Net income	Farmers' preference (%)
			----------('000 dong/ha)----------			
Cassava monoculture	29.03	-	8,709	3,900	4,809	-
C+peanut (1 row)	32.50	0.887	14,185	5,143	9,042	-
C+peanut (2 rows)	30.43	1.760	17,929	5,386	12,543	94.0
C+black bean (1 row)	27.27	0[1)]	8,181	5,020	3,161	-
C+black bean (2 rows)	25.83	0[1)]	7,749	5,140	2,609	-

[1)] No yield of black bean due to drought

[2)] Prices: cassava dong 300/kg fresh roots
peanut 5,000/kg dry pods

[3)] Costs: peanut seed 6,000/kg dry grain (need 40.5 kg/ha for 1 row, 81 kg/ha for 2 rows)
black bean seed 6,000/kg dry grain (need 20 kg/ha for 1 row, 40 kg/ha for 2 rows)
Cost cassava production 2.8 mil. dong/ha
Labor costs intercropping 1.0 mil. dong/ha
Cost manure and application 1.1 mil. dong/ha

Table 3. Average results of three FPR intercropping trials conducted by farmers in Tran Phu commune, Chuong My district in Ha Tay province in 2001/02.

Cropping system[1)]	Cassava root yield (t/ha)	Intercrop yield (t/ha)	Gross income[2)]	Production costs[3)]	Net income	Farmers' preference (%)
			------------('000 dong/ha)---------			
1. Cassava monoculture	29.46	-	8,838	3,660	5,178	0
2. C+ peanut (1 row)	22.37	0.975	11,586	4,546	7,040	0
3. C+ peanut (2 rows)	31.96	2.125	20,213	5,432	14,781	100
4. C+ mungbean (1 row)	33.45	0.133	11,099	4,560	6,539	12
5. C+ watermelon (2 rows)	32.09	0	9,627	3,860	5,764	0

1) Peanut planted 10 days before cassava
2) Prices: cassava dong 300/kg fresh roots
peanut 5,000/kg dry pods
mungbean 8,000/kg dry grain
3) Cost of fertilizers 859,500/ha

Table 4. Average results of four FPR intercropping trials conducted by farmers in Thach Hoa commune, Thach That district in Ha Tay province in 2001.

Cropping system[1)]	Cassava yield (t/ha)	Peanut yield (t/ha)	Gross income[2)]	Production costs[2)]	Net income	Farmers' preference (%)
			-----------('000 dong/ha)---------			
1. Cassava monoculture	24.9	-	7,470	3,660	3,810	0
2. C+1 row of peanut	23.1	1.293	13,395	4,546	8,879	0
3. C+2 rows of peanut	27.8	1.870	17,690	5,432	12,258	100
4. C+3 rows of peanut	29.9	2.220	20,070	6,118	12,932	0

1) Cassava planted 2 weeks after peanut
2) Prices: cassava dong 300/kg fresh roots
peanut 5,000/kg dry pods
peanut seed 6,000/kg dry pods
Source: *Trinh Phuong Loan et al., 2001.*

2. In Tuyen Quang province:

Table 5. Results of an FPR intercropping trial conducted by a farmer in Hong Tien commune of Son Duong district in Tuyen Quang province in 2001.

Treatments[1)]	Yield (t/ha) cassava	Yield (t/ha) intercrop	Gross income[2)]	Production costs[2)] labor	seed	fert.	Total	Net income	Farmers' preference (%)[3)]
			--------------------('000 dong//ha)------------------						
1. Cassava monoculture	23.60	-	11,800	2,900	-	1,430	4,330	7,470	11
2. C +maize	26.30	1.08	14,770	3,900	200	1,430	5,530	9,240	2
3. C +mungbean	33.30	-	16,650	3,900	250	1,430	5,580	11,070	5
4. C +peanut	29.10	0.76	18,350	3,900	300	1,430	5,630	12,720	50

1) All plots were fertilized with 1,100 kg/ha of 7:4:7 = 1.43 mil. dong/ha
2) Prices: cassava dong 500/kg fresh roots
maize 1,500/kg dry grain
peanut 5,000/kg dry pods
7:4:7 fertilizers 1,300/kg
maize seed 4,000/kg (use 50 kg/ha)
mungbean seed 12,500/kg (use 20 kg/ha)
peanut seed 6,000/kg (use 50 kg/ha)
labor cost of cassava monoculture: 2.8 mil. dong/ha
cost of fertilizer application: 0.1 mil. dong/ha
cost of intercropping: 0.3 mil. dong/ha
3) Out of 46 farmers

Table 6. Results of an FPR intercropping trial conducted by a farmer in Am Thang commune of Son Duong district in Tuyen Quang province in 2001.

Cropping system[1)]	Yield (t/ha)		Gross income[2)]	Production costs[2)]				Net income	Farmers' preference
	cassava	intercrop	labor	seed	fert.	Total			
			('000 dong//ha)						(%)[3)]
1.Cassava monoculture	15.00	-	7,500	2,900	-	1,430	4,330	3,170	11
2. C +maize	32.50	1.030	17,795	3,900	200	1,430	5,530	12,265	2
3. C +mungbean	31.20	0.400	18,000	3,900	250	1,430	5,580	12,420	5
4. C +peanut	23.70	0.500	14,350	3,900	300	1,430	5,630	8,720	50

[1)] 1.100 kg/ha of 7:4:7 applied to all treatments = 1.43 mil. dong/ha

[2)] Prices:
- cassava — dong 500/kg fresh roots
- maize — 1,500/kg dry grain
- peanut — 5,000/kg dry pods
- mungbean — 6,000/kg dry grain
- maize seed — 4,000/kg dry grain (use 50 kg/ha)
- peanut seed — 6,000/kg dry pods (use 50 kg/ha)
- mungbean seed — 12,500/kg dry grain (use 20 kg/ha)

[3)] Out of 46 farmers

Source: *Nguyen Thi Dang et al., 2001.*

3. In Phu Tho province:

Table 7. Results of two FPR intercropping trials conducted by farmers in Thong Nhat commune of Phu Ninh district in Phu Tho province in 2001/02.

Treatments[1)]	Cassava yield (t/ha) Hue	Luc	Av.	Intercrop yield (t/ha) Hue	Luc	Av.	Gross income[2)]	Product. costs[2)]	Net income
							('000 dong/ha)		
C monoculture	15.5	16.2	15.8	-	-	-	6,320	4,539	1,781
C+peanut	14.2	15.8	15.0	0.80	1.00	0.90	11,400	6,374	5,026
C+black bean	14.2	16.2	15.2	0.42	0.33	0.37	7,375	6,374	1,001

[1)]Fertilizers: 10 t FYM +80 N+40 P_2O_5+80 K_2O/ha = 1.924 mil. dong/ha

[2)]Prices:
- cassava — dong 400/kg fresh roots
- peanut — 6,000/kg dry pods
- black bean — 3,500/kg dry grain
- urea (45%N) — 2,000/kg
- SSP (17% P_2O_5) — 1,000/kg
- KCl (60% K_2O) — 2,500/kg
- FYM — 100/kg
- labor — 7,500/manday
- labor for monoculture cassava (272 md/ha) — 2.040 mil. dong/ha
- labor for intercropped cassava (450 md/ha) — 3.375 mil. dong/ha
- labor for fertilizer application (10 md/ha) — 0.075 mil. dong/ha
- bean seed — dong 5,000/kg — 0.5 mil. dong/ha
- peanut seed — 10,000/kg — 0.5 mil. dong/ha
- cassava stakes — 0.5 mil. dong/ha

Source: *Nguyen Hue et al., 2001.*

4. In Yen bai province:

Table 8. Results of an FPR intercropping trial conducted by farmers in Yen Hung commune of Van Yen district in Yen Bai province in 2001.

Treatments	Cassava yield (t/ha)	Intercrop yield (t/ha)	Gross income --------(mil.	Product. costs dong/ha)	Net income -------	Farmers' (%)
1. Cassava monoculture	41.5	-	12.45	4.20	8.25	0
2. C+ peanut (1 row)	39.2	0.970	16.61	6.60	10.01	
3. C+ peanut (2 rows)	38.5	1.660	19.85	7.60	12.25	30
(15 days before planting cassava)						
4. C+ peanut (1 row)	39.6	0.890	16.33	6.60	9.73	
5. C+ peanut (2 rows)	39.0	1.530	19.35	7.60	11.75	70
(at the same time as cassava)						
6. C+ peanut (1 row)	40.8	0.690	15.69	6.60	9.09	0
7. C+ peanut (2 row)	40.0	0.960	16.80	7.60	9.20	
(15 days after planting cassava)						

Prices: cassava: dong 300/kg fresh roots SSP: dong 1,100/kg
peanut: 5000/dry pods labor: 15,000/manday
urea: 2,200/kg

Source: *Vu Thi Luu et al., 2001.*

B. In the Central Region

1. In Thua Thien-Hue province:

In Thua Thien-Hue province intercropping with grain legumes, like peanut, red bean and black bean, did not significantly reduce the yield of cassava. In poor soils or without fertilizer application, cassava intercropping with red bean or black bean gave the best result (**Table 9**). In fertile soils or with fertilizer applications, cassava intercropping with peanut or red bean produced high yields of both the intercrops and cassava (**Table 10**). Based on the results of these FPR trials, almost all farmers selected this planting method.

Table 9. Average results of two FPR intercropping trials conducted by farmers in Hong Ha Commune of A Luoi district in Thua Thien-Hue province in 2000.

Intercropping treatments	Cassava yield (t/ha)	Starch content (%)	Intercrop yield (t/ha)	Gross income[1] --------('000	Product. costs[2] dong/ha)	Net income --------	Farmers' (%)
1. Cassava monoculture	7.14	27.0	-	3,570	1,800	1,770	0
2. C+red bean	8.80	27.3	0.600	6,500	2,940	3,560	100
3. C+peanut	8.77	27.7	0.400	5,985	4,060	1,925	0
4. C+black bean	8.84	27.8	0.600	6,520	2,940	3,580	100
5. C+mungbean	8.73	27.6	0.300	6,165	3,180	2,985	54

[1] Prices: cassava dong 500/kg fresh roots peanut seed 8,500/kg (need 160 kg/ha)
red bean 3,500/kg dry grain red/black bean seed 6,000/kg (need 40 kg/ha)
peanut 4,000/kg dry pods mungbean seed 12,000/kg (need 40 kg/ha)
black bean 3,500/kg dry grain labor 15,000/manday
mungbean 6,000/kg dry grain

[2] Cost of cassava monoculture: 1.8 mil. dong/ha (120 mandays)
Cost of intercropping: 0.9 mil. dong/ha (60 mandays)

Table 10. Results of an FPR intercropping and fertilizer application trial conducted by farmers in Thuong Long commune of Nam Dong district in Thua Thien-Hue province in 2001/02.

Cropping system[1)]	Cassava yield (t/ha)		Starch content (%)		Intercrop yield (t/ha)	
	no fert.	with fert.	no fert.	with fert.	no fert.	with fert.
1. Cassava monoculture	9.9	26.0	26.7	27.8	-	-
2. C + red bean	9.7	25.7	26.4	28.1	0.500	0.750
3. C + peanut	9.6	25.1	26.8	27.9	0.430	0.600
4. C + black bean	9.7	24.9	26.7	27.7	0.500	0.750
5. C + mungbean	9.6	25.0	26.5	28.0	0.300	0.450

Cropping system[1)]	Gross income[2)] ('000 dong/ha)		Product. costs[2)] ('000 dong/ha)		Net income ('000 dong/ha)		Farmers' Preference (%)	
	no fert.	with fert.	no fert.	with fert.	no fert.	with fert.	no fert.	with fert.
1. Cassava monoculture	4,950	13,000	1,800	3,700	3,150	9,300	0	0
2. C + red bean	6,600	15,475	2,940	4,840	3,660	10,630	0	100
3. C + peanut	6,950	15,550	4,028	5,928	2,922	9,622	0	100
4. C + black bean	6,350	14,700	2,940	4,840	3,410	9,860	0	10
5. C + mungbean	6,600	15,200	3,180	5,080	3,420	10,120	0	74

1) Fertilizers applied: 60 kg N+60 P_2O_5+120 K_2O/ha

2) Prices:

Prices:	cassava	dong 500/kg fresh roots
	peanut	5,000/kg dry pods
	red bean	3,500/kg dry grain
	black bean	3,000/kg dry grain
	mungbean	6,000/kg dry grain
Costs:	urea	3,500/kg
	SSP (17% P_2O_5)	1,500/kg
	KCl (60% K_2O)	3,000/kg
	labor	15,000/manday
	peanut seed	8,300/kg dry pods (use 160 kg/ha)
	red/black bean seed	6,000/kg (use 40 kg/ha)
	mungbean seed	12,000/kg (use 40 kg/ha)

Labor for cassava monoculture 120 mandays/ha = 1.8 mil. dong/ha
Labor for fertilizer application 20 mandays/ha = 0.3 mil. dong/ha
Fertilizer costs: 1.6 mil.dong/ha
Labor for intercropping 60 mandays/ha = 0.9 mil. dong
Source: *Nguyen Thi Cach et al.,2001.*

C. In the South

Short-duration crops such as mungbean, peanut and maize were intercropped with cassava. The results indicate that intercropping cassava with peanut or mungbean was most effective in increasing farmers' income as compared to monocropped cassava. The highest net income was obtained for the crop combination of cassava+peanut in Dong Nai, Binh Phuoc and Baria-Vungtau provinces (**Tables 11, 12, 13** and **14**). The next best combination was cassava+mungbean in Baria-Vungtau province (**Table 15**) . However, the yield of cassava intercropped with maize was significantly lower than that of the monocrop. In this case, the cassava yield was affected by the competition for nutrients and water, or by shading out by tall maize plants. **Tables 15** and **16** show that intercropping with peanut or mungbean produced better yields and income than intercropping with maize.

1. In Dong Nai province:

Table 11. Average results of three FPR intercropping trials conducted by farmers in An Vien village of Thong Nhat district in Dong Nai province in 1999/2000.

Treatments	Cassava root yield (t/ha)	Intercrop yield (t/ha)	Gross income[1]	Production costs[1]	Net income	Farmers' preference[2] (%)
			-------------	('000 dong/ha)	-----------	
1. Cassava monoculture	25.96	-	6,480	2,950	3,530	20
2. C+peanut (1row)	26.59	0.66	9,287	4,050	5,237	60
3. C+peanut (2 rows)	25.27	0.28	8,195	3,785	4,320	20

[1] Prices: cassava dong 290/kg fresh roots
peanut 4000/kg dry pods
urea 2000/kg
SSP 1000/kg
KCl 2200/kg
labor 20,000/manday

[2] Number of participating farmers: 20

Table 12. Average results of three FPR intercropping trials conducted by farmers in An Vien village of Thong Nhat district in Dong Nai province in 2000/01.

Treatments	Cassava root yield (t/ha)	Intercrop yield (t/ha)	Gross income[1]	Production costs[1]	Net income	Farmers' preference[2] (%)
			------------	('000 dong/ha)	------------	
1. Cassava monoculture	30.60	-	8,874	4,298	4,576	50
2. C+peanut	30.28	0.20	9,781	5,248	4,533	50
3. C+cowpea	23.89	0	6,928	4,798	2,130	0
4. C+mungbean	29.74	0	8,625	4,698	3,927	0

[1] Prices: cassava dong 290/kg fresh roots
peanut 5000/kg dry pods
urea 2300/kg
SSP 1000/kg
KCl 2300/kg
labor 25,000/manday

[2] Number of participating farmers: 22

Table 13. Average results of three FPR intercropping trials conducted by farmers in An Vien village of Thong Nhat district in Dong Nai province in 2001/02.

Treatments[1)]	Cassava root yield (t/ha)	Peanut yield (t/ha)	Gross income[2)]	Production costs[2)]	Net income	Farmers' preference (%)
			-----------('000 dong/ha)-----			
1. Cassava monoculture	29.15	-	12,243	4,651	7,592	30
2. C+ peanut (1 row)	33.32	-	13,994	5,051	8,943	50
3. C+ peanut (2 rows)	30.73	-	12,907	5,451	7,456	20

[1)] Fertilizers: 80 N+40 P_2O_5+80 K_2O/ha = 950,850 d/ha

[2)] Prices:

cassava	dong	420/kg fresh roots
urea (45%N)		2,300/kg
SSP (17% P_2O_5)		1,000/kg
KCl (60% K_2O)		2,300/kg
labor for planting		300,000 d/ha
land preparation		600,000 d/ha
peanut seed (8,000 d/kg)		400,000 d/ha for one row
fertilizer application		100,000 d/ha
weeding (3x)		1,600,000 d/ha
harvest (55 md/ha)		1,100,000 d/ha
labor		20,000 d/md

Source: *Nguyen Huu Hy et al., 2002.*

2. *In Binh Phuoc province:*

Table 14. Average results of two FPR intercropping trials conducted by farmers in Dong Tam village of Dong Xoai district in Binh Phuoc province in 2000/01.

Treatments	Cassava root yield (t/ha)	Intercrop yield (t/ha)	Gross income[1)]	Production costs[1)]	Net income	Farmers' preference[2)] (%)
			-----------('000 dong/ha)-----------			
Cassava monoculture	30.23	-	8,767	3,879	4,888	60
C+cowpea	29.33	-	8,506	4,359	4,147	0
C+peanut	30.22	0.225	9,889	5,139	4,750	40
C+mungbean	29.70	-	8,613	4,299	4,314	0

[1)] Prices:

cassava	dong	290/kg fresh roots
peanut		5,000/kg dry pods
peanut seed		6,000/kg (need 100 kg/ha)
cowpea seed		6,000/kg (need 30 kg/ha)
mungbean seed		8,000/kg (need 15 kg/ha)

[2)] Number of participating farmers: 24

Source: *Nguyen Huu Hy et al., 2001.*

3. In Baria-Vungtau province:

Table 15. Average results of two FPR intercropping trials conducted by farmers in Suoi Rao village of Chau Duc district in Baria-Vungtau province in 2000/01.

Treatments	Cassava root yield (t/ha)	Starch content (%)	Intercrop yield (t/ha)	Gross income[1)]	Product. costs[1)]	Net income	Farmers' preference (%)
				------('000 dong/ha)-----			
Cassava monoculture	36.13	30.4	-	10,839	6,843	3,996	-
C + peanut	40.20	29.6	0.524	14,890	8,360	6,530	67
C + mungbean	42.24	30.0	0.287	14,394	7,600	6,794	100
C + maize	29.07	27.7	4.653	13,467	8,200	5,267	-

1) Prices: cassava dong 300/ kg fresh roots
peanut 5,400/ kg dry pods
mungbean 6,000/ kg dry grain
maize 1,020/ kg dry grain

Table 16. Average results of three FPR intercropping trials conducted by farmers in Suoi Rao and Son Binh villages of Chau Duc district in Baria-Vungtau province in 2001/02.

Treatments	Cassava root yield (t/ha)	Intercrop yield (t/ha)	Starch content (%)	Gross income[1)]	Product. costs	Net income	Farmers' preference (%)
				---------('000 dong/ha)-------			
Cassava monoculture	31.88a	-	27.9	17,534	7,116	10,418	29.0
C + peanut	30.74a	1.483	27.7	25,805	10,071	15,734	48.3
C + mungbean	29.81a	0.570	26.7	20,383	8,640	11,743	41.9
C + soybean	34.54a	0	27.5	18,997	8,620	10,377	6.4
C + maize	21.00b	3.643	24.3	15,557	8,588	6,969	35.0
C.V. (%)	12.16						
LSD (0.05)	6.872						

1) Prices: cassava dong 550/kg fresh roots
peanut 6,000/kg dry pods
mung bean 7,000/kg dry grain
maize 900/kg dry grain
labor for cassava 4,140,000/ha (207 mandays/ha)
labor for intercrops 800,000/ha (40 mandays/ha)
labor for fertilizer application 100,000/ha (5 mandays/application)
cassava stakes 500,000/ha
fertilizers for cassava 1,095,600/ha
fertilizers for maize 550,000/ha

Source:*Tran Thi Dung et al., 2002.*

CONCLUSIONS

Cassava intercropping systems practiced by farmers generally had a greater total productivity than monocropping. The results of these FPR trials indicate that intercropping cassava with grain legumes produced generally a higher gross income than cassava grown in monoculture. The best intercropping systems were the combination of cassava and peanut, or cassava and mungbean. After evaluating the intercropping of several intercrops with cassava, peanut was found to be the most successful and profitable intercrop. The adoption of this technology would considerably improve the sustainability of the cropping system, optimize the use of land and increase farmers' income.

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THE ADOPTION OF NEW TECHNOLOGIES AND THE SOCIO-ECONOMIC IMPACT OF THE NIPPON FOUNDATION CASSAVA PROJECT IN VIETNAM

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ABSTRACT

During the second phase of the Nippon Foundation project in Vietnam (1999-2003) a methodology for conducting Farmer Participatory Research (FPR) and Farmer Participatory Extension (FPE) was developed in order to benefit a large number of small cassava farmers. Through collaboration between researchers, extension workers and farmers in all activities of the project, such as the conducting of FPR trials, FPR training courses, field days, and cross-site visits, farmers have identified the most suitable new technologies for adoption in their cassava fields. Thus, at the end of 2002, about 2,717 farmers in the FPR pilot sites are planting new high-yielding varieties (KM60, KM94, KM95-3, KM98-1, KM98-5, KM98-7 and SM 937-26) on 1,244 ha. About 222 farmers have planted contour hedgerows to control soil erosion by using *Tephrosia candida*, vetiver grass, *Paspalum atratum*, pineapple or various combinations of these on 99 ha. About 689 farmers adopted intercropping cassava with peanut, black bean or maize on 42 ha; and 157 farmers are using balanced fertilizers for cassava on 26 ha. Farmers in the central part of the country have also quickly adopted the new technology of using cassava root and leaf silage for pig feeding. The number of farmers applying this technology has increased to 1,027 within two years. The total number of farmers adopting new technologies has now reached 4,812, and the economic benefit in 2002 resulting from these improved technologies has been estimated at 4,116 million VND or US$ 274,400.

Results of the second phase of the project indicate that the effects of FPR/FPE methodologies are not limited only to economic benefits for a large number of farmers, but have also had positive effects on other aspects, such as better environmental management resulting in soil and water conservation, strengthening of the capacity of researchers, extensionists and farmers in conducting strategic and applied research in crop production and animal husbandry that will overcome constraints identified at the farm level; and last but not least, it has enhanced the establishment of different types of farmers' organizations for further self-development. The experience of working together in this project will further contribute to long-term sustainable rural development in Vietnam.

INTRODUCTION

Vietnam is producing about 2 million tonnes of fresh cassava roots yearly on an area of 238,700 ha. The average yield of cassava root is 8.9 tonnes/ha. The annual cassava production of Vietnam ranks fifth in Asia and thirteenth in the world. The major cassava regions are the Northern midland and mountainous region, the North Central Coast, the South Central Coast and the Southeastern region.

During the past decade, cassava in Vietnam has changed from a traditional food crop into a commercial crop, especially in such favorable regions as the Southeastern region.

Vietnam now has about twenty-six cassava starch processing factories, and is exporting more than 200,000 tonnes of cassava per year. In other less favorable regions, cassava is both an important food crop and a feed crop for smallholder farm households.

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Cassava has the advantage that it is easy to grow and it still gives rather high yields even under poor cultivating conditions such as poor soil, lack of rainfall and low inputs. The fact remains, however, that cassava is considered a crop of the poor in many regions. Therefore, research and the transfer of new technologies, like new high-yield and high-starch varieties as well as better cultivation technologies, have received little attention. In the 21st Century, cassava appears to have great new potential but also faces new challenges. Cassava yields can be doubled as compared to the current yields by promoting extension, recommending and disseminating research results about new cassava varieties together with appropriate cultivation techniques through the Vietnam Cassava Research Network.

In order for farmers to obtain high economic benefits as well as to conserve the soil resources for more sustainable agricultural development, it is necessary for researchers to work directly with farmers, helping them to gain more knowledge and improve their ability to apply new technologies to cassava production. Vietnam's Cassava Research and Extension Network, is part of the Asian Cassava Research Network. The Vietnam Network has been collaborating with CIAT in the 2nd Phase of the Farmer Participatory Research (FPR)" project, which is financially supported by the Nippon Foundation in Tokyo, Japan.

PROJECT OBJECTIVES

The overall objective of the project is to increase the living standards of smallholder farmers and to improve the agricultural sustainability in less-favored areas of Vietnam by improving the productivity and stability of cassava-based cropping systems.

The specific objectives are:

1) To increase cassava production and maintain the soil's fertility in smallholder farms through the direct participation of farmers.
2) To identify the constraints, conduct FPR trials with farmers' evaluation and selection of the most suitable technologies.
3) To develop and disseminate new technologies that are best suited to farmers' needs and adapted to local conditions.
4) To strengthen the FPR capacity in national institutions and in a number of rural communities.

METHODOLOGIES

The 2nd Phase (1999-2003) of the project focused on the following activities:

- To use various farmer participatory methodologies such as participatory diagnosis of problems and the conducting of FPR trials in a number of pilot sites. In 2002, the project was working in a total of 25 sites in different regions of Vietnam.
- To organize training courses on FPR methodologies for extension workers and farmers.
- To organize field days (on-farm workshops), and cross-visits at the time the trials are harvested.
- To facilitate the adoption of new technologies which had been selected by farmers.
- To analyze and evaluate the results, as well as the impacts of the project on farmers' income and soil conservation, as well as the ability of researchers,

extension workers and farmers to adopt a more participatory approach in research for development.

The various steps in the process used in this project are shown in **Figure 1** and include the following activities: Participatory diagnosis→Participatory selection of potential solutions → Participatory trials→Participatory evaluation and selection of new technologies→ Participatory extention and adoption of new technologies.

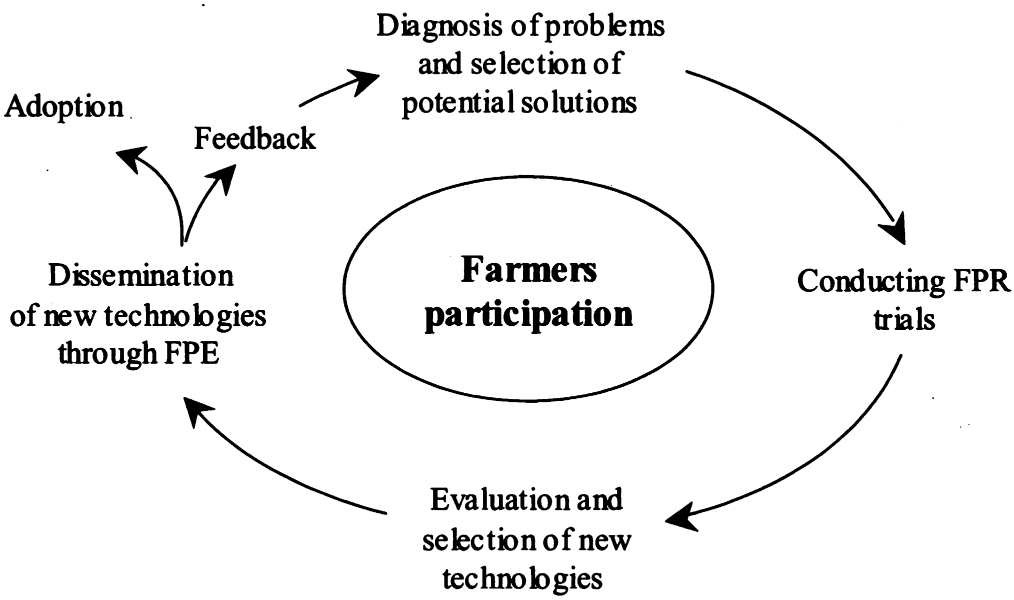

Figure 1. Steps in the farmer participatory research and extension activities.

RESULTS AND DISCUSSION

1. Identification of Constraints

By 2002, the project had conducted Rapid Rural Appraisals (RRA) with farmer participation in 25 pilot sites and farmers had determined and selected several component technologies to be tested in FPR trials. The results of these RRAs indicate that the main constraints to obtaining high cassava yields (the average yield varied from 7.0 to 16 t/ha) can be ranked in priority order as follows:

- Low fresh root yield and low starch content of the local cassava varieties.
- Serious soil erosion in many cassava producing areas.
- No or little fertilizer input; farmers are used to applying only nitrogen (N) and sometimes phosphorus (P).
- Poor cultivation technologies, such as plant spacing, planting time, weed management etc.
- Lack of knowledge about the effective use of cassava for animal feeding.

- Unstable cassava prices.
- Farmers haven not received any training in cassava technologies

2. FPR Trials

Based on the needs of farmers and the constraints identified through discussion and the use of various participatory diagnosis methodologies, seven different technology components were selected for the FPR trials **(Table 1).**

Table 1. Technology components and the number of FPR trials conducted by six collaborating institutions in Vietnam in 2002.

Technology components	Institution						
	IAS	TDUAF	HUAF	VASI	NISF	TUAF	Total
Varieties	7	4	6	9	5	16	47
Soil erosion control	4	4	5	2	8	7	30
Intercropping		4	5	6	7	9	31
Fertilization	7	4	4	3	1	5	24
Plant spacing			5		11	3	19
Weed control							0
Cassava leaf production	1		1				2
Pig feeding of cassava root and leaf silage			16				16
Total							169

The technology components that were considered most important by farmers in all pilot sites were: 1) new high-yielding cassava varieties; 2) effective soil erosion control practices; 3) intercropping; and 4) more balanced fertilization suitable for cassava. The other technology components were considered of importance mainly in certain regions. For instance, farmers in the Southeastern region were interested in trying out new methods of weed control, while the farmers in Thua Thien-Hue province wanted to try ensiling technologies of cassava leaves and roots for pig feeding. The initial studies on cassava leaf production were conducted at Thai Nguyen University of Agriculture and Forestry (TUAF) in the north and at Hung Loc Agric. Research Center of IAS in South Vietnam.

3. Training and Field Days

Training and farmer field days were important activities of the project in order to give extension workers and farmers a clearer understanding of the project's objectives and methodologies. Together they would analyze the problems, determine the type of FPR trials to find solutions that would meet the farmers' needs. Field days were organized at FPR sites at the time of harvesting the trials. The farmers participated in the harvest, scored the various treatments in each trial, and finally discussed, analyzed and selected the most appropriate technologies for the local conditions. Up to 2002, five farmer training courses had been organized in three regions of Vietnam with a total of 152 extension workers and farmers participating.

Farmer field days and cross-site visits were organized yearly by all six collaborating institutions; a total of 360 farmers and local officials participated in these activities. This was a very effective extension method, since farmers were directly involved and participated in the evaluation and the selection of those technologies that they prefered.

4. Effect of Applying New Technologies

After participating in the conducting of FPR trials, in training courses, field days and cross-visits, the farmers quickly adopted and expanded the new technologies they selected on a larger scale. At each FPR site, farmers adopted some or all of the technological components, such as new cassava varieties, intercropping, soil erosion control, both separately or combining them in certain cropping systems, such as new cassava varieties + intercropping; new cassava varieties + intercropping + fertilizing; or new cassava varieties + intercropping + soil erosion control by planting contour hedgerows. The effects of applying these new technologies during the past three years (2000-2002) are very encouraging and they have already caught the attention of both farmers and local leaders. In many areas, the leaders have reconsidered their development policies. Cassava is now being considered as a commercial crop, effectively contributing to the elimination of hunger and poverty, and to rural development and modernization through agro-industry. Van Yen district in Yen Bai province is a good example. Starting from the intercropping trials in 2001 and 2002, the area under cassava intercropped with peanut was enlarged to 6 ha in 2003. Similarly, the initial FPR variety trials were soon expanded to an area of 20 ha of new cassava varieties of high yield and starch content, such as KM60 and KM94. After the field days evaluating the results, the district and provincial officials decided to concentrate their efforts on enlarging the area of new cassava varieties; this reached a total area of 1,030 ha in 2002. Van Yen district is a good example of how cassava production suddenly expanded in North Vietnam with the adoption of new varieties and improved agronomic practices.

4.1 Adoption of soil erosion control practices

The major reason why soil erosion can be serious when cassava is grown on sloping land is that the crop is usually planted at low density (0.8-1.0 m x 0.8-1.0 m), while cassava grows slowly during the first 3-4 months; this time also coincides with the rainy season resulting in serious soil erosion on cassava land. This may be as high as 50-110 tonnes of eroded soil/ha. Therefore, soil erosion control is a very important practice, that contributes to more sustainable cassava production. One of the ways to reduce erosion is to plant hedgerows along the contours with a distance between rows of 6 to 10 m, depending on the slope. Hedgerow species tested in this project were *Tephrosia cadida,* vetiver grass, *Paspalum atratum*, *Panicum maximum* and pineapple.

Depending on their knowledge and on local conditions, farmers in each region selected the most appropriate hedgerow species. Farmers in the north generally preferred *Tephrosia candida,* farmers in the Central Coast preferred pineapple, while in the South the farmers liked vetiver grass or *Paspalum atratum*.

After three years, the number of households applying these technologies increased from 62 in 2000 to 222 in 2002 with the area using erosion control increasing from 21.1 ha to 98.8 ha. By applying soil conservation practices fresh root yields increased, ranging from 2.15 to 8.4 t/ha as compared to areas with no hedgerows; the gross income from cassava was estimated to be about 118,158 million VND (US$ 7,8877) higher than that of areas using their traditional practices without erosion control (**Table 2**).

Table 2. Extent of adoption of erosion control practices, and their effect on cassava yield and income of farmers in Vietnam participating in the Nippon Foundation project from 2000 to 2002.

Responsible institution and year	No. of house-holds	Area (ha)	Cassava yield (t/ha) Farmers' practice	Cassava yield (t/ha) Improved technique	Additional gross income (million VND)[1)] Perha	Additional gross income (million VND)[1)] Total
TUAF						
2000	21	4.0	17.7	20.6	1.00	4.00
2001	67	26.0	18.8	21.0	0.75	19.55
2002	88	52.0	18.8	21.0	0.75	39.10
NISF						
2000	33	14.0	11.8	11.8	0	0
2001	99	18.8	18.0	20.2	0.75	14.12
2002	96	19.9	18.0	20.2	0.75	14.97
VASI						
2000	2	0.12	25.5	30.3	1.70	0.20
2001	10	0.7	24.5	27.2	0.94	0.66
2002	14	1.0	24.5	27.2	0.94	0.94
HUAF						
2000	6	3.0	5.6	13.1	2.25	6.75
2001	12	9.7	5.2	13.6	2.52	24.44
2002	16	16.5	5.2	13.6	2.52	41.58
TDUAF						
2000	-	-	-	-	-	-
2001	6	3.3	20.0	27.0	2.03	6.70
2002	4	5.4	20.0	27.0	2.03	16.96
HARC						
2000	-	-	-	-	-	-
2001	6	1.4	19.8	22.6	0.81	1.14
2002	4	4.0	19.8	22.6	1.23	4.93
Total 2002	**222**		**12.1**			**118.16 =US$ 7,877**

[1)] Price of cassava fresh roots: VND 350/kg in the north, 300 in the Central Coast and 290 in the south in 2000/01 and VND 440 in 2001/02.

4.2 Adoption of improved fertilization practices

Since cassava can grow with few inputs, farmers generally apply only nitrogen fertilizers. Phosphorus and especially potassium are almost never applied to cassava. After three years of testing various new fertilizer technologies, only 157 households had adopted balanced fertilizer application to cassava on an area of 26.0 ha, even thought while participating in field days they had seen the remarkable difference in cassava yield between the fertilized and non-fertilized plots.

Fertilizer application to cassava doubled cassava yield in many places. The average yield increase ranged from 4.5 to 12 t/ha. The value of this increase in production ranged from 0.55 to 5.28 million VND as compared to the farmer's traditional practice of no fertilizer application (**Table 3**).

Table 3. Extent of adoption of improved fertilization practices, and their effect on cassava yield and income of farmers in Vietnam participating in the Nippon Foundation project from 2000 to 2002.

Responsible institution and year	No. of house-holds	Area (ha)	Cassava yield (t/ha)		Additional gross income (million VND)[1)]	
			Farmer practice	Improved technique	Per ha	Total
TUAF						
2000	12	2.0	11.0	16.8	2.03	4.06
2001	42	3.5	27.7	33.7	1.80	6.30
2002*	48	5.0	27.7	33.7	1.80	9.00
NISF						
2000	33	7.0	17.2	28.5	3.20	22.40
2001	47	7.6	19.4	28.2	3.08	23.41
2002	38	7.3	19.4	28.2	3.08	22.48
VASI						
2000	3	0.15	27.1	32.5	1.89	0.28
2001	6	0.5	23.0	27.2	1.47	0.70
2002	20	2.0	23.0	27.2	1.47	2.94
HUAF						
2000	15	0.7	7.5	12.5	1.50	1.05
2001	20	1.5	10.0	15.5	1.65	2.48
2002	44	6.2	10.0	15.5	1.65	10.23
TDUAF						
2000						
2001						
2002	3	1.5	38.0	50.0	5.28	7.92
HARC						
2000	1	1.0	19.3	29.6	2.99	2.99
2001	8	2.2	33.3	35.2	0.56	1.23
2002	4	4.0	33.3	35.2	0.84	3.38
Total 2002	**157**	**26.0**				**57.42 = US$ 3,828**

[1)] Price of cassava fresh roots: VND 350/kg in the north, 300 in the Central Coast and 290 in the south in 2000/01 and VND 440 in 2001/02.

4.3 Adoption of intercropping practices

Since cassava initially grows slowly and the rows are normally spaced widely, it can be intercropped with short-duration crops like legumes. Through the FPR intercropping trials, farmers in the north and the central part of Vietnam selected intercropping with peanut, usually two rows of peanut in between rows of cassava. The use of this intercropping pattern did not decrease cassava yields, but produced an additional 0.8-1.2 tonnes of dry peanut pods/ha. Moreover, about ten tonnes of residue was returned to the soil as green manure. In the Southeastern region, farmers preferred intercropping cassava with maize or mungbean.

Since the advantages of intercropping are remarkable, 689 households applied the intercropping technology in 2002. Cassava yields increased between 1.58 and 4.8 t/ha. The gross income/ha increased by 0.498 to 1.977 million VND. The total additional gross income from cassava and the intercrops was 142,797 million VND as compared to the farmer's traditional practice of planting cassava in monoculture (**Table 4**).

Table 4. Extent of adoption of intercropping practices, and their effect on cassava yield and income of farmers in Vietnam participating in the Nippon Foundation project from 2000 to 2002

Responsible institution and year	No. of house-holds	Area (ha)	Cassava yield (t/ha)		Additional gross income (million VND)[1)]	
			Farmer practice	Improved technique	Per ha	Total
TUAF						
2000	70	5.6	17.6	23.2	1.97	22.25
2001	82	6.7	18.8	24.4	1.98	26.65
2002	115	10.5	18.8	24.4	1.98	41.76
NISF						
2000	33	3.5	14.2	16.2	0.73	9.55
2001	34	3.7	15.8	16.9	0.38	8.74
2002	35	3.9	15.8	16.9	0.38	9.25
VASI						
2000	3	0.2	29.0	30.4	0.49	0.37
2001	64	3.0	29.4	31.9	0.88	8.62
2002	320	5.0	29.4	31.9	0.88	14.38
HUAF						
2000	20	1.5	7.1	8.8	0.50	3.75
2001	170	12.0	5.0	9.8	1.44	41.20
2002	215	18.5	5.0	9.8	1.44	63.64
TDUAF						
2000						
2001						
2002	1	1.5	36.1	40.2	1.79	5.68
HARC						
2000	1	1.0	26.6	26.6	0.29	3.29
2001	10	2.4	29.2	30.7	0.70	6.49
2002	3	3.0	29.2	30.7	0.70	8.08
Total 2002	**689**	**42.2**				**142.80 = US$ 9,520**

1) Price of cassava fresh roots: VND 350/kg in the north, 300 in the Central Coast and 290 in the south in 2000/01 and VND 440 in 2001/02.

4.4 Adoption of new cassava varieties

In agriculture in general, and particularly in cassava, farmers normally concern themselves only in selecting the appropriate varieties. New high-yield varieties are usually more readily accepted than other new technologies, as adopting these other technologies normally require additional investments. By changing the variety, production can be increased without much additional investment. Moreover, higher investment for obtaining higher yield can be more easily accepted when using new varieties. If we recommend farmers to apply fertilizers to their old cassava varieties, even thought there is a remarkable increase in yield, adoption will still be slow. But it will be more readily accepted if we recommend them to apply balanced fertilizers to new cassava varieties.

Therefore, after three years of conducting the project's activities, there were at least 2,717 households growing new cassava varieties on an area of about 1,243 ha in 2002. The principal new varieties grown in each region are as follows: KM94 KM98-5 and SM937-26 in the Southeastern region; KM94, KM98-1 in the Central region; KM98-7 in Thai Nguyen; and KM94, KM60 and KM95-3 in other parts of the Northern region. By using these new varieties the fresh root yield increased between 2.9 and 24.2 t/ha. Yields in many areas doubled as compared to the local varieties. Consequently, by growing new varieties the higher yields obtained resulted in additional gross income of 3,650.07 million VND as compared to growing the local cassava varieties (**Table 5**).

4.5 Adoption of the use of cassava root and leaf silage for pig feeding.

For smallholder cassava farmers, various cassava products can be used as feed resources for pigs. Usually, there are still a lot of young cassava leaves remaining on the plant at time of root harvesting. Although cassava leaves are high in protein, one of the main constraint for using fresh cassava leaves and roots as a pig feed is the toxicity of free HCN released from the fresh roots and leaves. The use of silage technology overcomes this problem and makes it possible to effectively use these cassava leaves; moreover, it also makes it possible to store the feed for 6-12 months. Learning about this technology through training courses and field days, many households in the central part of Vietnam adopted this technology in on-farm animal feeding. Our survey indicates that in 2002 there were 1,027 households using the leaf and root silage technology for pig feeding, with the total number of pigs being 2,742. The total additional gross income resulting from using this technology was 147.54 million VND (**Table 6**).

4.6 Adoption of various new technologies and the estimated increase in gross income of farmers

Summarizing the results presented in **Tables 2** to **6**, we estimate that about 4,812 households adopted new technologies in an area of about 1,411 ha, while 2,742 pigs were fed with cassava root or leaf silage. The total additional gross income obtained was estimated at 4,115.99 million VND, equal to US$ 274,400. These are very worthy and encouraging effects of the project (**Table 7**).

5. Example of the Impact of the Nippon Foundation Project on the Livelihoods of Farmers in Tien Phong Village

In 1994, we selected Tien Phong village in Pho Yen district of Thai Nguyen province as one of the first pilot sites for implementing the first phase of the project. The RRA/PRA results showed that the fresh cassava root yield in Tien Phong village was very low, only 8.5 t/ha. The total gross income was only 3.4 million VND/ha, while the net income was 0.47 million VND/ha. After conducting the FPR trials (1994-2001), and adopting the new technologies, cassava yields increased nearly three times, from 8.5 t/ha to 22.7 t/ha. The gross income/ha increased from 3.4 to 14.26-16.94 million VND, and the net income resulting from cassava production reached 9.9-11.78 million VND/ha (**Table 8**).

Table 5. Extent of adoption of new cassava varieties, and their effect on cassava yield and income of farmers in Vietnam participating in the Nippon Foundation project from 2000 to 2002.

Responsible institution and year	No. of house-holds	Area (ha)	Cassava yield (t/ha) Farmer practice	Cassava yield (t/ha) Improved technique	Additional gross income (million VND)[1] Per ha	Additional gross income (million VND)[1] Total
TUAF						
2000	38	2.5	21.5	31.0	3.32	8.31
2001	235	46.5	21.3	29.5	2.87	132.88
2002	1,270	450.0	21.3	29.0	2.87	1,291.50
NISF						
2000	22	1.2	20.2	23.1	1.015	1.22
2001	89	3.1	20.2	23.1	1.015	3.15
2002	97	4.2	20.2	23.1	1.015	4.26
VASI						
2000	-	-				
2001	39	5	24.1	28.0	1.365	6.82
2002	68	15	24.1	28.0	1.365	20.48
HUAF						
2000	22	2.0	18.9	33.6	4.41	8.82
2001	60	9.0	15.6	34.8	5.76	51.84
2002	120	38.0	15.6	34.8	5.76	218.88
TDUAF						
2000	-	-				
2001	14	9.0	20.0	27.0	3.08	27.72
2002	12	15.5	20.0	27.0	3.08	47.74
HARC						
2000	6	2.0	19.3	43.5	7.02	14.04
2001	10	3.9	23.3	29.6	2.77	10.81
2002	70	21.0	23.3	29.6	2.77	58.21
Total 2002	**2,717**	**1,243.7**				**1,614.07 = US$ 109,405**

[1] Price of cassava fresh roots: VND 350/kg in the north, 300 in the Central Coast and 290 in the south in 2000/01 and VND 440 in 2001/02.

CONCLUSIONS

1. Farmer participatory research and extension were found to be very effective methodologies for developing and transferring new technologies to farmers.
2. In 2002, at least 4,812 households in the 25 pilot sites of the project had adopted new technologies. It is estimated that the use of these technologies had increased farmers' income by about 4,116 million VND as compared to the farmers' traditional practices.

3. Adoption of these new technologies, not only increased cassava yields but also helped to maintain and improve the soil resources for more sustainable agricultural development, through better erosion control and soil fertility maintenance.
4. The project strengthened the capacity of farmers, extension workers and researchers in conducting strategic research and disseminating new technologies that will contribute to rural development.

Table 6. Extent of adoption of the use of cassava roots and leaves for pig feeding in three communes in central Vietnam, and their effect on the income of farmers participating in the Nippon Foundation project from 2000 to 2002.

Adopted technology and year	No of household	No. of pigs	Benefit/pig (VND)	Total gross income (million VND)
Leaf silage				
2001	28	96	86,000	8.26
2002	60	290	86,000	24.94
Root silage				
2001	759	1,896	50,000	94.80
2002	967	2,452	50,000	122.60
Total				**250.57** **= US$ 9,836**

Table 7. Extent of adoption of new technologies and the estimated increase in gross income of farmers in the FPR pilot sites in Vietnam in 2002 as a result of the Nippon Foundation project.

Technology component	No. of households	Area (ha)	Increase in gross income (million VND)
New varieties	2,717	1,244	3,650.07
Intercropping	689	42	142.80
Erosion control	222	99	118.16
Balanced fertilization	157	26	57.42
Root and leaf silage for pig feeding	1,027	-[1)]	147.54
Total	**4,812**	**1,411**	**4,115.99** **= US$274,400**

[1)] 2,742 pigs

Table 8. Impact of the Nippon Foundation project on the livelihoods of farmers in Tien Phong village, Pho Yen district, Thai Nguyen province in North Vietnam.

	No. of farmers	Cassava area (ha)	Cassava yield (t/ha) New varieties	Cassava yield (t/ha) Local variety[1)]	Gross income (million dong/ha)	Production costs (million dong/ha)	Net income (million dong/ha)	Total net income (million dong)
1994								
Traditional	115	50	-	8.5	3.40	2.93	0.47	23.50
2000								
New varieties	25	1.31	30.9	21.5	15.46	4.36	11.10	14.54
Intercropping	37	2.59	29.3	-	18.70	5.16	13.54	35.07
Erosion control	4	0.20	24.7	-	14.59	5.46	9.13	1.83
Total	66	4.10						51.44
2001								
New varieties	89	4.70	28.5	22.7	14.26	4.36	9.90	46.53
Intecropping	40	3.38	26.2	-	16.94	5.16	11.78	39.82
Erosion control	4	0.20	-	-	-	-	-	1.83
Total	133	8.28						88.18

1) Vinh Phu

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FARMER PARTICIPATORY RESEARCH (FPR) IN THE NIPPON FOUNDATION CASSAVA PROJECT IN HAINAN PROVINCE OF CHINA

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ABSTRACT

The FPR Cassava Project in China is a cooperative project between CIAT and CATAS, and is financially supported by the Nippon Foundation of Japan. This paper mainly describes results of the FPR trials conducted in Hainan province of China during 2000-2002, and discusses the benefits of the FPR approach in the transfer of cassava technologies, the existing problems and our development prospects.

This project involves the following aspects of research: cassava varieties, soil and water conservation, fertilizer management etc. Several tropical pasture species, peanut and grain legume crops have been tested as contour barrier crops to protect the soil from erosion.

During 2000-2002, five towns with 600 farmers joined the FPR project. More than 200 people have been trained directly in Hainan.

More than 50,000 bags of vetiver grass have been distributed.

More than 2 km of vetiver grass contour barriers have been established.

About 800 farmers have tested new cassava varieties in Tunchang county, and the area of new varieties has now reached about 1,000 ha.

Planting material of new varieties have been distributed to plant 98% of the cassava area in Baisha county where the area of new varieties reached about 2,000 ha. Six farmers participated in the FPR project in Qiongzhong county, and the planting area of new varieties was about 20 ha.

Some students of the University have been trained and will participate in our FPR project. Another PRA was conducted in some new villages and some new pilot sites will be set up. More and more farmers will join our project in the future.

INTRODUCTION

Since the 1970s, various ways of involving farmers in agricultural research have been proposed and studied in many parts of the world, including Farmer Participatory Research (FPR) and Extension (FPE). Guided by researchers, farmers participate in the diagnosis of their problems, then select the type of experiments they want to do and the treatments to be tested; they conduct the trials, evaluate the trial results and then select and possibly adopt the most suitable treatments.

From 1994 to 2003, farmer participatory research (FPR) has been conducted in Hainan as part of a cooperative project between CIAT and CATAS, supported by the Nippon Foundation in Japan. The first phase, from 1994 to 1998, had as its objectives: a) to reconcile the short-term needs of farmers to increase crop yields and income with the long-term objective of preserving the soil's productivity, i.e., to provide benefits to both farmers and society; and b) the essence of this approach is that farmers own the process: they develop the most suitable practices for their own conditions by testing a range of options on their own fields.

The second phase of this project, from 1999 to 2003, had as its main objective to enhance and accelerate the extension of improved varieties and efficient cassava production practices that had been identified in the first phase. The results of the FPR project indicate

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that there are many ways to reduce erosion, maintain or increase soil productivity and increase the income of cassava farmers in Hainan.

The methodology used and the results obtained during the first phase of the project have been described in detail by Zhang Weite *et al.* (1998) and Huang Jie *et al.* (2001).

Demonstration Plots at CATAS, Danzhou, Hainan, 2000-2002.

1. Comparison of various tropical grasses, legume species and pineapple used as contour barrier crops for protecting the soil from erosion

An erosion control experiment was conducted on 5-10% slope at CATAS since 1995. Results of the earlier trials have been reported by Huang Jie *et al.* (2001). Results of the trials conducted from 1999 to 2001 are shown in **Table 1**. They indicate that:

1) dry soil loss due to erosion decreased year by year, while cassava yields remained fairly constant
2) after three years, all the live barrier treatments were very effective in decreasing soil loss by erosion. Dry soil loss (4.1-15.1 t/ha) decreased by 68-91% as compared to the check treatment (47.1 t/ha)
3) some of these live barriers, such as vetiver grass, *Clitoria ternatea, Cassia rotundifolia*, and *Tephrosia candida*, became more effective in controlling erosion over the years and showed less competition with cassava, resulting in slight increases in root yield as compared to the check plots without barriers. On the other hand, *Arachis pintoi, Brachiaria* and king grass competed strongly with nearby cassava, resulting in lower yields.

Table 1. Result of the soil erosion control demonstration plots at CATAS, Hainan, China, 1999-2001.

Barrier species[1)]	Dry soil loss (t/ha)				Fresh root yield (t/ha)			
	1999	2000	2001	Average	1999	2000	2001	Average
Check without barriers	97.8	31.2	12.2	**47.1**	19.9	21.7	21.6	**21.1**
King grass	12.4	3.8	2.8	**6.3**	19.6	14.3	18.7	**17.5**
Vetiver grass	20.2	5.7	2.0	**9.3**	24.8	21.4	22.4	**22.9**
Clitoria ternatea	14.6	10.8	5.4	**10.3**	28.7	25.7	20.8	**25.1**
Cassia rotundifolia	17.3	8.9	6.5	**10.9**	23.1	22.4	23.5	**23.0**
Paspalum atratum	-	7.7	2.6	**5.2**	-	18.6	17.4	**18.0**
Arachis pintoi	5.6	8.3	1.4	**5.1**	13.4	19.0	15.2	**15.9**
Tephrosia candida	20.5	10.6	10.6	**13.9**	22.0	22.1	21.0	**21.7**
Desmodium ovalifolium	34.1	5.9	5.4	**15.1**	21.4	17.3	19.6	**19.4**
Brachiaria brizantha CIAT 26110	-	9.6	3.0	**6.3**	-	17.8	18.8	**18.3**
Brachiaria decumbens CIAT 606	-	5.7	2.5	**4.1**	-	17.9	16.3	**17.1**
Pineapple	18.1	5.9	5.3	**9.8**	22.9	20.4	18.0	**20.4**
Lemon grass	-	6.5	5.2	**5.9**	-	20.1	20.4	**20.2**

1) Only two rows of barriers in each plot.

2. The competitive effect of vegetative barriers used for erosion control on cassava grown on 6-8% slope at CATAS

Vetiver grass contour barriers were found to be very effective in reducing erosion in cassava fields. However, farmers do not easily adopt the use of vetiver due to the fact that it can not be used to any great extent as animal feed. In order to further select the best vegetative barriers, a preliminary trial on the competitive effect of vegetative barriers was conducted at CATAS from 1998-2001. Average results for the first two years were reported by Huang Jie *et* al. (2001). The results, shown in **Table 2**, indicate that cassava yields varied from year to year; lemon grass, vetiver grass, *Paspalum atratum* and hybrid elephant grass were the least competitive species and will therefore be recommended for erosion control barriers. *Panicum maximum,* dwarf and common elephant grass, king grass, sugarcane and *B. ruzuziensis* were found to be too competitive, resulting in low cassava yields when used as barriers for erosion control.

Table 2. Effect of grass barriers of various species used for erosion control on the fresh root yield of cassava planted between these barriers in CATAS, Danzhou, Hainan, China from 1998 to 2001.

	Cassava yield (t/ha)				
Treatments[1]	1998	1999	2000	2001	Average
Vetiver grass	19.0	47.2	33.5	30.6	**32.6**
Lemon grass	20.0	47.0	45.0	32.1	**36.0**[3]
Dwarf elephant grass	19.8	20.3	8.8	7.2	**14.0**
Common elephant grass	17.1	28.2	13.4	10.5	**17.3**
Hybrid elephant grass	19.7	40.3	31.7	25.5	**29.3**
King grass	18.9	26.8	16.3	11.6	**18.4**
Sugarcane	14.3	35.2	18.7	7.8	**19.0**
Brachiaria ruziziensis	20.6	25.3	18.3	12.8	**19.2**
Brachiaria decumbens	16.2	36.3	24.1	16.0	**23.2**
Brachiaria brizantha CIAT 26110	17.6	36.7	27.5	17.7	**24.9**
Paspalum atratum	17.3	39.5	32.6	28.7	**29.5**
Panicum maximum TD 58	14.1	22.5	5.8[2]	6.1	**12.1**
Average	**17.9**	**33.8**	**23.0**	**17.2**	**23.0**

[1] Three rows of cassava were grown between two rows of grass; 1 meter space between cassava rows and 0.5 m space between grass row and cassava row. The six cassava rows were harvested separately (10 plants in each row). The grass species (except sugarcane) were cut back at 30 cm above the soil whenever necessary.

[2] Low yield due to root rot

[3] High yield because lemon grass grew poorly

3. New demonstration plots on erosion control conducted on 6-8% slope at CATAS in 2002.

Based on the best options selected by farmers and researchers during the first phase of the project, some new treatments for erosion control were established in 2002 in new demonstration plots located on 6-8% slope at CATAS. Results for the first year, shown in **Table 3**, indicate that all the treatments were quite effective in decreasing soil loss by erosion, but intercropping with peanut was less effective than the grass contour hedgerows, while the use of plastic mulch or barriers of closely spaced cassava stems were most effective. Dry soil loss (8.5-50.5 t/ha) decreased by 37-89% compared to the check treatment (80.0 t/ha). Although the highest yield (35.67 t/ha) and the lowest soil loss (8.5 t/ha) were obtained by the treatment of soil covered with plastic, it seems that its cost is higher than that of other treatments.

Table 3. Result of the soil erosion control trial established at CATAS, Hainan, China in 2002.

	Dry soil loss (t/ha)			Fresh root yield (t/ha)		
Treatments[1)]	I	II	**Mean**	I	II	**Mean**
Check without soil conservation	57.92	102.11	**80.02**	35.16	27.58	**31.37**
C+peanut intercrop	50.94	50.13	**50.54**	29.14	27.19	**28.17**
C+*Panicum maximum* hedgerows	44.53	18.63	**31.58**	21.41	21.17	**21.29**
C+*Brachiaria decumbens* hedgerows	59.22	19.67	**39.45**	33.42	27.66	**30.54**
C+vetiver grass[1)] hedgerows	38.00	24.88	**31.44**	36.64	23.59	**30.12**
C+plastic mulch	7.84	9.20	**8.52**	36.56	34.77	**35.67**
Closely-spaced cassava hedgerows	7.11	11.67	**9.39**	28.20	30.47	**29.34**

[1)] Planting: 2002/3/26; Harvest: 2003/2/23; only two rows of barriers in each plot

Trials at Farmers' Fields

During 1999-2002, most FPR trials conducted on farmers' fields or outside of CATAS were varietal evaluation trials. Results, shown in **Tables 4-9**, indicate that two new varieties had excellent performance in many places and were selected for release by farmers themselves: SC5=ZM9057 and SC6=OMR33-10-4. They also identified several promising clones, such as CMR38-120-10, OMR36-40-9 and KU 50, which might be released on a large scale in the near future in China.

Table 4. FPR variety trials conducted in Qiongzhong county, Tunchang county and Danzhou city of Hainan province in 2002.

Location	Variety or clone	Fresh root yield (t/ha)	Relative yield (% of SC205)
Old Songtao village, Qiongzhong county	SC205	23.25	100.0
	SC5	27.50	118.3
	SC6	33.25	143.0
	OMR36-40-9	24.00	103.2
	ZM8639	28.75	123.7
	ZM8229	21.00	90.3
	ZM8641	27.00	116.1
	ZM8803	21.25	91.4
	BRA900	21.50	92.5
Nanlao village, Nankun town, Tunchang county	SC205	24.06	100.0
	SC5	34.38	142.9
	SC8002	31.25	129.9
	SC124	24.69	102.6
Maling village, Nankun town, Tunchang county	SC5	81.25	
Qiaozhi farm, Danzhou city	SC5	57.81	

Table 5. Variety trial conducted on October Field farm, Changjiang county, Hainan, province in 2002.

	Fresh root yield (kg/5 plants)		Fresh root yield (t/ha)[2]		
Variety or clone[1]	I	II	I	II	Av.
SC205	**6.0**	**4.0**	**15.00**	**10.00**	**12.50**
ZM8316	6.7	5.0	16.75	12.50	**14.62**
ZM35-70-1	0.5[3]	4.5	2.28	11.25	**6.76**
BRA900	9.0	5.8	22.50	14.50	**18.50**
SC6=OMR34-10-4	6.6	8.5	16.50	21.25	**18.87**
ZM8803	9.0	5.9	22.50	14.75	**18.62**
OMR36-40-9	5.5	5.6	13.75	14.00	**13.87**
CMR36-40-12	6.0	6.5	15.00	16.25	**15.62**
ZM8641	5.5	3.1	13.75	7.75	**10.75**
ZM8229	5.2	4.0	13.00	12.50	**12.75**

[1] Planting: 2002/4/22; Harvest: 2002/11/29; Plant spacing: 1.0x0.8 m
[2] Low germination because of dry weather
[3] Only harvested 3 plants

Table 6. FPR variety trial conducted in Qifang town, Baisha county, Hainan province in 2002.

	Fresh root yield (kg/5 plants)		Fresh root yield (t/ha)		
Variety or clone[1]	I	II	I	II	Av.
SC205	**9.6**	**8.3**	**24.00**	**20.75**	**22.37**
SC6 = OMR33-10-4	9.3	17.0	23.25	42.50	**32.87**
ZM8639	11.8[2]	22.5	49.17	56.25	**52.60**
BRA900	10.9	15.0	27.25	37.50	**32.37**
ZM8803	11.0	12.5	27.50	31.25	**29.37**
ZM8229	14.5	11.0	36.25	27.50	**31.87**
ZM8316	13.5	11.5	33.75	28.75	**31.25**
OMR36-40-9	13.5	14.0	33.75	35.00	**34.37**
ZM8641	10.0	11.0	25.00	27.50	**26.25**

[1] Planting: 2002/4/11; Harvest: 2002/11/28; Plant spacing: 1.0x0.8 m
[2] Only harvested 3 plants

Training Course at CATAS

During 1999-2002, two training courses were organized at CATAS. There were about 80 participants from Hainan, Guangxi and Yunnan provinces, including farmers and officials of the Agricultural Bureau and extension agents. Besides class room lectures, they also went to see the demonstration plots and other cassava trials at CATAS. Farmers seemed to be most interested in the new varieties and in fertilizer application.

Table 7. Variety trial conducted at GSCRI in Nanning city, Guangxi province in 2002.

Variety or clone[1)]	Fresh root yield (kg/5 plants)	Fresh root yield (t/ha)[2)]
SC5	9.0	22.50
SC8013	17.5	43.75
ZM8229	9.0	22.50
ZM6068	8.4	21.00
ZM8641	19.0	47.50
KU 50	21.5	53.75
Rayong 5	15.0	37.50
Rayong 72	8.5	21.25
Rayong 90	10.0	25.00

[1)] Planting: 2002/4/11; Harvest: 2002/11/26; Plant spacing: 1.0x0.8 m
[2)] Low germination because of dry weather, but SC8013, ZM8641, KU 50, Rayong 5 and Rayong 90 had bigger roots.

Table 8. FPR variety trial conducted at Shan Xu, Guangxi province in 2002.

Variety or clone[1)]	Fresh root yield (kg/5 plants)			Fresh root yield (t/ha)[2)]				Relative yield
	I	II	III	I	II	III	Av.[3)]	(% of SC 205)
SC205	**16.0**	**27.5**	**26.5**	**40.00**	**68.75**	**66.25**	**58.33**	**100.00**
OMR36-40-9	15.5	24.0	17.5	38.75	60.00	43.75	47.50	81.43
OMR33-10-4	10.5	11.5	13.0	26.25	28.75	32.50	29.17	50.01
KU50	14.5	22.0	13.0	36.25	55.00	32.50	41.25	70.72
CMR38-120-10	17.5	18.0[2)] (3 plants)	-[2)]	43.75	75.00	-[2)]	59.38[3)]	101.80[3)]
ZM8639	21.5	15.5	27.0	53.75	38.75	67.50	53.33	91.43
SM2300-1	26.0	33.5[2)] (4 plants)	-[2)]	65.00	104.69	-[2)]	84.85[3)]	145.47[3)]
BRA900	11.0	11.0	14.0	27.50	27.50	35.00	30.00	51.43
ZM8803	14.5	21.0	14.5	36.25	52.50	36.25	41.67	71.44
SC5	12.0	8.0	11.0	30.00	20.00	27.50	25.83	44.28
SC201	11.0	17.5	45.5[2)]	27.50	43.75	113.75	61.67[3)]	105.73
OMR36-31-1	21.0	23.0	21.5	52.50	57.50	53.75	54.58	93.57
GR911	20.0	21.5	21.0	50.00	53.75	52.50	52.08	89.29
SM1600	9.5	25.0	25.5	23.75	62.50	63.75	50.00	85.72
GR891	17.5	16.5[2)] (3 plants)	-[2)]	43.75	68.75[2)]	-[2)]	56.25[3)]	96.43[3)]

[1)] Planting: 2002/3/26; Harvest: 2002/11/22; Plant spacing: 1.0x0.8 m
[2)] CMR 38-120-10, GR 891 of II only 3 plants; SM 2300-1 of II only 4 plants; SC 201 of III only 5 plants; GR 891 and CMR 38-120-10 of III all plants had root rot. No plants of SM 2300-1 in III
[3)] It may be difficult to calculate yields because of many missing plants

Table 9. FPR variety trial conducted in Wuming county, Guangxi province in 2002.

Variety or clone[1)]	Fresh root yield (kg/5 plants)	Fresh root yield (t/ha)	Relative yield (% of SC205)
SC205**	**13.08**	**36.33**	**100.00**
ZM8639*	24.58	45.52	125.30
SC5*	19.58	36.26	99.81
GR891*	18.58	34.41	94.72
OMR36-34-4*	15.58	28.85	79.41
KU50*	30.58	56.63	156.01
Rayong 72*	14.68	27.19	74.84
OMR36-31-1*	18.08	33.48	92.16
GR911**	15.58	43.28	119.13
ZM8316**	16.18	44.94	123.70
ZM8803**	16.58	46.06	126.78
Nanzhi 199**	13.68	38.00	104.60
CMR38-120-10**	19.08	53.00	145.88
BRA900**	18.98	52.72	145.11
OMR36-40-9**	15.58	43.28	119.13

[1)] Planting: 2002/3/7; Harvest: 2002/11/23; * Plant spacing: 0.9x1.2 m; ** = 0.9x0.8 m

Impact of the FPR Project on the Transfer and Adoption of New Cassava Technologies

- Two promising clones, ZM9057 and OMR33-10-4, showed excellent performance in FPR trials and were selected for release by the farmers themselves; these were officially approved as new varieties and named SC5 and SC6, respectively, by the Variety Examination Committee of China.
- During 2000-2002, five towns with about 600 farmers joined the FPR project.
- More than 200 people have been trained directly in Hainan.
- More than 50,000 bags with vetiver grass plants have been distributed.
- More than 2 km of vetiver grass barriers have been established.
- About 800 farmers tested new varieties in Tunchang county, while the total area under new varieties reached about 1,000 ha.
- In Baisha county, new varieties have been planted in 98% of the cassava area and the areas with new varieties reached about 2,000 ha. Six farmers participated in the FPR project in Qiongzhong county, where the planting area of new varieties is now about 20 ha.
- Some students of the University have been trained and will participate in our FPR project.
- PRA were conducted in some new villages, and new pilot sites will be set up. More and more farmers will join our project in the future.

Work Plan for the Future

The following activities are planned at CATAS:

1. Another training course will be organized for 30 persons during three days; the course contents will include cassava varieties, fertilization, erosion control etc. We will also keep the demonstration plots on the use of vegetative barriers for erosion control.

2. Some demonstration trials will be set up in various parts of Hainan province: about 10 trials on cassava varieties or clones; 3-5 trials on cassava fertilization; 3 erosion-control trials on vegetative barriers in mountainous areas.
3. Three cooperative trials on cassava varieties or clones will be conducted in Guangdong, Guangxi and Yunnan provinces.
4. In 2003-2004, we will try to reach this goal: more than 1,000 farmers participating in the FPR project; 5 varieties will be recommended to be extended to up to 10,000 ha. Adapted fertilizers from CATAS will be recommended in different cassava growing areas and used in up to 2,000 ha. About 5 km of vertiver grass contour barriers will be planted for erosion control.

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FARMER PARTICIPATORY RESEARCH (FPR) IN THE NIPPON FOUNDATION CASSAVA PROJECT IN GUANGXI AND YUNNAN PROVINCES OF CHINA

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ABSTRACT

The Nippon Foundation sponsored FPR project started in Guangxi in 1999. It focused mainly on the testing and dissemination of new cassava varieties with high yield and high starch content, and of improved management technologies. Presently, a total of 42 households in 22 villages, in eight counties are participating in this project. Through these farmer participatory trials on cassava varieties and management practices the areas using new promising varieties and improved management practices have increased, reaching about 600 and 1,000 hectares, respectively. In fact, the FPR methodology used in Guangxi for the development and extension of agricultural technologies at this moment is not only for cassava but is also used for other crops, such as rice, maize, beans, watermelon, etc. Although only some aspects of the FPR approach are being used, the results are very satisfactory.

The experience with FPR in this project in Guangxi revealed that the difficulty in using the FPR approach with poor farmers and relatively rich farmers is quite different. Comparatively speaking, the FPR approach is more successful with smaller farmers than with richer farmers that cultivate larger areas.

INTRODUCTION

Guangxi province is located in the southern part of the P. R. of China and the soil and climatic conditions are very suitable for growing cassava. Guangxi is the largest cassava producing province of the country; the annual harvested area is 260,000 ha, producing 3,900,000 tonnes of fresh roots, or approximately 62% of the national area and production. Moreover, Guangxi is also the most developed area in terms of cassava processing. There are more than 50 cassava starch factories in the province which produce a total of about 320,000 tonnes of cassava starch every year, comprising 75% of that produced in the country. As such, cassava is a very important crop in Guangxi province, both for farmers and the starch processing industry. Since demand for cassava starch is still increasing, the cassava processing industry developed fast, which in turn promoted the development of cassava cultivation. The price of cassava roots increased a lot compared with the past year, which together with the income from intercropping, resulted in a substantial increase in farmers' incomes from cassava cultivation. Thus, cassava varieties with high yield and high starch content are much appreciated by farmers and starch factories in the main cassava cultivation areas of Guangxi province.

Yunnan is located in the southwestern part of China. Because of a lack of agricultural land, cassava is mainly cultivated on very steep slopes in mountainous areas. The increase in cassava area is mainly because the local Animal Husbandry Institute has developed technologies for making silage from cassava roots and leaves for animal feed. This kind of silage can be used as a substitute for maize, which is the traditional feed in the mountainous areas of the province. Another reason is that there are many alcohol factories which previously used molasses as their raw material for alcohol making, but have now

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started to use dry cassava chips. It means that cassava has become a new source of income for farmers, not only to be used as animal feed but also for sale to factories.

Based on the above, the Nippon Foundation started to support an FPR project in these two provinces, with the objective to test, select and then disseminate promising cassava varieties as well as improved management practices using a farmer participatory approach. These varieties and improved management practices had previously been developed by CATAS and GSCRI where researchers had spent more than 15 years conducting research on these aspects.

The technology components that are being tested in the project are as follows:

1. Cassava varieties of high yield and high starch content
2. Cassava fertilization
3. Cassava intercropping
4. Erosion control
5. Silage making from cassava leaves and roots.

METHODOLOGY

The steps in the process that we adopted are as follows:

1. Contact the local government (Agricultural Technology Extension Station or Science and Technology Bureau)
2. Select a pilot site and discuss the objectives of the project with farmers
3. Indentify farmers' needs for particular technology components
4. Provide technological options for farmers to evaluate and select for testing
5. Set up demonstrations and help farmers conduct FPR trials
6. Provide technical support and training
7. Organize farmer field days to evaluate and select new technologies
8. Provide the materials that are necessary for farmers to adopt the new technologies (local government requirement).

RESULTS OBTAINED UP TO THE YEAR 2002

I. Guangxi Province

The project activities were conducted in nine counties: Fangcheng, Pingguo, Wuming, Liuzhou, Yongning, Qinzhou, Guilin, Binyang and Hengxian. In total, 46 farmers from 22 villages or production teams joined the project (Table 1). Through the project, farmers adopted new technologies of cassava cultivation, their cassava yields increased and their income from cassava cultivation increased. In the poorer mountainous areas, located far from roads or from the city, farmers' traditiional agricultural practices have been improved, creating new income channels for farmers. As a result of the project, new cassava varieties have extended to up to 1,900 ha, producing an additional 6,000 tonnes of roots and increasing farmers' gross income by 1,400,000 of RMB. About 3,000 farmers have benefited from the project in Guangxi.

Table 1. Location, number of farmers participating, and type of FPR trials conducted in Guangxi province.

District/city	County	Town	Village	No of farmers	Type of trials
Nanning city	Yongning	Suxu	Longed	3	intercropping
Fangcheng city	Fangcheng	Pingwang	Hengguo	4	variety
Nanning city	Wuming	Taiping	Xinlian	5	variety, erosion control
Base district	Pingguo	Bangxu	Zhouxu	7	variety, fertilizer
Nanning district	Hengxian	Maling	Lintou	4	variety
	Binyang	Gula	Dahe	4	variety
		Luxu	Luxu	12	intercropping
Guilin district	Lingchuan	Daxu	Wulin	2	variety
Qinzhou district	Qinzhou	Luwu	Pingtou	2	variety
Liuzhou city	Liuzhou	Luorong	Luorong	3	erosion control, variety

II. Yunnan Province

Farmers participating in the project were mainly from very poor villages located in mountainous areas in the southern part of the province. Before this project, the main crops there were maize, sweetpotato, taro, etc. produced on a small scale. The yields were very low and all products were mainly used as food for human consumption. Sometimes there was not even enough for food, so very little was left for selling to obtain money. In some areas, farmers grow cassava, or, if conditions are more suitable, they grow tea or sugarcane for sale in order to get money, but this is still at a very small scale. As part of the project, some new cassava varieties, improved management practices for cassava cultivation, and silage making from cassava leaves were introduced to the area. This has produced very good results, which have markedly changed the situation: 1. farmers now have enough feed to raise more pigs. In the past, one family could raise only 1-2 pigs, but now they can raise 5-7 pigs, sometimes even more than that; 2. the cassava yields have increased by about 50%, and cassava has become another important source of income. Our project, in collaboration with the local government, which has done much to extend these technologies, has shown and demonstrated how you can use the local natural conditions combined with suitable new agricultural technologies to develop and increase farm productivity and animal production together with the local people. Many farmers have benefited from this project. By 2002 59 farm families had joined the project (Table 2), and each family obtained on average 6,000 RMB more from pig feeding as compared with the past. Also, training courses have been organized. Farmers like to participate in the project as these new technologies have already made important contributions to the alleviation of poverty.

Table 2. Location, number of farmers participating, and type of FPR trials conducted in Yunnan province.

District	County	Town	Village	No. of farmers	Type of trials
Mengzhe	Pingbian	Beihe	Laha Beisizai	47	silage making
	Yuanyang	Xincheng	Dafengya	12	silage making, variety, erosion control

EXPERIENCES AND OBSERVATIONS

1. Problem diagnosis with farmers is a very important step to determine whether the recommended technologies are really satisfying the priority needs of the farmers. This diagnosis should be done together by researchers and farmers. The researchers' role is only to be a facilitator during the discussion, but not to take part in the decision making. If the problems diagnosed by the farmers are in line with the researchers' idea, and can be solved by the particular abilities of the researchers, it will be easy to do and be done well; otherwise, it is difficult to do.
2. The ability of the researchers is also a very important factor to be successful. It is difficult to explain the "ability of the researcher", but it basically includes his/her working methods and the skill to interview farmers. The results of farmer participatory diagnosis are very different (problems, demands, etc), so they require a combination of many types of work. To possess the necessary abilities requires a broad working experience and a very good understanding of the local conditions. It also requires a lot of skill to clear farmers' minds of doubts and misgivings.
3. Everything needs to be clear and open to the farmers; the more they participate in the activities and decision making, the more they enjoy it, and the easier the work can be done.
4. Comparatively speaking, the FPR approach is more successful with smaller farmers than with richer farmers. It seems easier to get close and to communicate with poor farmers in poor areas (they are not as conservative and stubborn as some people imagine); they are actually very anxious to get help from outside. In contrast, farmers from richer areas seem not to be very interested mainly because to them the economic value of cassava is too low, and the cassava area is very small. The income from cassava is not important compared with that from other crops or activities. Many farmers don't like to conduct FPR trials; they say it is a waste of time, and they sometimes need the researcher's guarantee that they will get a high yield with the new varieties. This has happened mostly in the relatively rich areas, making working there more difficult.
5. In China the farmer participatory research approach is now very popular in the agricultural extension service, especially the extension of new crop varieties, like rice, beans, maize, sweet potato, peanut, watermelon, and many kinds of fruits. Although only some aspects of the FPR approach are being used, the results are very satisfactory.

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ACHIEVEMENTS AND LESSONS LEARNED IN THE NIPPON FOUNDATION CASSAVA PROJECT IN ASIA

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ABSTRACT

Towards the end of the first phase (1994-1998) of the Nippon Foundation project on "Enhancing the Sustainability of Cassava-based Cropping Systems in Asia", many farmers in the 2-3 project's pilot sites in China, Indonesia, Thailand and Vietnam had adopted the use of new cassava varieties, more balanced fertilization, planting of contour hedgerows of vetiver grass, *Tephrosia candida,* pineapple, *Leucaena leucocephala* or *Gliricidia sepium* to control erosion, while in Vietnam many farmers had started to intercrop cassava with peanut or black bean. The adoption of these practices, however, was still limited to rather small areas.

Towards the end of the 4th year of the second phase (1999-2003) of the project, adoption of the farmer selected improved practices is spreading like wildfire in the 50-plus pilot sites in China, Thailand and Vietnam, and beyond. In Thailand more than 865 farmers have now planted about 130 km of vetiver grass contour hedgerows in their cassava fields to control erosion in over 900 ha. Several communities have set up their own vetiver grass nurseries to supply planting material to those farmers that want to expand their hedgerows. Most farmers in those sites are applying chemical fertilizers high in N and K, and some are planting green manures or applying animal manures in addition to chemical fertilizers. Practically all cassava farmers are now planting new varieties, mainly KU 50, Rayong 5 and Rayong 90.

In Vietnam, new high-yielding varieties are now planted in about 1,244 ha in the 25 pilot sites, and in an estimated 90,000 ha nationwide. In addition, at least 689 farmers in the pilot sites are intercropping cassava with peanut or black bean in north Vietnam and mainly with maize in south Vietnam. Most farmers in the pilot sites have started to apply chemical fertilizers high in N and K, in addition to the traditional practice of applying pig manure. Moreover, 222 farmers have planted about 100 ha with contour hedgerows of *Tephrosia candida*, vetiver grass, pineapple or *Paspalum atratum* to reduce erosion.

In China, farmers are concentrating on the adoption of new varieties, but in some sites in Hainan, farmers have also adopted the planting of vetiver hedgerows to reduce erosion.

During the process of developing the methodology and implementing the project the following lessons were learned:

- Farmers base decisions about the adoption of new practices mainly on the ability of those practices to increase net income. Thus, soil conservation practices are seldom adopted by themselves, but only in combination with other practices that increase income. Trial results should thus be expressed in terms of realistic estimates of gross and net income.
- Some incentives in kind may be necessary and justified to achieve more widespread adoption of soil conservation practices that benefit both farmers and society at large.
- Farmers must first become aware of the extent of soil erosion and its impact on soil productivity before they will invest in soil conservation practices. The conducting of FPR erosion control trials on their own fields allows them to observe the extent of soil erosion and the effectiveness of various simple production practices in reducing soil losses by erosion.
- Farmers like to experiment with new varieties and new practices and are more than willing to help disseminate the improved practices to other farmers in their community and beyond.
- Local officials and community-based self-help groups should be active partners in the project.
- Training of researchers, extensionists and key farmers in the FPR approach is essential, and is a highly effective way to expand the project to new sites in order to reach more people.

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INTRODUCTION

The Nippon Foundation supported cassava project in Asia started in 1994 with the objective to enhance the adoption by cassava farmers of soil conservation practices that would prevent or reduce erosion and make cassava production more sustainable. To achieve that objective the project used a farmer participatory research (FPR) approach, involving farmers directly in the development of location-specific erosion control practices that were not only effective in reducing erosion, but also easy to manage and to incorporate into the existing farming systems. The first phase of the project (1994-1998) was executed in close collaboration with research and extension institutions in China, Indonesia, Thailand and Vietnam. At the end of that first phase, many farmers in the pilot sites of the project had selected and then adopted the best new varieties, more balanced fertilizer application, various types of erosion control measures, and, in some cases, especially in Vietnam, intercropping with peanut or black bean.

In the second phase of the project (1999-2003), the FPR methodologies developed earlier were used in an increasing number of pilot sites, about ten in China and 20 each in Thailand and Vietnam for a total of about 50 sites. Expanding to new sites every year was possible by increasing the number of collaborating people and institutions in each country, and by training of more and more researchers, extensionists and key farmers in cassava production technologies and farmer participatory methodologies. **Table 1** shows that during the nine years of the project, from 1994 to 2002, 17 training courses were held for government officials at various levels, and for key farmers in the selected pilot sites, with a total of 560 people participating in these courses.

Table 1. FPR training courses conducted as part of the Nippon Foundation project from 1994 to 2002.

Country	Year	Type of training course	Location	Number of participants
China	1998	Researchers and extensionists	Danzhou	27
	2001	Researchers, extensionists and farmers	Danzhou	32
				59
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
				226
Total number of participants				**560**

Implementation of the Second Phase of the Project

As indicated earlier (Howeler, 2007), the main objective of the second phase was to achieve widespread adoption of soil conservation practices as well as other practices that would increase farmers' yields and income in order to offset some of the costs associated with soil erosion control. To achieve this objective, the project had to expand rapidly to more sites, involve more farmers in conducting FPR trials and to focus more and more on effective ways to disseminate the farmer-selected technologies to more farmers outside the pilot sites, using various farmer participatory extension (FPE) methodologies. During the second phase the project is being implemented by three research institutions in China, five research and extension institutions in Thailand, and six research institutes and universities in Vietnam. In all three countries these institutes in turn worked closely with district and subdistrict (or commune) officials as well as with village leaders to implement the project and conduct the trials.

While initially farmers wanted to conduct FPR trials mainly on new varieties, fertilization, erosion control and intercropping, once those issues were resolved and the selected varieties and practices adopted, farmers also wanted to conduct FPR trials on chemical and organic fertilizers, green manures, weed control, plant spacing, leaf production, and even pig feeding with ensiled or dried cassava roots or leaves. **Table 2** shows that in the three countries during the first four years of the second phase of the project, farmers conducted a total of 910 FPR trials, mostly on new varieties but also many trials on erosion control and fertilization as well as on other topics of interest.

As the project expanded to new sites every year, the various steps in the FPR process – from problem diagnosis to evaluating a range of treatments in demonstration plots, to testing and evaluating in FPR trials, and finally selecting the best practices for adoption (Howeler, 2007) – were repeated in each new site. But instead of working with individual farmers, it was found to be much more efficient to work with organized groups of farmers, such as the "Cassava Development Villages" in Thailand, or the district, commune or village committees in Vietnam and China.

Farmer Participatory Extension (FPE) Methodologies

While the conducting of FPR trials was becoming more and more efficient, the number of farmers that could be reached directly through this approach was still rather limited. The FPR approach needed to be combined with various methods of farmer participatory extension (FPE) in order to reach more farmers and disseminate the selected technologies more widely. Thus, farmers in the older sites became the "teachers" for those in the newer sites through various FPE activities, such as:

1. Cross-site visits

Farmers that had already conducted FPR trials and had already selected and adopted new varieties and production practices, would serve as hosts for farmers from new sites, explaining how they had done the trials, why they had selected certain treatments, and then show in the field the new varieties and practices that they had adopted. These cross-visits by farmers from new sites to older sites and the farmer-to-farmer extension was a very effective way of convincing those new farmers to conduct their own trials or to adopt the farmer selected practices in their production fields. For instance, seeing the vetiver grass contour hedgerows growing in a farmers field and seeing the natural terraces being formed by these hedgerows is more convincing to farmers than listening to researchers or extension workers describe the benefits of the same practice in a small plot. Seeing the effectiveness of the hedgerows with their own eyes convinced many farmers to take home bundles of vetiver plants for multiplication in their own village and for future planting in their own fields.

Table 2. Number of FPR trials conducted during the first four years of the 2nd phase of the Nippon Foundation Project in China, Thailand and Vietnam.

Country	Type of FPR trial	1999	2000	2001	2002	Total
China	Varieties	9	9	20	69	**107**
	Erosion control	3	5	8	17	**33**
	Fertilization	-	-	-	4	**4**
	Intercropping	-	-	-	9	**9**
	Pig feeding	-	-	-	59	**59**
		12	**14**	**28**	**158**	**212**
Thailand	Varieties	11	16	16	19	**62**
	Erosion control	14	10	6	-	**30**
	Chemical fertilizers	16	6	23	17	**62**
	Chem.+org fertilizers	-	-	10	11	**21**
	Green manures	-	-	13	11	**24**
	Weed control	-	-	17	5	**22**
	Plant spacing	-	-	3	-	**3**
	Intercropping	-	-	16	7	**23**
		41	**32**	**104**	**70**	**247**
Vietnam	Varieties	12	31	36	47	**126**
	Erosion control	16	28	29	30	**103**
	Fertilization	1	23	36	24	**84**
	Intercropping	-	14	32	31	**77**
	Weed control	-	3	-	-	**3**
	Plant spacing	-	1	7	19	**27**
	Leaf production	-	-	2	2	**4**
	Pig feeding	-	-	11	16	**27**
		29	**100**	**153**	**169**	**451**
Total		**82**	**146**	**285**	**397**	**910**

2. Farmer field days

At the time of harvest of the FPR trials, a farmer field day is organized at the subdistrict, district or provincial level. At the subdistrict level, farmers from the village and surrounding communities are invited to come, see and evaluate the treatments in all the trials. Usually, the central part of each plot had already been harvested on the day before the field day, but the pile of harvested roots with a sign indicating the yield and starch content was left in the center of each plot. Farmers visiting the trial can note down the yields, and they were asked to score each treatment, based on their own criteria, as either 1 = very bad, 2 = OK or 3 = very good. After farmers have visited and evaluated treatments in all the trials, the average results of the trials, together with data on gross income, production costs and net income obtained for each treatment, are presented and discussed with farmers. Finally, for each treatment farmers are asked to raise their hands to indicate if they consider the treatment "very good". The number of raised hands gives an indication which varieties or practices farmers consider most useful. **Table 3** is an example of the type of results presented and discussed, and the farmers' preferences for particular treatments. Based on these preferences farmers may want to retest some of the best treatments next year, or they may already start to adopt the selected variety or practice in their production fields.

Table 3. 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)]	Dry soil loss (t/ha)	Yield (t/ha) cassava	Yield (t/ha) peanut[1)]	Gross income[2)]	Product. costs	Net income	Farmers ranking
				(mil. dong/ha)			
1. C monocult., with fertilizer, no hedgerows (TP)	106.1	19.17	-	9.58	3.72	5.86	6
2. C monocult., with fert., *Tephrosia* hedgerows	32.5	23.33	-	11.66	4.54	7.12	4
3. C+P, no fertilizer, no hedgerows	103.9	13.08	0.70	10.04	5.13	4.91	5
4. C+P, with fertilizer, no hedgerows	64.8	19.23	0.97	14.47	5.95	8.52	-
5. C+P, with fertilizer, *Tephrosia* hedgerows	40.1	14.67	0.85	11.58	5.95	5.63	3
6. C+P, with fertilizer, pineapple hedgerows	32.2	19.39	0.97	14.55	5.95	8.60	2
7. C+P, with fertilizer, vetiver hedgerows	32.0	23.71	0.85	16.10	5.95	10.15	1

[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

Source: *Thai Phien et al., 1998; Howeler et al., 2001.*

If organized at the provincial level the field day may attract over a thousand visitors, including high government officials, many farmers from various districts, school children and newspaper or TV reporters. Farmers from the village where the field day is being held may explain the results of their own FPR trials or show how the selected treatments have been adopted in their field. Farmers may also be interviewed for newspaper reports or TV programs. This an excellent way to reach a large number of farmers and disseminate widely the importance of erosion control and other practices that can increase farmers' yields and income.

3. Cassava Development Villages

In Thailand the project could reach even more farmers by the setting up of "Cassava Development Villages", organized by the Dept. of Agric. Extension with Thai government funding. In those pilot sites where farmers and local extension workers were keen to participate in the project, the farmers were encouraged to organize a community-based self-help group, with at least 40 members, elect their own leaders, and design their own by-rules about members' duties and benefits. Once organized each "Cassava Development Village" received a certain amount of fertilizers to be used for cassava production by the members; the value of these fertilizers plus a small interest, need to be paid back to the managers of the village's rotating credit fund at the time of the cassava harvest. The money returned to the fund could then be lent out to others for the purchase of fertilizers or other production inputs the following year. By organizing these self-help groups and training the local extension workers together with the groups' leaders it became much easier to reach a large number of farmers and to conduct a large number of FPR trials. Some of these "Cassava Development Villages" also established their own vetiver grass nurseries, so that vegetative planting material was always available when needed to plant more contour hedgerows.

4. Training of "FPR teams"

One way of increasing the efficiency of conducting the FPR trials is to train "FPR teams" in each pilot site. The team consists of a subdistrict extension agent and 2-3 key farmers of the village who are keen to participate in the project. Every year these teams from each new pilot site join a 4-day training course to learn about and discuss various cassava technologies, as well as farmer participatory methodologies and simple experimental techniques in order to help other farmers set out and conduct FPR trials. The various teams learn from each other and each team goes home with new ideas and with renewed enthusiasm to improve cassava production in their village.

5. Posters, booklets, pamphlets, videos etc.

Information about the new varieties or improved production practices can also be disseminated through posters, booklets, pamphlets etc.

A video about the farmer participatory approach, made by DOAE in Thailand, was also a good media to spread the knowledge about soil conservation practices, and the FPR and FPE approach used in the project. The video can be shown in farmers' meetings, to extension workers, and also in schools in rural communities.

Detailed descriptions of the implementation of the project in each country are reported by Watananonta *et al.* (2007), Vongkasem *et al.*(2007), Nguyen The Dang (2007), Nguyen Thi Cach *et al.* (2007), Tran Thi Dung and Nguyen Thi Sam (2007), Tran Ngoc Ngoan and Howeler (2007), Li Kaimian *et al.* (2007) and Tian Yinong (2007).

ACHIEVEMENTS

During the 4th year of the second phase of the Nippon Foundation project, many farmers in the pilot sites and far beyond had started to adopt some of the tested technologies.

In China, new varieties, mainly the breeding lines ZM 9057 and OMR 33-10-4, tested and selected by farmers in Kong Ba village and recently released as SC 5 and SC 6, respectively, are now widely grown in Hainan province, while the newly released varieties GR 891, GR 911, SC 124 and Nanzhi 199 were tested and are now widely grown in Guangxi province. The total area under new varieties is not well known, but is estimated at about 30,000 ha. Some farmers have adopted the planting of vetiver grass hedgerows to control erosion, but that practice is not wide-spread as farmers are not yet convinced that it will lead to increased yields and income (Li Kaimian *et al.*, 2007; Tian Yinong *et al.*,2007).

In Thailand the area under new varieties increased from about 300,000 ha in 1994 (Rojanaridpiched *et al.*, 1998) to about 1 million ha or 98% of the total cassava growing area in 2002/03. While the main "improved varieties" in 1994 were Rayong 3 and Rayong 60, in 2003 these had been largely replaced by Kasetsart 50, Rayong 5 and Rayong 90.

This rapid dissemination of new varieties was achieved through the efforts of many government and non-government organizations, especially DOAE and TTDI, but the Nippon Foundation project also contributed by the widespread testing of new varieties in FPR trials in about 20 pilot sites.

Moreover, by 2002, about 856 farmers had planted a total of 130 km of contour hedgerows of vetiver grass in 943 ha of cassava fields, while many farmers had adapted the use of NPK compound fertilizers, especially those high in K; some farmers applied chemical fertilizers in combination with chicken manure or they intercropped *Canavalia ensiformis* as a green manure (Vongkasem *et al.*,2007).

In 2002 a Participatory Monitoring and Evaluation (PM & E) was conducted in four pilot sites where the project had been active for some years. Using various farmer participatory evaluation techniques, farmers were asked to estimate the extent of adoption of various new technologies in their own cassava fields. **Table 4** shows that in all four villages new varieties had been adopted in 100% of the cassava area, chemical fertilizer use ranged from 79 to 100%; of the area; planting of vetiver grass contour hedgerows ranged from 20 to 55%; green manures from 0 to 50%; and intercropping had not been adopted at all as most farmers don't have the labor to attend to intercrops.

Table 4. 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: *K. Klakhaeng, personal communication, 2002.*

In Vietnam it is estimated that in 2002 new varieties, mainly KM 94, had been planted in 95,000 ha, corresponding to 33% of the total cassava area. **Table 5** shows how the adoption of new varieties and production practices in the project pilot sites increased year by year, especially the adoption of new varieties. By the end of 2002, 2,717 farm households had adopted new varieties in a total of 1,244 ha; over 1000 farmers had adopted the use of cassava root and leaf silage for pig feeding; 689 farmers were intercropping cassava with peanut or blackbean in 42 ha; 222 farmers were planting hedgerows of *Tephrosia candida*, pineapple, vetiver grass or *Paspalum atratum* to control erosion in about 100 ha; and 157 farmers were using more balanced fertilization in 26 ha. The total increase in gross income due to the higher yields obtained was 4,116 mil dong or US$ 274,400 or about $ 57.- per household (Tran Ngoc Ngoan and Howeler, 2007).

The adoption of new varieties and improved production practices can have a profound impact on cassava yields obtained and the farmers' net income. **Table 6** shows how the adoption of new technologies in Tien Phong village increased every year, resulting in markedly increased yields and a tripling of the total net income from cassava in the community between 1994 and 2001, even though these new technologies had been adopted in less than 20% of the cassava area.

Table 5. Trend of adoption of new cassava technologies in the Nippon Foundation project sites in Vietnam from 2000 to 2002[1].

Technology component	Number of households adopting 2000	2001	2002	No. of ha 2002	Increase in gross income (mil. dong)
1. New varieties	88	447	2,717	1,244	3,650
2. Improved fertilization	64	123	157	26	57
3. Soil conservation practices	62	200	222	99	118
4. Intercropping	127	360	689	42	143
5. Pig feeding with cassava root silage	-	759	1,027	-	148
					4,116 [2]

[1] Number of project sites: 1999 = 9; 2000=15; 2001=22; 2002=25
[2] 4,116 mil. dong = US$ 274,400
Source: Tran Ngoc Ngoan and Howeler, 2007.

Table 6. Impact of the Nippon Foundation project on the livelihoods of farmers in Tien Phong village of Pho Yen district, Thai Nguyen, Vietnam.

	No. of farmers	Cassava area (ha)	Cassava yield (t/ha) new varieties	Vinh Phu[2]	Gross income (mil. dong/ha)	Product. costs (mil. dong/ha)	Net income (mil. dong/ha)	Total net income (mil. dong)
1994[1]								
Traditional	115	50		8.5	3.40	2.93	0.47	23.50
2000								
New varieties	25	1.31	30.9	21.5	15.46	4.36	11.10	14.54
Intercropping	37	2.59	29.3	-	18.70	5.16	13.54	35.07
Erosion control	4	0.20	24.7	-	14.59	5.46	9.13	1.83
Total	*66*	*4.10*						*51.44*
2001								
New varieties	89	4.70	28.5	22.7	14.26	4.36	9.90	46.53
Intercropping	40	3.38	26.2	-	16.94	5.16	11.78	39.82
Erosion control	4	0.20	-	-	-	-	-	1.83
Total	*133*	*8.28*						*88.18*

[1] data from RRA conducted at the start of the project in 1994
[2] traditional variety
Source: Nguyen The Dang, personal communication, 2002.

LESSONS LEARNED

After conducting the project for nearly nine years there are several important lessons that we have learned:

1. Farmers must become aware of the extent of soil losses by erosion and the effect on yield before they will adopt soil conservation practices. By doing FPR erosion control trials on their own fields, farmers can see with their own eyes how much soil is lost

every year, and how some simple agronomic or soil conservation practices can markedly reduce those losses.

2. Farmers are only interested in testing technologies that are clearly superior to what they are doing now. The combined use of high-yielding varieties with adequate fertilization, weeding and erosion control will often double or triple yields as compared to the traditional practices. Under those circumstances farmers will be keen to participate in the project and to help others in adopting these new technologies.
3. New varieties and other agronomic practices that increase yields are good entry points for the testing and adoption of soil conservation practices. Promoting only soil conservation is an uphill battle as farmers generally do not see the immediate economic benefits of those practices and are thus not interested in adopting them.
4. Researchers and extensionists should not recommend or promote any particular variety or practice; they should present farmers with a range of options and then let farmers choose; value their knowledge, culture and local experience.
5. Farmers base their decisions about adoption mainly on the potential economic benefits obtained. For that reason, the results of trials should not only indicate agronomic aspects like yield, starch content or soil loss, but also the estimated gross income obtained from selling the crop(s), the production costs of each treatment and the net income, as shown in **Table 3**. Based on those data, farmers can make intelligent choices.
6. Seeing the adoption of soil conservation practices in other farmers' fields is more convincing to farmers than listening to researchers or extension workers, or visiting researcher-managed demonstration plots.
7. Training of a large number of researchers, extension workers and key farmers is crucial for being able to extend the FPR approach to many sites and for achieving widespread adoption.
8. Local officials and community-based self-help groups should be actively involved in the project.
9. Some incentives in kind may be necessary to achieve wide-spread adoption of soil conservation practices; this is justified because these practices usually require additional labor or money while they benefit not only the farmers but also society at large.
10. A project like this should start small and then extend to more sites only after the methodology has been worked out, and after people have been trained and feel comfortable with the FPR approach.
11. The farmer participatory approach will become institutionalized only after administrators become convinced of its effectiveness. This can be achieved through seminars and workshops, but is most convincing when it is seen being practiced by farmers in the field.

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FARMER PARTICIPATORY RESEARCH (FPR) IN CASSAVA THROUGH THE INSTITUTION-VILLAGE LINKAGE PROGRAMME (IVLP) IN INDIA

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ABSTRACT

Cassava, upon which millions in the tropics depend for their livelihood and food security, is mostly confined to southern India, with Kerala, Tamil Nadu and Andhra Pradesh states accounting for more than three-fourth of the area planted to cassava. While cassava continues to play an important role as a food crop in the state of Kerala, in the other two states the harvested roots are used mainly as a raw material for the starch and sago factories.

Although the average yield of cassava in India, over 20 t/ha, is the highest in the world, this can still be further increased through the breeding of high yielding varieties supported by sound agronomic management. But it is also clear that varieties need to be developed based on farmers' preferences. Realizing this, CTCRI has initiated during the early nineties farmer participatory research (FPR) in cassava, especially with regard to varietal selection. This culminated in the release of two early-maturing cassava varieties, Sree Jaya and Sree Vijaya, which are now becoming popular in the lowland production system in Kerala.

When the Institution-Village Linkage Programme (IVLP) came into operation on a pilot scale in 1995, the scope of FPR in cassava was widened. IVLP is a novel front-line extension program, the implementation of which begins with the selection of a suitable village; this is followed by a detailed agro-ecosystem analysis of the selected village, diagnozing the problems of each production system and prioritizing these; identification of technological interventions based on problem-cause relationships; the development of action plans and their implementation; and a detailed socio-economic evaluation, including farmers' reaction and perception about the interventions. This is carried out in a short time using various PRA and RRA tools and techniques. The most significant and underlying factor in the entire process is the active participation of farmers from the beginning to end. CTCRI has been implementing IVLP in Chenkal village of Thiruvananthapuram district, Kerala, with cassava as one of the important crops in the production system of the village. This paper, besides detailing the IVLP approach, gives an account of the technological interventions relating to the cassava production system, namely, the performance assessment of high yielding varieties, intercropping technologies and nutrient management. The impact of these interventions in enhancing the productivity and income from cassava is also discussed in this paper.

INTRODUCTION

Cassava, the third most important food crop after cereals and grain legumes, is a staple food for millions of people in the tropics; it plays an important role as a food security crop. In India, it is the most important root crop, the cultivation of which is mostly concentrated in the southern states of Kerala, Tamil Nadu and Andhra Pradesh, which together account for a little over 90% of the area and production of cassava in the country (Anantharaman *et al.*, 1992). In the major growing state of Kerala, cassava continues to occupy a place as a secondary staple food of the people, however, to a lesser extent as compared to the sixties and early seventies. In contrast, in Tamil Nadu and Andhra Pradesh, a major quantity of the roots harvested is being used as a raw material by the starch and sago industries located there.

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The present yield of cassava in India, 26.32 t/ha, is the highest in the world and more than two and a half times that of world productivity (FAOSTAT, 2002). This is mainly because of the enthusiasm exhibited by the farmers, especially of Tamil Nadu and Andhra Pradesh, to use high-yielding varieties with sound management practices. In a varietal coverage study undertaken by Ramanathan *et al.* (1990), two high-yielding varieties of cassava, namely H-165, and H-226, were found to be grown in about 80% of the cassava area of Salem, Namakkal, South Arcot and Dharmapuri districts of Tamil Nadu. The farmers there harvested on average more than 35 t/ha of roots. The picture in Andhra Pradesh is not much different from Tamil Nadu. In East Godavari, the main cassava district of Andhra Pradesh, over 90% of the cassava area is being occupied by a single variety, H-165 (Balagopalan *et al.*, 1998). Cassava farmers of both Tamil Nadu and Andhra Pradesh were observed to apply a large quantity of chemical fertilizers, more than the recommended dose, to increase yields (CTCRI, 2002a; Srinivas and Ananthraraman, 2000). It may be noted that the Central Tuber Crops Research Institute, responsible for the research and development of cassava in India, has so far released 11 high-yielding cassava varieties for general cultivation by the farmers (Nair *et al.*, 2000) They include three short-duration varieties, one triploid with high starch, one high-carotene variety and two top cross hybrids. In addition, CTCRI, together with the All-India Coordinated Research Project on Tuber Crops, have developed location specific agro-techniques of cassava to get higher production.

With the availability of many high-yielding cassava varieties coupled with efficient management practices, it is possible to increase yields to over 50 t/ha. This process could be enhanced, when varieties are developed with farmers as research partners. Farmer participatory research (FPR) is an effective mechanism to successfully identify varieties preferred by the farmers. Ashby (1990) defined FPR as a set of methods designed to enable the farmers to make an active contribution as decision makers in planning and execution of agricultural technology generation. Participation of farmers in the research process highly facilitates the means of obtaining feedback for the research and extension process, paves the way for the subsequent dissemination and adoption of the technologies and builds up the confidence of farmers in conducting research and in their own innovativeness (Shamebo and Belehu, 1999). Careful selection of new varieties, which show local adaptability and stability as well as good quality characteristics required by the farmers and consumers helps in increasing adoption and cassava yield.

Hence, a methodology based on farmers' participation in the selection of materials could enhance the transfer and adoption of any new technology. Realizing the potential of the FPR approach in the identification of appropriate technologies and their more rapid adoption by farmers, CTCRI has initiated FPR studies in cassava in the mid nineties.

1. FARMER PARTICIPATORY RESEARCH IN CASSAVA IN INDIA - A BACKGROUND

Farmer participatory research in cassava in India was started in 1994 for varietal evaluation, since varieties have a major influence on productivity (Anantharaman and Ramanathan, 2001). FPR in cassava is carried out by conducting on-farm trials of promising genotypes in farmers' fields by adopting consultative participation of farmers, which emphasizes researcher-managed and farmer implemented trials (Ashby, 1986). Initially, participatory varietal evaluation was conducted in both upland and lowland cassava production systems of Kerala State and was later extended to Tamil Nadu and Andhra Pradesh. A three-stage evaluation trial was designed by Anantharaman *et al.,* (1999) and implemented; it comprised of "Initial on-farm trial", "Confirmation on-farm trial" and "Validation on-farm trial". The varieties were evaluated both at pre- and at post-harvest stages by the four evaluator groups, i.e. farmers, farm women, traders and scientists, especially formed for this purpose. Under the first stage of the trial, 11 cassava genotypes, three released, four promising, one improved and three local cultivars, were grown under farmers' management. The trials in individual farmers fields served as replications. Based on the evaluation of crop stand, root yield and root characteristics, five promising genotypes were carried forward to the confirmation trial. From that stage, the two genotypes preferred most by the evaluator groups were selected for inclusion in the next stage, for validating their performance. During the course of these trials, various PRA tools, such as key informant interview, matrix ranking, direct observation etc., have been used to elicit information on varietal performance and spread.

1.1 Yield performance and varietal selection by farmers

The yield performance of cassava genotypes in three stages of trial under both upland and lowland production systems is shown in **Table 1**. Four pre-released genotypes, CI-664, CI-649, CI-731 and CI-732 were preferred by the farmers, farm women and traders, not only due to their high yield, but also considering the root characteristics such as root shape, size, number, uniformity and cooking quality. In the confirmation trial they continued to exhibit their high yield potential under the two types of production systems. At the final stage of the trial, i.e. the validation trial, two cultivars, CI-649 and CI-732, gave average root yields of more than 30 t/ha at seven months and were most liked by the farmers. At Pallichal village, CI-731 was preferred, in addition to CI-649. The farmers and farm women, besides traders gave weightage to cooking quality and marketability while selecting a cultivar, apart from their yield, as a major portion of the roots produced is going for human consumption in Kerala. Based on the overall performance and farmers' preference, the two genotypes CI-649 and CI-731 have been released for the State of Kerala in the name of "Sree Jaya" and 'Sree Vijaya," respectively (Unnikrishnan *et al.*, 2000). These two varieties are early-maturing, harvestable at 6-7 months, suitable for lowland cultivation as a rotation crop in paddy-based cropping systems.

The two short-duration varieties Sree Jaya and Sree Vijaya have become so popular in the villages where the trials have been conducted, and were found to spread amongst the cassava cultivators. A rapid assessment of the spread effect of these varieties at the end of the three years of evaluation indicated that nearly 53% of the farmers of Anacode village were cultivating the two new varieties in 30% of their cassava area. Similarly, in Pallichal village, these varieties have almost covered 50% of the cassava area by the third year and nearly 70% of cassava farmers of this village cultivated them. In Kodankara village, about 30% of the farmers cultivated these varieties in about 43% of the cassava area. Taking lessons from the FPR on cassava varietal evaluation for successful evolution of varieties that have a greater diffusion effect in the cassava production system, this approach has been extended to evaluate new cassava varieties in Tamil Nadu and Andhra Pradesh. When the

Institution-Village Linkage Programme (IVLP) came into operation during 1996 with CTCRI as one of the implementing centers, the scope of FPR in cassava was widened to include nutrient management, intercropping technologies etc. in addition to varietal evaluation.

Table 1. Yield performance of cassava genotypes tested under FPR in three villages in Kerala, India.

	Average root yield (t/ha)								
	Lowland production system						Upland production system		
	Anacode			Pallichal			Kodankara		
Cassava genotypes[1)]	IOFT[2)]	COFT	VOFT	IOFT	COFT	VOFT	IOFT	COFT	VOFT
1. Sree Vishakam*	22	29	-	32	24	-	23	-	-
2. Sree Sahya*	28	-	-	24	-	-	17	-	-
3. Sree Prakash*	27	-	-	27	-	-	27	-	-
4. CI 664**	20	23	-	18	-	-	28	27	-
5. CI 649**	55	40	38	32	29	35	22	29	30
6. CI 731**	32	35	-	33	23	30	18	22	-
7. CI 732**	29	46	41	33	26	-	29	25	27
8. M4***	22	-	-	23	-	-	13	-	-
9. Monkozhunthan****	31	-	-	24	-	-	25	-	-
10. Karukannan****	27	-	-	27	-	-	20	-	-
11. Kariyilaporiyan****	20	-	-	21	-	-	19	-	-

[1)] * Released varieties ** Pre-released genotypes *** Improved variety **** Land races
[2)] IOFT = Initial on-farm trial; COFT = Confirmation on-farm trial; VOFT = Validation on-farm trial
Source: *Anantharaman et al., 1999.*

2. INSTITUTION-VILLAGE LINKAGE PROGRAMME

It is an innovative project initiated by the Indian Council of Agricultural Research (ICAR) on a pilot basis from 1995-96, which was later brought under the World Bank funded National Agricultural Technology Project (NATP) in 1999. It is different from the earlier first line extension efforts of ICAR, in the sense that it lays emphasis on the research aspect through the participation of farmers to be carried out by the multidisciplinary team of scientists. Moreover, IVLP is a production system oriented project with agro-ecosystem analysis of the adopted village as the basis to identify problems, prioritize them and find out technological intervention points which are further developed into action plans to overcome the problems through assessment and refinement of technologies. Active participation of the farmers has to be ensured throughout the implementation of this project, and in this regard various PRA tools and techniques are to be employed to study the agro-ecosystem, develop action plans, implement the same and assess their appropriateness to the village.

2.1 Concept of IVLP

The IVLP is conceptualized based on the realization of the fact that the majority of the agricultural technologies are developed and perfected at the research institutes under ideal conditions, which seldom exists among the small and marginal farmers that form the bulk of the farming community in India. The impact analysis of the various transfer of technology (TOT) projects of previous years brought to the limelight that the cause for non-adoption or partial-adoption of agricultural technologies by the farmers operating under complex, diverse, risk-prone (CDR) production systems really did not lay with the farmers or extension system or input supply system as believed generally; rather, it was the technology that was found to be a mismatch to the production system of the farmers. It is against this background, that the need to evaluate agricultural technologies for their appropriateness to the environmental and socio-economic conditions of small and marginal farmers was felt strongly. Hence, a more holistic approach encompassing the detailed analysis of the agro-ecosystem of an adopted village, problem diagnosis, assessment and refinement of identified technological interventions etc., with farmers participation as the underlining principle, was thought of by ICAR and named as Institution-Village Linkage Programme (IVLP), to address the problems of the farming community, particularly of the CDR system.

2.2 Objectives of IVLP

The main objectives of the project include

a) To introduce technological interventions with emphasis on stability and sustainability along with productivity and profitability, taking into account environmental issues in well endowed and small production systems.
b) To introduce and integrate appropriate technologies to increase the productivity with marketed surplus in commercial and off-farm production systems.
c) To monitor the socio-economic impact of technological interventions for different production systems, and
d) To identify extrapolation domains for new technology/technology modules based on environmental characterization at meso and mega levels.

The various steps envisaged in the implementation of the IVLP are detailed below, with special emphasis on the cassava production system (Anantharaman *et al.,* 2001).

2.3 Selection of Operation Site

The village is the basic unit of operation of IVLP projects. While selecting a village, the factors such as proximity to the implementing Centre, size of the village (800-1000 farm families), contiguity, institutional development, availability of various kinds of production systems, co-operative and willing nature of farmers, etc. should be given due consideration. As regard to CTCRI, care was taken to select a village with cassava as an important crop in the agro-ecosystem of the village, besides giving due weightage to the above criteria. Taking all the above aspects into consideration, Chenkal village in Neyyattinkara Taluk of Thiruvananthapuram district, Kerala, was selected for implementation of IVLP. It is situated about 35 km south of Thiruvananthapuram city. Chenkal village (west) has 600 families, out of which 570 derive their income from agriculture and allied activities.

2.4 Constitution of Multidisciplinary Team

The project is to be implemented by a multidisciplinary Core Team of 4-5 scientists drawn from the host institute with one amongst them acting as the Nodal Officer. It is the primary responsibility of the team members to select the village, prepare a project document, implement the action plans contemplated, monitor day-to-day activities and submits reports periodically. Apart from the Core Team, an Optional Team is also constituted with members from disciplines other than those of the Core Team from the host institution as well as from other institutions to render technical guidance as per the need of the project. The core team of CTCRI consisted of 5 members: a plant breeder, an agronomist, a plant protection scientist and two extension specialists, one each acting as a Nodal Officer and Core Team Leader.

2.5 Agro-ecosystem Analysis

Agro-ecosystem analysis is a recent concept of multidisciplinary nature and can be used at all levels of hierarchy of agro-ecosystems, from field through farm, village and watershed, to region and nation. It also provides a technique of analysis and packages of technology that focus not only on productivity, but also explicitly on trade-offs between them. The complexity of the system in terms of its dynamic consequences can have four system properties which together describe essential behaviour of agro-ecosystems. These are productivity, stability, sustainability and equitability. To understand the system properties, the pattern analysis is widely used which includes four patterns that reveal the key functional relationship that determine system properties. Three of them, i.e. space, time and flow are known to be important in understanding the system properties and are also neutral with respect to scientific disciplines. The fourth, pattern-decision, reflects the process of human management of agro-ecosystems. The agro-ecosystem analysis was carried out by employing various PRA and RRA tools and techniques such as key informant interview, focused group discussion, village transect, mapping, diagramming, matrix ranking etc.

2.5.1 Pattern analysis

2.5.1.1 Space

The spatial patterns of the village is better understood by making a village map and village transect. While the village map gives a total picture of the village with regard to domicile pattern, land utilization, availability of various facilities etc., the transect represents the cross section of the village indicating the topography, soil type, crops grown, livestock details, irrigation source, problems etc. of the village. Cassava is an important crop of the upland production system of the adopted village Chenkal, and the crop is grown in red laterite soil, both as a sole crop and in mixed stands with coconut. Cassava is also found cultivated under lowland conditions in clay soil, which is traditionally used for paddy cultivation. Under upland conditions, cassava is grown purely as a rainfed crop whereas the crop may receive canal water under lowland conditions.

2.5.1.2 Time

The time patterns are best expressed by graphical representations. Historical transect, rainfall pattern, cropping pattern, seasonality of pests and diseases, yield trends, labor availability, fodder availability etc. are some of the key parameters in the analysis of time patterns of the village. This in turn will help in identifying the periods in the year when the timing of operations and the availability of resources is critical for productivity and stability. Long-term changes in production, prices, climate etc. and the stress and perturbation occurring in the agro-ecosystem are also analyzed to reveal productivity trends and to measure the stability/instability of production.

As regard to the cassava crop, the high yielding varieties were introduced into Chenkal village after 1975. During the period 1988-90, the Lab-to-Land Programme (LLP) of CTCRI was in operation in this village and under this progaramme, the high-yielding cassava varieties Sree Vishakam and Sree Sahya have been introduced by setting up demonstrations in farmers' fields. Except for cassava mosaic disease and rat damage during the root bulking stage, no other serious pests/diseases have been noticed. The present root yield of cassava **(Figure 1)** of 20 t/ha is a little higher than the district yield (18.8 t/ha) and block yield (16.43 t/ha). A gradual and steady increase in cassava yields was observed in the adopted village **(Figure 2);** it was below 10 t/ha in 1950, increased to 10 t/ha in the sixties and increased further to the present level of 20 t/ha. The yield level has more or less stabilized over the years.

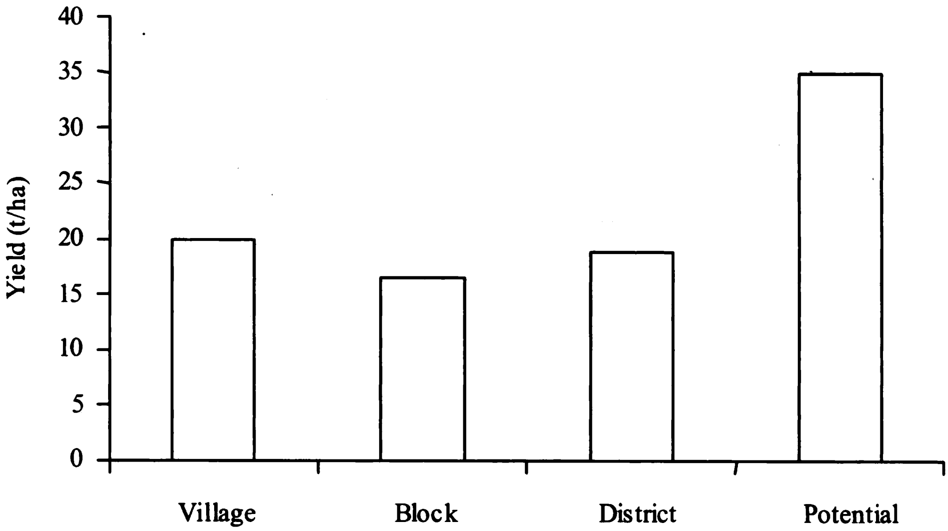

Figure 1. Yield of cassava in the village, block and district, and the potential yield.

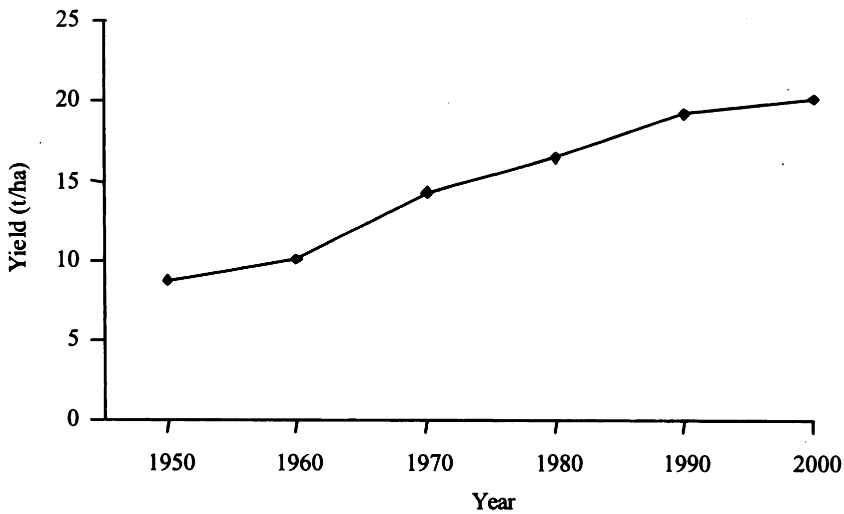

Figure 2. Trends in yield of cassava in Chenkal village, Thiruvananthapuram district of Kerala, India from 1950 to 2000.

2.5.1.3 Flow

The patterns of flow represent the transformations of energy, materials, money, information etc. in the agro-ecosystem. Flow diagrams are used to depict the interrelationship between the various elements. The resource flow diagram of the adopted village revealed that 90% of the cassava produced is going out of the village through sales and only 10% is consumed within the village. The mobility map and livelihood analysis are the other important flow patterns used to get an idea about the behaviour of the farmers and their allocation of resources towards income and expenditure patterns.

2.5.1.4 Decisions

This refers to the individual farmer's choice in the selection of enterprises, crops and crop varieties as well as management practices, such as what to grow, where to grow, how and from where to purchase inputs etc., which occur at all levels in the hierarchy of agro-ecosystems. They are mainly represented in the form of matrices and they help in identifying the priorities given by the farmers as well as the selection criteria used by them in arriving at such priorities. The matrix ranking of crops and cassava varieties ranking are presented in **Tables 2 and 3,** respectively, which has relevance to the cassava production system of the village. In **Table 2** a score of 1 was awarded for the most preferred crop with respect to a particular character, and the scores of 2, 3, 4 and 5 were given for the crops in the order of preference with 5 indicating the least preferred. The crops' ranking indicate that cassava is most preferred for its food security, profitability and low pest and disease incidence. With respect to low input requirement and marketability, it is ranked fourth. In respect to **Table 3**, a score of 5 represented the highest and most preferred variety for a particular attribute and the rank 1 is the lowest score given for the least preferred variety. The varietal preferences of cassava varied with the varietal characteristics, as evidenced from the varieties ranking matrix. The farmers preferred Ullichuvala most owing to its yield, duration, root shape, market preference, cooking quality and suitability to lowland cultivation. It is followed by Vellanoorumuttan, M4, Mankozhunthan, Kariyilaporiyan and Narukku in that order.

Table 2. Matrix ranking of crops by farmers in Chenkal village of Thiruvananthapuram district of Kerala, India in 1999.

Characters	Rice	Coconut	Cassava	Banana	Vegetables
Food Security	5	4	1	4	3
Profitability	2	3	1	5	5
Low pest and disease incidence	1	3	1	5	5
Drought tolerance	1	3	5	4	2
Low input requirement	1	5	4	3	2
Marketability	1	5	4	3	3

Note: 1 = highest rank = best
Source: *Anantharaman et al., 2001.*

Table 3. Matrix ranking of six cassava genotypes by farmers in Chenkal village of Thiruvananthapuram district of Kerala, India in 1999.

Characters	Kariyila-poriyan	Narukku	M4	Ullichu-vala	Vellanooru-muttan	Mankozhun-than
High yield	3	3	2	5	4	2
Short duration	5	2	2	5	3	3
Good root shape	5	2	3	5	3	2
High starch content	2	5	4	3	4	5
Good market preference	4	3	5	5	4	3
Excellent cooking quality	5	3	5	5	4	3
Suitability to grow under lowland condition	5	1	2	5	3	1
Suitability to grow under upland condition	2	4	4	3	5	5

Note: 5 = highest score = best
Source: *Anantharaman et al., 2001.*

2.5.2 Analysis of system properties

2.5.2.1 Productivity

The yield of cassava (20 t/ha) in Chenkal village, though higher than the productivity of the respective block and district, is much below the realizable potential as opined by the scientists **(Figure 1)**. This means that farmers can probably achieve the potential yield by replacing the existing land races with high-yielding varieties. Hence, the cassava yield of the village may be regarded as medium.

2.5.2.2 Stability

Contrary to many of the other crops like paddy, banana, coconut, vegetables etc. which showed variability in production, cassava exhibited consistency with steady increase in yield from a low 9 t/ha during the 1950s to the present level of 20 t/ha **(Figure 2).**

2.5.2.3 Sustainability

Owing to the steady increase in cassava yield during the past five decades, the sustainability of this crop in the adopted village can be considered as high.

2.5.2.4 Equitability

Equitability is estimated using wealth ranking and it was observed that there is no equal distribution of wealth among the villagers, with agricultural laborers accounting for more than 65% of farm families. However, as far as cassava cultivation is concerned, there is high equitability, since it is grown uniformly by all the sections of the farmers cutting across land holding size, resource availability, caste etc.

2.5.3 Problem diagnosis and prioritization

By effectively utilizing the technique of key informant interview, focused group discussion and direct observation, the various problems confronting the production of crops and other enterprises are diagnosed. The root causes for problems are also listed and grouped into bio-physical and socio-economical. In consultation with the farmers and concerned experts in the field, the causes are prioritized for possible technological interventions. This entire exercise is depicted in the form of a problem-cause relationship diagram with respect to low cassava yields, and represented in **Figure 3.** It is clear from the diagram that non-availability of planting material of improved varieties is the primary cause for low yield. High incidence of cassava mosaic disease, rat damage and non-availability of seeds of suitable intercrops are also identified as other causes for low productivity and income from cassava production systems. Among the different socio-economic factors limiting the productivity, poor knowledge about production and processing was selected for suitable technological intervention.

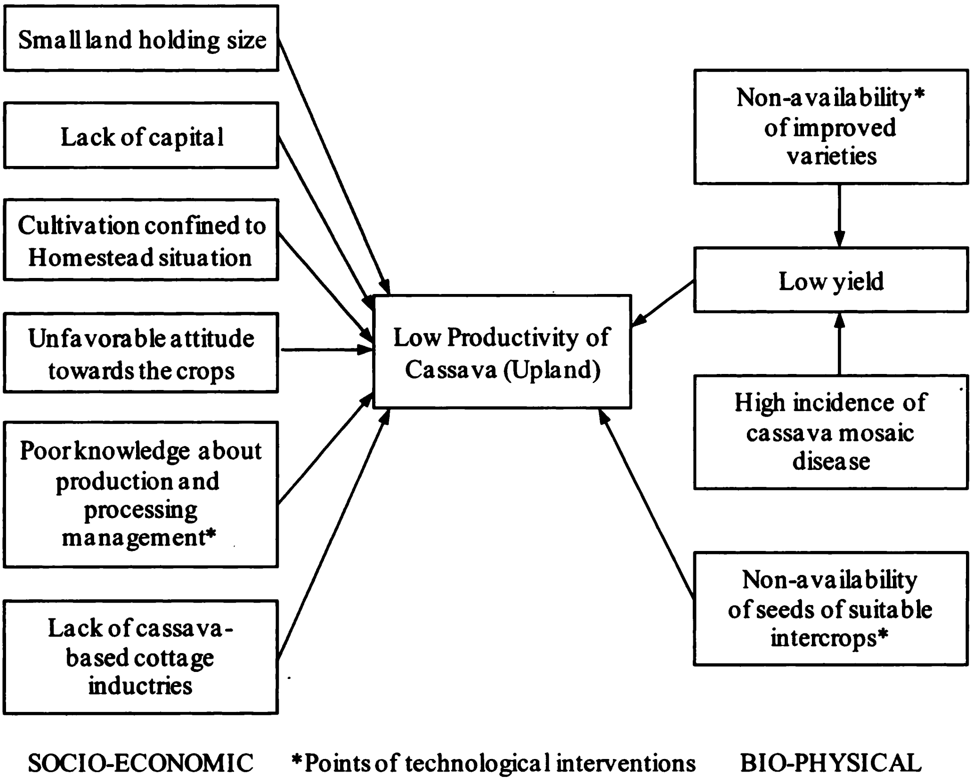

Figure 3. Problem-cause relationships for low productivity of cassava.

2.5.4 Legitimization of problems and solutions

Legitimization is a process by which problems and solutions are presented and discussed with the villagers in order to get their concurrence; this is done through focused group discussion, in which farmers, Core Team members and experts take part. This forms the basis for developing appropriate action plans to be implemented to overcome the problems identified.

2.5.5 Action plan and implementation

Keeping the problem-cause relationship as the basis, action plans are prepared for each technological intervention, with the active participation of farmers and facilitated by

IVLP Core Team members. The action plans prepared for cassava based interventions, such as assessment of the performance of high-yielding varieties, assessment of the effect of nutrient management practices in cassava, and the assessment of the performance of intercropping technologies, are given in **Tables 4, 5 and 6**, respectively. The action plan gives an account of the micro-farming situation, the problems and their causes, intervention points, potential solutions, nature of intervention, treatments, critical inputs etc. The technological interventions contemplated under the action plans are implemented in the selected farmers' fields, either as on-farm trials or verification trials. At each and every stage of the trial, the participating farmers are involved in assessing the interventions, using various performance indicators such as technical observations, economic observations, farmers' reaction etc.

Table 4. On-farm trial on new high-yielding varieties of cassava to be conducted by farmers in Chenkal village.

Name of the intervention	Assessment of the performance of new high-yielding varieties of cassava
Micro farming situation	Cassava-based cropping system under upland rainfed condition
Problem and its causes	Non-availability of planting materials of new high-yielding varieties of cassava. All the local varieties are low yielding (20 t/ha) and infected with cassava mosaic disease, and disease-free planting materials are not locally available
Intervention points	Non-availability of planting materials of high-yielding varieties of cassava
Potential solutions	There will be an increase in yield and income from cassava plots by planting disease-free planting materials of high-yielding varieties of cassava
Nature of intervention	On-farm trials
Treatments	1. Sree Jaya 2. Sree Vijaya 3. M-4, 4. Sree Vishakam 5. Sree Prabha 6. Sree Rekha 7. TCH-3 8. TCH-4 9. Local (Ullichuvala)
No. of replications	20
Critical inputs	Planting materials of high-yielding cassava varieties

***Source:** Anantharaman et al., 2001.*

2.6. Assessment of Cassava-based Technological Interventions

2.6.1 Assessment of the performance of high yielding cassava varieties

Non-availability of planting material of new high-yielding varieties of cassava was identified as the major limitation in increasing cassava yields in the adopted village. To combat this problem, an action plan has been developed to evaluate new high-yielding cassava varieties developed and released from CTCRI, along with local varieties in selected farmers' fields in the form of on-farm trials. The trials were conducted under upland production system conditions during the rainy seasons of 1998, 2000 and 2001. The yield performance of the varieties are shown in **Table 7.** Of the 12 varieties evaluated for their

Table 5. On-farm trial on nutrient management practices in cassava to be conducted by farmers in Chenkal village.

Name of the intervention	Assessment of the effect of nutrient management practices in cassava
Micro farming situation	Cassava-based cropping system under upland rainfed conditions
Problem and its causes	The farmers generally have a poor knowledge about production and processing management of this crop. The low productivity of cassava (20 t/ha) in this area is due to inadequate and imbalanced nutrient use. Poor economic base of the farmers prevents them from practicing balanced nutrient management
Intervention points	Non-availability of phosphate fertilizers and lack of knowledge regarding judicious application of fertilizers
Potential solutions	There will be a yield increase due to timely and balanced application of a combination of organic, inorganic and bio-fertilizers
Nature of intervention	On-farm trials
Treatments	1. Farmers practice (40 kg N+40 kg P_2O_5 +30 K_2O/ha) 2. Recommended nutrient management (100 kg N+ 50 P_2O_5 +100 kg K_2O/ha); half N, full P and half K as basal and half N and half K one month after planting 3). Use of VAM[1)] + 100 kg N + 25 P_2O_5 + 100 K_2O/ha (VAM + half N, full P, half K as basal and half N and K one month after planting
No. of replications	10
Critical inputs	Fertilizers and VAM

[1)]VAM = vesicular-arbuscular mycorrhiza

Source: *Anantharaman et al., 2001.*

Table 6. On-farm trial on intercropping in cassava to be conducted by farmers in Chenkal village.

Name of the intervention	Assessment of the performance of leguminous intercrops in cassava
Micro farming situation	Cassava-based cropping system under upland rainfed condition
Problem and its causes	Non-availability of seeds of suitable intercrops.
Potential solutions	There will be an increase in yield and income from cassava plots due to intercropping and the more effective utilization of interspaces by growing suitable intercrops
Nature of intervention	On-farm trial
Treatments	1. Farmer's practice (no intercrop) 2. Intercropping with peanut, var. TMV 2 and JL-24 3. Intercropping with French bean, var. Contender 4. Intercropping with cowpea, var. C-152 and Arka Garima
No. of replications	31
Critical inputs	Seeds of intercrops

Source: *Anantharaman et al. 2001.*

suitability to the village conditions during the past three years, the new top-cross hybrid cassava varieties "Sree Prabha" and "Sree Rekha", had consistently high root yields of more than 35 t/ha and the yield was as high as 53 t/ha in 2001. They outyielded other varieties and resulted in a net income of Rs.57,000-139,700/ha during different years depending upon the price of the roots. The preference for these two varieties became very clear by the matrix ranking **(Table 8),** as well as the farmers' evaluation of the positive and negative aspects of the varieties **(Table 9).** In **Table 8**, the scoring pattern similar to the one followed in **Table 2** was adopted with a score of 1 indicating the most preferred variety and 5 for the leased preferred one. Farmers preferred Sree Prabha and Sree Rekha because of high yield, good root size and shape, excellent cooking quality (Sree Rekha), low mosaic incidence and intermediate starch content. The beneficiary farmers who took part in the assessment of cassava varieties became the source of planting material for other farmers who have shown a keen interest in growing these varieties. These two varieties are now spreading gradually in the IVLP village, Chenkal.

Table 7. Assessment of the performance of high-yielding cassava varieties under upland production systems in Chenkal village, Kerala, India from 1998 to 2001.

	1998 rainy season[2]		2000 rainy season[3]		2001 rainy season[4]	
Cassava genotypes[1]	Root yield (t/ha)	Net income (Rs/ha)	Root yield (t/ha)	Net income (Rs/ha)	Root yield (t/ha)	Net income (Rs/ha)
1. Sree Vishakam*	25.92	32,400	-	-	-	-
2. Sree Jaya*	26.09	32,610	27.80	65,600	15.43	28,490
3. Sree Vijaya*	28.15	35,190	-	-	20.40	43,400
4. Sree Prabha*	46.74	58,430	34.60	86,000	52.50	139,700
5. Sree Rekha*	45.92	57,400	36.20	90,800	51.90	137,900
6. M4**	24.96	31,200	-	-	-	-
7. TCH-3***	29.63	37,040	-	-	-	-
8. TCH-4***	39.20	49,000	-	-	-	-
9. Manjanoorumuttan****	24.44	30,550	-	-	-	-
10. Kaliyanmanja****	-	-	25.60	59,600	-	-
11. Narayanakappa****	-	-	16.40	31,400	-	-
12. Ullichuvala****	-	-	-	-	22.20	48,800

[1] *Released varieties; ** Improved variety; *** Pre-released genotypes**** Land races; planted in early rainy season (June)

[2] 6 replications [3] 10 replications [4] 20 replications

Source: CTCRI, 1999; CTCRI, 2001; CTCRI, 2002b.

Table 8. Matrix ranking of seven cassava genotypes by farmers in Chenkal village.

Root characters	Sree Jaya	Sree Vijaya	Sree Prabha	Sree Rekha	Kaliyanmanja	Narayanakappa	Ullichuvala
High root yield	3	4	1	2	3	5	4
Good root shape	2	2	3	1	4	5	2
Optimum root size	3	3	2	1	3	3	2
Excellent cooking quality	1	4	5	1	5	4	2
Good taste	1	3	2	3	5	4	1
Low mosaic incidence	5	3	1	2	4	3	3
High starch content	5	5	2	3	4	1	2

Note: 1 = highest ranking = best

Source: *CTCRI, 2001; and CTCRI, 2002b.*

Table 9. Farmers evaluation of seven cassava genotypes: positive and negative aspects.

Cassava genotypes	Positive aspects	Negative aspects
Sree Jaya	Moderate yield Excellent cooking quality and taste	High mosaic incidence Low starch content
Sree Vijaya	Moderate yield Good root shape	Low starch content Poor cooking quality
Sree Prabha	High yield Good root size Low mosaic incidence Moderate starch content	Poor cooking quality
Sree Rekha	High yield Good root shape & size Excellent cooking quality Low mosaic incidence Moderate starch content	-
Kaliyanmanja	Moderate yield	Poor cooking quality & taste High mosaic incidence Low starch content
Narayanakappa	High starch content	Poor yield Poor cooking quality & taste High mosaic incidence
Ullichuvala	Moderate yield Excellent taste Moderate starch content	Moderate mosaic incidence

Source: *CTCRI, 2001; CTCRI, 2002b.*

2.6.2 Assessment of the performance of leguminous intercrops in cassava

To increase the income of farmers from the cassava production system, intercropping was thought to be a viable proposition. The agro-ecosystem analysis showed that intercropping was not used much in the adopted village. Hence, an action plan was developed to conduct on-farm trials in selected farmers' plots with various intercrops such as peanut, cowpea, French beans etc. in cassava over a period of four years. The performance assessment of various intercrops and the farmers' reaction are shown in **Tables 10 and 11,** respectively. While peanut and vegetable cowpea were found to be very suitable to the village conditions, French beans was found totally unsuitable. Both varieties of peanut, TMV-2 and JL-24, gave an average pod yield of over 0.8 t/ha with a additional net income of Rs.15,000-22,000/ha, depending on the yield levels. Similarly, vegetable cowpea (var. Arka Garima) was also assessed to be an ideal intercrop of cassava. In contrast, there was a total failure of French beans, which did not flower at all. Likewise, the grain cowpea (var. C-152) did not have a high yield due to a severe aphid attack and mosaic incidence. Besides additional yield and income, peanut and cowpea were found to have good marketability and an alternate use as green manure or cattle food. There is enthusiasm amongst the IVLP farmers to adopt intercropping of peanut or/vegetable cowpea whenever cassava is grown under upland conditions.

Table 10. Assessment of the performance of leguminous intercrops in cassava under upland production systems in Chinkal village. Kerala, India from 1996 to 2000.

Intercrops	1996 rainy season[1)]		1997 rainy season[2)]		1998 rainy season		2000 rainy season[4)]	
	Yield (t/ha)	Net income (Rs/ha)	Yield (t/ha)	Net income (Rs/ha)	Yield (t/ha)	Net income (Rs/ha)	Yield (t/ha)	Net income (Rs/ha)
Peanut								
TMV 2	0.650	13,000	0.975	22,000	-	-	0.750	15,000
JL 24	-	-	-	-	0.827	20,540	0.900	18,000
Cowpea								
C-152	-	-	0.200	2,000	0.300	3,000	-	-
Arka Garima	-	-	-	-	-	-	2,000	12,000
French beans								
Contender	-	-	Crop loss		-	-	-	-

[1)] 41 replications [3)] 31 replications
[2)] 31 replications [4)] 79 replications; early rainy season (June) planting
***Source:** CTCRI, 1999; CTCRI, 2002b.*

Table 11. Farmers evaluation of three intercropping systems: positive and negative aspects.

Intercrops	Positive aspects	Negative aspects
Groundnut	Additional yield Improvement in soil fertility Haulms used as green manure & cattle feed High marketability Nutritious food for children	Attracts rats
Cowpea	High yield Most preferred as vegetable Attractive dark green color High marketability	Severe aphid and mosaic attack in grain type Several harvests needed in vegetable type
French beans	-	Flowering not occurred Highly sensitive to rainfall Not suited to adopted village

***Source:** CTCRI, 1999; CTCRI, 2002b.*

2.6.3 Assessment of the effect of nutrient management in cassava

To overcome the problem of imbalanced nutrition in cassava, various nutrient management practices, including the use of organic manure were assessed for their effectiveness. As compared to the farmers' practice, the recommended nutrient management practice increased the root yield from 25 t/ha to 30 t/ha, and further increased to 33 t/ha by the use of VAM and half the recommended dose of P_2O_5 with full dose of N and K_2O **(Table 12).** Accordingly, there was an increase in the net income too, from Rs.31,000/ha under farmers practice to Rs.38,000/ha under recommended practice, and to Rs.41,000/ha with the use of VAM. Farmers were convinced of the benefits of using VAM which reduced the cost of cultivation while increasing the yield of cassava. However, lack of availability of VAM culture at the village or nearby villages was experienced as the most serious impediment to the spread of this technology. Excepting CTCRI, where VAM is produced mostly for research purposes, no other agency is engaged in the large-scale multiplication and distribution of VAM inoculum.

Table 12. Assessment of various nutrient management systems in cassava under upland production systems in Chenkal village, Kerala, India in 1996.

Nutrient management practices[1)]	Root yield (t/ha)	Net income (Rs/ha)
Farmers practice: 40kg N+ 40 P_2O_5+40 K_2O/ha	25.50	31,035
Recommended: 100 kg N+50 P_2O_5 + 100 K_2O/ha	30.20	38,180
VAM[2)] +100 kg N+ 25 P_2O_5+100 K_2O/ha	32.60	41,215 [3)]

[1)] 10 replications
[2)] VAM = Mycorrhizal inoculation
[3)] Even though the use of VAM increased the yield of cassava and net income, the technology could not be adopted on a large scale due to non-availability of VAM inoculum at the village or nearby.
***Source:** CTCRI, 1999.*

CONCLUSIONS

The use of FPR in cassava in India is of recent origin, when CTCRI started using this approach for varietal evaluation of cassava in 1994. It is only through the FPR approach, that the two short-duration cassava varieties "Sree Jaya" and "Sree Vijaya" were selected by farmers and released for the state of Kerala. As these varieties were developed with the farmers as partners in the varietal evaluation process, their acceptance was found to be of crucial importance for the spread of these varieties in the lowland production systems, where they suit ideally as a sequence crop after the harvest of paddy rice. When IVLP came into operation in 1996, FPR was used as an integral part of this programme, and this methodology is being used as an effective tool to assess the various cassava production technologies amongst the farmers of the IVLP village, Chenkal. New cassava varieties, intercropping technologies and nutrient management practices have been assessed for their appropriateness to the village. The new top cross cassava varieties "Sree Prabha" and "Sree Rekha", as well as intercropping with peanut and vegetable cowpea have been accepted by farmers, and are now gradually being adopted by the IVLP farmers. In contrast, the unavailability of VAM is a major limiting factor for the acceptance of improved nutrient management practices. Realizing the potential of IVLP as a vehicle for FPR in cassava, more and more new production and processing technologies of cassava developed at CTCRI are being assessed for their field application and acceptability by the farmers.

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FARMER PARTICIPATORY RESEARCH AND EXTENSION APPROACHES USED IN THE ASIALAND SLOPING LANDS PROJECT OF IWMI

Suraphol Chandrapatya[1]

ABSTRACT

The ASIALAND sloping lands network was established in 1988 with its initial purpose: to help national agricultural research systems (NARS) to develop appropriate soil management practices that provide a sustainable form of agriculture on sloping land areas. Researchers implemented Phases 1 and 2 (1988-1994) to validate and revalidate the effectiveness of various improved technologies against the farmers' practice. During Phases 3 and 4 (1995-2001), on-farm, joint researcher-farmer experimentation was carried out in seven participating countries (China, Indonesia, Lao PDR, Malaysia, Philippines, Thailand and Vietnam) with selected technologies. The research suggested that sloping land conservation technologies (alley cropping, strip cropping, intercropping, hillside ditch, and agro-forestry) significantly reduced soil erosion and runoff as compared to the farmers' traditional practice.

Phase 5 (2002-2004) is the phase for developing the network further through the farmer participatory extension approach. This includes involving new partners, mainly from extension services, as well as establishing the NARS--NARES (national agricultural research and extension system). NARS-NARES will serve as a nexus to jointly promote widespread adoption of improved sloping land conservation measures by the farmers.

Using PRA/RRA, potential villages in target areas have been selected to be pilot conservation farming villages for the introduction of improved sloping land management technologies. Using the farmer field school approach, farmers in these villages are encouraged to learn the new technologies by carrying out their own field studies in a common field and sharing knowledge and experiences. The combination of indigenous knowledge and the new ideas and practices are then discussed to find potential solutions for the problems encountered.

The extension worker's role in this process is as a facilitator of the learning process, providing assistance and support to the farmers. As a consequence, the farmers themselves become experts on the particular practices they have been investigating. Such farmers can therefore become promoters of sloping land conservation measures to the other farmers in the same village and in surrounding areas.

The training for farmer promoters will be organized to increase the knowledge and skills required for the effective dissemination of sloping land conservation and management systems for productive and sustainable agricultural development. The other learning activities to be conducted are field days, demonstrations, study tours, regular group meetings, formal and informal group discussions and workshops. Integrated with these soil conservation learning activities are additional farming techniques to assist with the control and reduction of household expenses. These include such activities as plant propagation, food preservation, straw mushroom cultivation, and organic fertilizer production. Through these extension efforts, farmers and farmer organizations will be empowered for self-reliance and mutual assistance in improving farm productivity and upgrading the mutual quality of life.

It is not the aim of this project to change the whole extension system in the partner countries, but to introduce one extension approach that is a practical manifestation of participatory development practices. IWMI and the implementing agencies in the partner countries will monitor and assess how the introduced extension approach works in the real circumstances in the pilot conservation farming villages.

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INTRODUCTION

The *ASIALAND* Management of Sloping Lands for Sustainable Agriculture (ASL/SL) Network was established in 1988 by the International Board for Soil Research and Management (IBSRAM) to assist the national agricultural research systems (NARS) in conserving soil resources on sloping lands in the Asian region through research and promotion of the application of appropriate land management technologies for sustainable agriculture (IBSRAM, 1992). The participating countries are China, Indonesia, Lao PDR, Malaysia, Philippines, Thailand and Vietnam. These countries are all affected to various degrees by soil degradation, particularly on sloping land. Initially, the network was funded by the Asian Development Bank (ADB), the Swiss Agency for Development and Cooperation (SDC), and the International Development Research Center (IDRC). Since Phase 2, SDC has been the sole donor of the project.

Prior to the present phase, the implementation of the network was carried out in four phases:

Phases 1 (1988-1991) and 2 (1992-1994): The project mainly focused on research. Various improved technologies, i.e., alley cropping, intercropping, grass strip cropping, hillside ditch and agro-forestry, were developed and validated by the national collaborators on research stations and on farmers' fields, using the farmers' practice as a control.

Phases 3 (1995-1997): The promising conservation technologies obtained in the previous phases were validated by farmers in their fields to provide a sound basis for technology transfer.

Phase 4 (1997-2001): The project continued on-farm research and conducted training aimed at further expanding and sustaining the adoption of conservation farming technologies by farmers.

Based upon the external review commissioned by SDC in August 2000, the 12 years of investment by SDC in the four phases of the ASL/SL network and the effort put in by the national teams in seven participating countries had produced significant results, the impact of which is visible and could be substantially enhanced in the fifth phase. All participating countries were keen to continue the network and will actively participate in future activities. Hence, in the network project-Phase 5 (2001-2004), there is a solid base for developing the network further, while involving new partners, mainly from extension services, establishing the NARS-NARES (national agricultural research and extension systems) nexus. The goal of the Phase 5 project is to promote widespread adoption of SLM practices on sloping land areas in the participating countries.

On 31 March 2001 IBSRAM was dissolved and all of its programs including the ASL/SL network were transferred to IWMI with the explicit consent of SDC and of the partner organizations. IWMI will therefore bring in its international experience and complementary research expertise in water and land resources management to ensure best results possible from this project.

CONCEPTS OF THE ASL/SL NETWORK PROJECT-PHASE 5

To accomplish the project goal, two principal concepts are emphasized: (1) the development of integrated conservation farming systems, and (2) the empowerment of farmers and the community.

Development of Integrated Conservation Farming Systems

Soil and water conservation measures will be introduced to farmers for application as an integral part of their farming systems. Farmers use conservation farming practies to control erosion while including other farming techniques to increase farm productivity and income or reduce household expenses. These include such activities as plant propagation, food preservation, straw mushroom cultivation, and organic fertilizer production. The holistic approach and system approach are included, and rapid rural appraisals/participatory rural appraisals (RRA/PRA) will be conducted by an interdisciplinary team to assess the circumstances of farming communities and households before introducing the recommendations to farmers. The dialogue with the farmers will be related to SLM. The assessment will be the basis for the recommendations and efforts will be made to implement the relevant activities in a true partnership arrangement.

Empowerment of Farmers and the Community

The concept of empowerment in the ASL/SL Project-Phase 5 is based on Blanchard *et al.* (1996) who indicated that 'People already have power through their knowledge and motivation. Empowerment is letting this power out'. In this light, the project trusts the farmer's skills and commitment and therefore focuses on empowerment based upon the self-reliance principle, human-centered development and participatory community-based development for individual, group and community benefits. Pilot conservation farming villages (CFVs) will be established in all participating countries for interested farmers or farmer volunteers to test and disseminate conservation technology options. Farmers will be encouraged to participate in the project process steps since the beginning as active and self-directed partners and become key figures in the innovation-decision making process. Research and extension personnel will act as facilitators in the learning process and also provide information, technical advice and support to the farmers.

THE PROJECT FRAMEWORK AND PROCESS

The Project-Phase 5 has four main components: (1) community-based preliminary investigations and planning, (2) farmer and site preparation, (3) farmer participatory research, and (4) farmer participatory extension. There are 12 process steps: (1) selecting and characterizing villages to be pilot conservation farming villages (CFVs) for testing and disseminating improved conservation technology options, (2) selecting and characterizing the farmers, (3) identifying community needs and problems, (4) searching for potential solutions, (5) developing action plans, (6) training and capacity building of farmers, (7) testing and verifying introduced soil and water conservation practices by the farmers, (8) process review, self-evaluation and planning, (9) training and capacity building of farmer trainers, (10) disseminating appropriate conservation practices to other farmers by the farmer trainers, (11) developing a farmers' network to promote widespread adoption of integrated farming systems based on the self-help principle, and (12) impact assessment and review (see **Figure 1**).

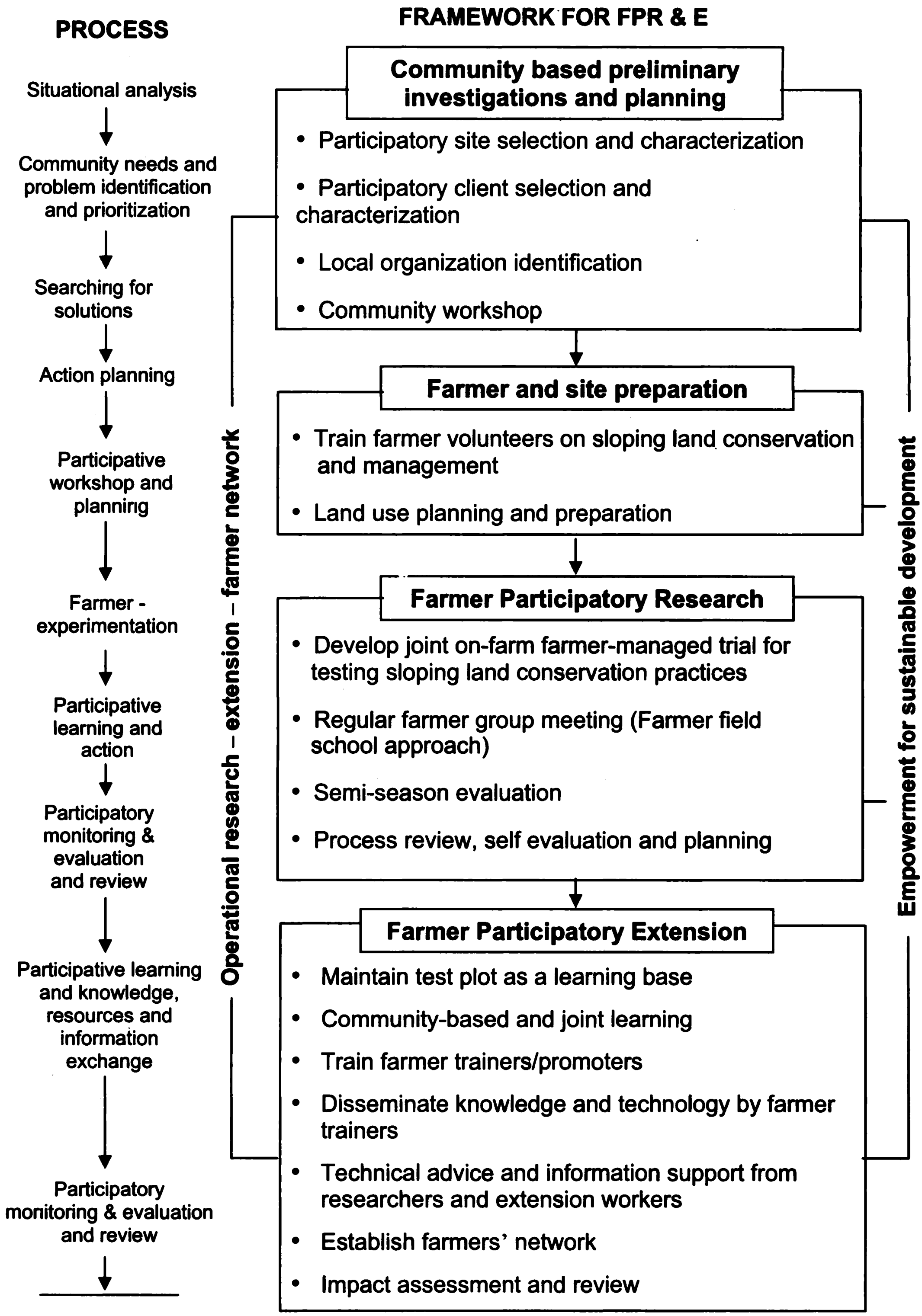

Figure 1: Farmer participatory research and extension approaches used in the sloping land project of IWMI

Farmer Participatory Research

The farmer participatory research (FPR) or participatory technology development (PTD) is a farmer-centered and need-driven based approach aiming to strengthen local capacity to experiment and innovate. Farmers are encouraged to generate and evaluate indigenous technologies and to choose, test and adapt external technologies based on their own knowledge and value systems. FPR/PTD is not a substitute for station-based research or researcher-managed on-farm trials, but it is a complementary process that involves linking the power and capacity of agricultural science to the priorities and capacities of farming communities to develop productive and sustainable farming systems (Wallingford, 1997). It is seen as a way of enabling farmers to further develop and validate potential options. FPR not only seeks to generate technologies adapted to local environments, but also seeks to develop the local capacities, socio-cultural structures and organizational linkages necessary to sustain the process.

The ASL/SL-Phase 5 uses FPR to enable farmers to develop and validate potential soil and water conservation options. It is an integrated community-based approach that the potential village is established as a pilot CFV for the introduction of improved sloping land management technologies for testing by the farmers themselves. A group of interested farmers in the village will be encouraged to conduct joint on-farm, farmer-managed trials in a common field and also in their own fields, with technical advice and support from field research and extension personnel, whether the recommendations are suitable for adoption or need adaptation to be compatible with actual farming systems and in correspondence with the farmers' goals and preferences.

The farmer field school approach is applied by which the farmers are encouraged to learn and the indigenous knowledge and new ideas and practices will be discussed between and among researchers, extension workers and the farmers to share knowledge and experiences and to find potential solutions for the problems encountered. The role of extension workers is to be a catalyst who helps farmers and communities achieve the goals and preferences, and a facilitator who facilitates learning by the farmers. Action learning (learning by doing, seeing, discovering and experimenting) encourages reflection and can increase farmers' analytical capacities. It can therefore increase the farmers' capacity for effective problem solving and for developing their own technical and social solutions (Hagmann et al., 2000).

Farmer Participatory Extension

Farmer participatory extension (FPE) – or to use other names, such as farmer-to-farmer extension, farmer-led extension, farmer-based extension, participatory technology development and dissemination (PTD&D) – is broadly defined as a multi-directional communication process between and among extension staff and farmers, involving the sharing, sourcing and development of knowledge and skills, in order to meet farmers' needs and develop innovative capacity among all actors, in which farmers have a controlling interest. Farmers are 'center stage', are the protagonists and play a key role in technology development and delivery; and involving farmers in training other farmers and trainers, and in sharing, sourcing and transferring knowledge and skills (Scarborough et al., 1997). The Project-Phase 5 uses this approach to encourage the farmers' participation in disseminating appropriate conservation practices to other farmers for their adaptation or selective adoption. The on-farm experimentation plot in the CFV will be used as a demonstration plot or learning base for introducing the tested or verified conservation technologies in comparison with the current farmer's practices. Learning through seeing and discussion among farmers with technical advice and support from field research and extension personnel should be very helpful in creating awareness and interest among farmers, and then persuade them to carry out conservation farming to improve soil fertility and increase farm productivity.

PROJECT STRATEGIES

To accomplish the project goal in promoting widespread adoption of SLM practices on sloping land areas in the participating countries, four strategies will be implemented by the participating countries with assistance and support from IWMI: (1) developing operational research and extension linkage systems, (2) training and capacity building for human resource development, (3) technical supervision and information support, and (4) participatory monitoring, evaluation and review.

Developing Operational Research and Extension Network/Linkages Systems

The connection between research and extension networks at local and national levels in the participating countries will be established by the implementing agencies in collaboration with the other agencies involved, including non-government organizations (NGOs). The mechanism will include regular meetings of national partners in the project to determine supply and demand of recommendations for sloping land farming. This will help in the flow of information and resources between and among organizations.

The ASL/SL on-farm research sites from previous phases will be maintained by the implementing agencies in the potential villages as learning bases for the sloping land conservation system. These are the trials in which improved sloping land technologies have been validated already and used as demonstration sites for extension workers to create awareness among farmers and interested groups on the use of sloping land conservation measures to reduce runoff and prevent soil erosion. These are the technology-based education sites with low cost of maintenance; the value of the sites is high because the cumulative effects of the diversified sloping land conservation measures are clearly illustrated.

Training and Capacity Building for Human Resource Development

Training the trainers will be conducted to assist in building/strengthening the capacity of the participating NARES in undertaking farmer participatory research and extension (FPR&E), in order to promote the impact of SLM technologies within a country. The trained personnel will organize and conduct training workshops for other research and extension personnel in respective countries to enable them to perform the job effectively. Cross-country visits will also be arranged based on requests and the available budget. Monitoring and evaluation of the results of the training will be done.

A training and capacity building program, including formal and non-formal training, farmer workshop, on-farm trials, field trips, cross-visits, farm demonstrations, field days, group meetings, semi-annual and annual review meetings, will also be implemented for farmers to increase their confidence in solving problems and improving soil conserving practices through their own initiative and full use of local resources. Farmer volunteers who joined the farmer field school activity will be trained to be farmer trainers who introduce and share information on sloping land conservation farming for wider use by other farmers. Farmers will be encouraged to organize their own groups or to develop existing groups in the village and to establish a farmers' network, incorporating villages and provinces for sharing and caring among them, and for collective action, including building solidarity. This is to empower farmers and farmer organizations for self-reliance and mutual assistance in improving farm productivity and upgrading their quality of life.

Technical Supervision and Information Support

Farmers should be able to access information sources, e.g., the project training workshops, meetings, printed materials, radio and television programs, videos etc. Consistent technical supervision should be provided for farmers to take corrective action and improve conservation farming practices. The web-based extension on sloping land conservation and management is being developed to be a supporting tool for extension agents to discuss with the farmers for their sound decision-making in solving soil erosion problems. In principle it can bring to farmers site- and situation-specific information, and respond to individual inquiries. The database can be downloaded, adapted, and printed out for use as extension and training materials. The information will be provided in eight languages: English, Chinese, Filipino (Tagalog), Indonesian, Lao, Malaysian, Thai and Vietnamese. The database is indexed and fully linked to provide a wide range of easily searched information for extension agents and other users. An off-line version on CD-ROM will also be created for use in remote areas where internet connections are rarely accessible.

Participatory Monitoring, Evaluation and Review

Participatory monitoring, evaluation and review is found to be an important mechanism to follow up on the implementation of the conservation farming practices, to discuss what has been happening, what problems have occurred, and in consequence provide constructive feedback and advice to farmers for reviewing and upgrading the practices. The combination of indigenous knowledge and the new ideas and practices would be discussed to find potential solutions for the problems encountered. Women farmers and farm children should be encouraged to participate in the conservation farming activities to enhance their awareness and understanding, including a sense of belonging and leadership. In doing this, the research and extension personnel should increase their knowledge and skills and also change their attitudes in working with farm families to reduce bureaucratic interference.

CONCLUSIONS

The ASL/SL Project-Phase 5 (2001-2004) has as its aim to promote widespread adoption of the promising SLM practices by farmers in sloping land areas in the participating countries. The objectives of the project are the development of integrated conservation farming systems and the empowerment of farmers and the community. The process includes four major activities: (1) community-based preliminary investigations and planning, (2) farmer and site preparation, (3) farmer participatory research, and (4) farmer participatory extension. Strategies used for increasing the project's effectiveness are: (1) developing operational research and extension linkage systems, (2) training and capacity building for human resource development, (3) technical supervision and information support, and (4) participatory monitoring, evaluation and review.

It is not the aim of this project to change the whole extension system in the participating countries, but to introduce one extension approach that is a useful, practical and more responsive to farmers' needs, goals and preferences, and in consequence enhances greater acceptance of innovative practices by farmers. IWMI and the implementing agencies in the participating countries will monitor and assess how the introduced extension approach works in the real circumstances in the pilot conservation farming villages. There will be a performance evaluation in all participating countries to measure the efficiency of the project in generating the immediate products and the effectiveness of these products in contributing to the attainment of the project's expected outputs. Furthermore, the assessment of the project's impact will be undertaken at the end of the project to quantify changes in the biophysical, human, social and economic environment that can be attributed to the project.

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THE DEVELOPMENT OF A CASSAVA GROWTH MODEL IN THAILAND

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and Attachai Jintrawet[3]

ABSTRACT

This study was conducted at Khon Kaen Field Crops Research Center from 1996 to 1999 on four recommended cassava cultivars, namely Rayong 1, Rayong 5, Rayong 90 and Kasetsart 50 using the DSSAT-GUMCAS cassava process-oriented model. The phenology of these cassava cultivars is strongly affected by environmental factors, especially air temperature. Rayong 5 and Rayong 90 have a branching plant type, with a higher leaf appearance rate per day than those cultivars with fewer branches (Rayong 1 and Kasetsart 50). For the early rainy season planting in 1997, first branching of Rayong 90 occurred at 73 and 74 days after emergence, according to simulation and actual observation, respectively, while root dry matter yield was 6.38 and 5.69 t/ha for the simulation and actual observation, respectively. In general, the model gave close estimates on branching habit, but overestimated crop dry matter production. In the model application phase, the model was used to predict cassava yields in farmers' field in the Khon Kaen area. The results from the simulation model supported the farmers' decision to grow Rayong 90 on Satuk and Korat soil series; and Kasetsart 50 on Yasothon soil series. The potential fresh root yield of Rayong 90 was simulated to be 60.3, 51.8 and 47.2 t/ha on Satuk, Korat and Yasothon soil series, respectively, whereas that of Kasetsart 50 was simulated to be 52.8, 48.1 and 45.3 t/ha on Yasothon, Korat and Satuk soil series, respectively.

INTRODUCTION

Cassava is one of the main economic crops of Thailand. The planted area is spread all over the country, but especially in the Northeast. In 2000, the total planted area was 1.11 million ha, with a total root production of 18.75 million tonnes, with an average fresh root yield of 16.86 t/ha, which generated an export value of 20,075 million baht (OAE, 2000). Cassava is well adapted to low fertility soils and requires low inputs, which is why it has become a popular crop among resource-poor farmers. One way to improve the production efficiency is to combine suitable cultivars with good crop management for a specific area, and these new technologies need to be delivered to and adopted by farmers. There are a number of newly released cultivars, e.g. Rayong 90, Kasetsart 50, and Rayong 5. However, the current method of wide-spead testing on a regional scale is costly and not always reliable.

Nowadays, Information Technology (IT) plays an important role in the development of the country. Crop simulation models are examples of IT tools that can be used to test crop or varietal suitability and to make decisions at the farm or at the regional level. The DSSAT-GUMCAS cassava simulation model is a computer program that was developed to simulate the phenology and growth processes of cassava under the condition of different cultivars, soil, climate and management for a specific area. The application of the cassava simulation model under the Decision Support Systems for Agrotechnology

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Transfer (DSSAT) need four categories of input data, i.e. soil data, weather data, management data, and genetic coefficients of each cassava cultivar (Jones *et al.,* 1998). There have been no previous attempts to test the model in Thailand with Thai cassava cultivars. This paper reports the initial testing of the model in Thailand during the 1996-1999 crop years.

Data Requirement

The DSSAT-GUMCAS model operates on a daily time step basis. Matthews and Hunt (1944) described the important processes included in the model. Three growth phases are defined, i.e. 1) planting to emergence, 2) emergence to first branching (the switch to reproductive phase), and 3) first branching to maturity or final harvest (subsequent branchings may occur during this stage). The rate of vegetative development is influenced by temperature and moisture conditions, while the rate of reproductive development is influenced by both of these factors as well as by photoperiod.

The functional capabilities of DSSAT are summarized in **Figure 1.** Crop simulation models are at the center of the system. Data bases describe weather, soil, experimental details, and genotype information which are needed to apply the models to different situations.

A Minimum Data Set (MDS) is required for the operation of a model destined for use in agrotechnology transfer **(Table 1).** Information for the minimum soil data set can often be obtained from soil survey publications. However, because some aspects measured during soil profile characterization (e.g. organic carbon, bulk density) may change slowly over time, particularly in the surface (plow) layer, the soil profile data may need to be supplemented with soil analysis information for the surface layer.

METHODOLOGY AND RESULTS

The testing of the cassava simulation model in Thailand from 1996 to 1999 consisted of four steps:

1. Study of growth and phenology of four cassava cultivars.
2. Calibration of genetic coefficients.
3. Model testing.
4. Model validation.

1. Study of Growth and Phenology

The experiments were planted in both the early and late rainy season at Khon Kaen Field Crops Research Center (KKFCRC) and at Roi-Et Field Crops Experiment Station, both in the Northeast of Thailand, during 1996-1999. The phenology data was taken from each individual cassava plant. For growth data, each individual plant was separated into tuberous roots, stems and leaves. The leaf area and the dry matter content of each plant part were determined at two-month intervals, while daily rainfall, maximum and minimum temperature and solar radiation were recorded year-round.

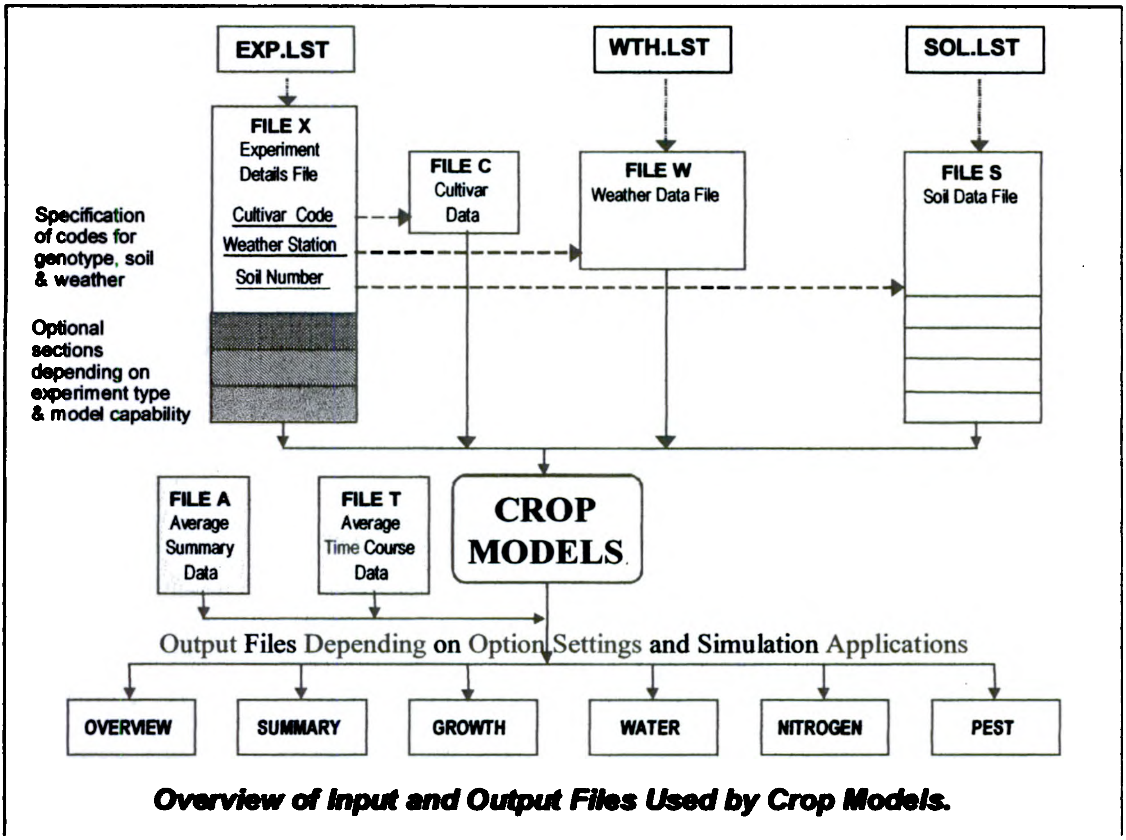

Figure 1. *The structure of a Crop Simulation Model*
Source:*Tsuji et al., 1994.*

The results show that the Growing Degree Days (GDD) for the first branching date and the number of leaves per plant, rate of leaf formation as well as the dry matter content of each plant part for each cultivar for early and late planting were different. This means that the environment affected the phenology and growth of cassava. Cultivars with several branching phases, such as Rayong 5 and Rayong 90 show more variation in the number of leaves per plant during the growing season than cultivars with fewer branching phases, such as Rayong 1 and Kasetsart 50 **(Figure 2).**

Calibration of genetic coefficients

From the collected data, including soil, weather and management data, we produced FILEX (Experimental Details File), FILET (Average Time Course Data), and FILEA (Average Summary Data) for calibration of the genetic coefficients in file CSSIM980.CUL by the method of Boote (1994). The genetic coefficients can be calibrated by adjusting the output of simulated data as compared to actual data until they are acceptable.

For cassava, the genetic coefficients were separated into two parts, i.e. phenology coefficients (e.g. duration of branch phase 1, 2 and higher phases; sensitivity to photoperiod), and growth coefficients (e.g. maximum canopy photosynthesis rate; stem weight to node weight ratio; leaf number increase rate and increase period; maximum leaf area and duration to reach maximum; leaf life; leaf area at 300 days after emergence (DAE); leaf area to weight ratio; stem number, and shoot number) **(Table 2)**.

Table 1 Contents of minimum data sets for model operation.

1. Weather
   - Daily global solar radiation, maximum and minimum temperatures, precipitation
2. Soils
   - Classification using the local system and the USDA-SCS taxonomic system
   - Basic profile characteristics by soil layer: *in situ* water release curve characteristics (saturated, drainage upper limit, lower limit); bulk density, organic carbon, pH; root growth factor; drainage coefficient
3. Soil analysis
   - Surface layer measurements of bulk density, organic carbon, pH, organic nitrogen, available P and exchangeable K
4. Initial conditions
   - Previous crop, root, and nodule amounts; numbers and effectiveness of rhizobia (for nodulating crops only)
   - Water, ammonium and nitrate contents by soil layer
5. Management
   - Cultivar name and type
   - Planting date, depth and method; row spacing and direction; plant population
   - Irrigation and water management, dates, methods and amounts of depths
   - Fertilizer (inorganic) and inoculant applications
   - Residue (organic fertilizer) applications (material, depth of incorporation, amount and nutrient concentrations)
   - Chemicals (e.g. pesticide) applied
   - Tillage method
   - Environment (aerial) adjustments
   - Harvest schedule

***Source:** Adapted from Hunt and Boote, 1998.*

Model Testing

In the first stage we had to get the data on the date of planting, fertilization and harvesting as well as cultivar codes, weather station codes and soil codes to built up FILEX; the latter consisted of 16 sections, such as: experiment, cultivar treatment, planting details and simulation controls. FILEW (Weather Data File) records the daily weather from the data logger. FILES (Soil Data File) was taken from the soil database DLDSIS from the Land Development Department. The genetic coefficients (FILEC: Cultivar Data File) were compiled from stage 2. The data sets from stage 1, for instance, the dry matter from each plant part of the interval samplings, e.g. stems, leaves, and roots dry matter, including LAI, were taken to built up FILET, and the data from the final harvest e.g., dry matter from each plant parts and maximum leaf area, were taken to built up FILEA.

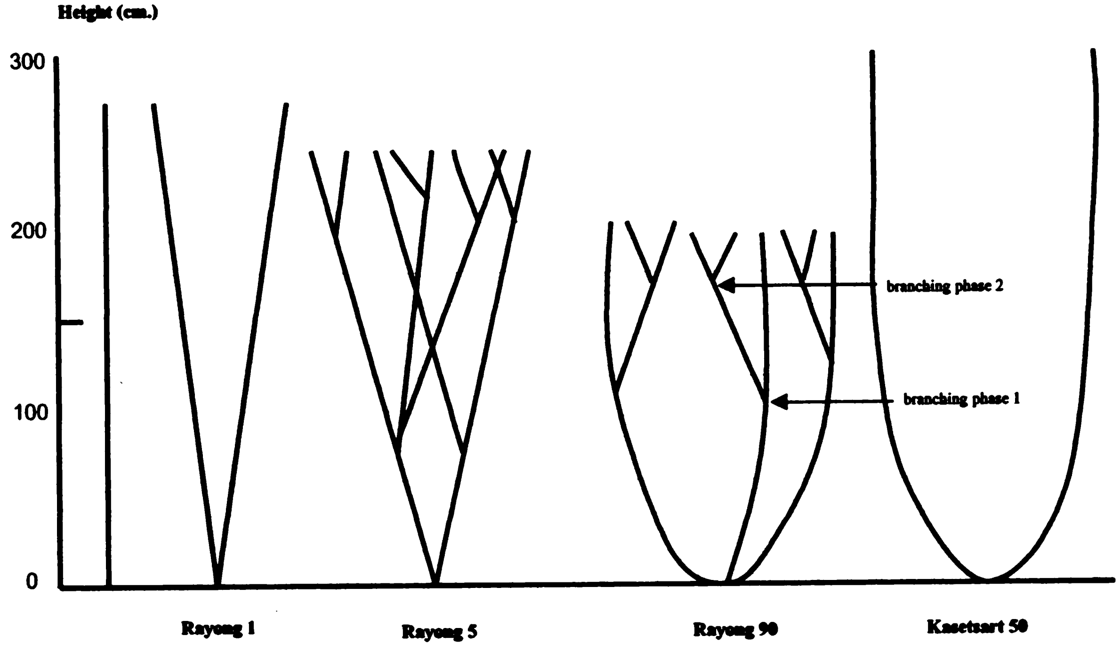

Figure 2. *Branching habit of four cassava cultivars.*
Source: *Adapted from Oka et al., 1987.*

To test the model, the simulated data on duration of first branching and dry root yield were compared with the observed data during the year 1996-1999 at KKFCRC by 1:1 line graph (Jongkaewwatana, 1995), and the dispersion of simulated and observed data by the Root Mean Square Error Statistic (RMSE).

The results from phenology showed that the model gave a reasonable estimation of the first branching date, especially in Rayong 90 which occurred at 73 and 74 days after emergence, according to the simulation and actual observation, respectively, while root dry matter yield was 6.38 and 5.69 t/ha for the simulation and actual observation, respectively **(Figure 3)**.

Model Validation

Fresh yields of two cassava cultivars, Rayong 5 and Rayong 90, from the Regional Yield Trails at Rayong, Mahasarakham, and Khon Kaen Field Crops Research Centers during 1991-1995 seasons were compared with simulated data from the cassava model that used data sets of weather and soil from each site. The simulated and observed data was compared by the 1:1 line graph method (Jongkaewwatana, 1995).

The results showed that most of the simulated yield data were higher than the observed values in all locations. The simulated yields of both cultivars were highest at Mahasarakham. Rayong 90 gave a simulated yield of 79.3 t/ha, while the observed data was

39.1 t/ha. Rayong 5 gave the highest simulated yield of 63.5 t/ha compared with the observed yield of 40.4 t/ha **(Figure 4).**

Table 2. Example of parameters in cultivar data file (FILEC).

*CASSAVA GENOTYPE COEFFICIENTS - CSSIM980 MODEL

Most phase durations are expressed in 'biological' days (Bday); these are equivalent to chronological days at the optimum temperature and daylength, and with no water or nutrient limitations.

DUB1 Duration of branch 1 phase (Bday germination to first branch)
DUBR Duration of branch 2 and greater phases (Bday between branches)
DESP Development, sensitivity to photoperiod (h-1) (0=insensitive)
PHCX Photosynthesis, canopy, maximum rate (g dm m-2 d-1)
S#PE Stem number per plant at emergence (#)
S#FX Shoot no per fork, maximum (#)
S#PX Shoot no per plant, maximum (#)
SWNX Stem weight to node weight ratio (fr)
L#IS Leaf number, increase rate, standard (leaves(shoot-1) Bday-1)
L#IP Leaf number, increase period (Bday after emergence)
LALX Leaf area, maximum (cm2 leaf-1)
LAXA Leaf area, maximum, age at which reached (Bday after emergence)
LAL3 Leaf area, 300 days after emergence (cm2 leaf-1)
LAWS Leaf area to weight ratio, standard (cm2 g-1)
LFLI Leaf life (Day)

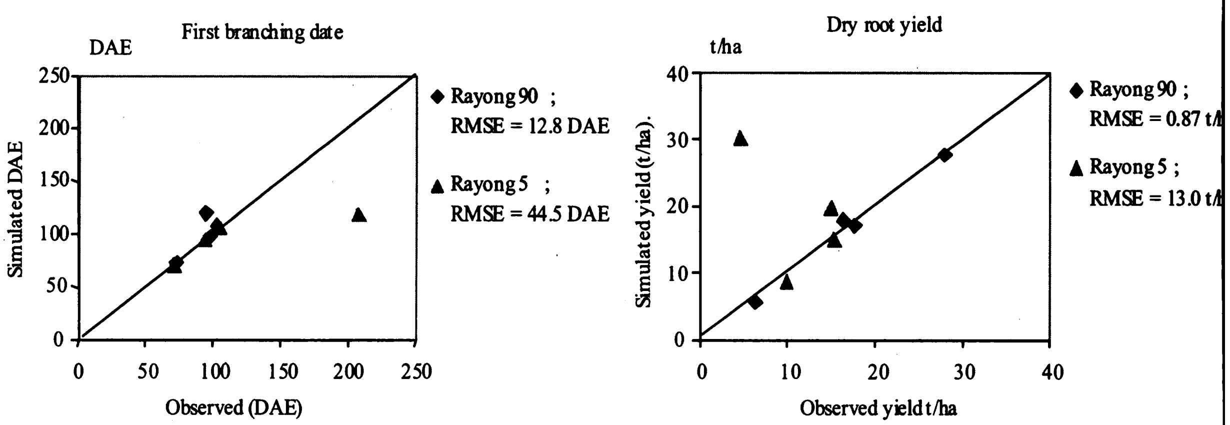

Figure 3. *Days after emergence (DAE) to first branching (left) and dry root yield (right) of simulated and observed data of Rayong 90 and Rayong 5 during 4 years (1996-1999) at Khon Kaen FCRC. RMSE = root mean square error statistic.*

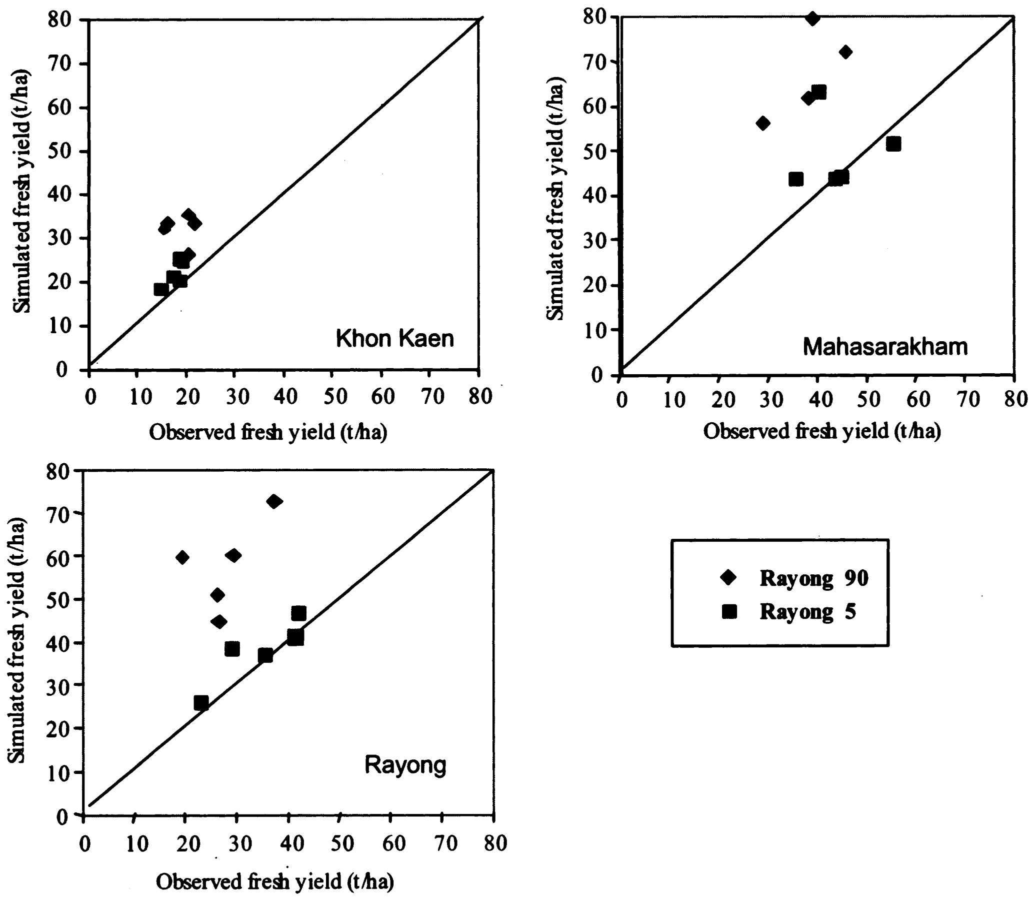

***Figure 4**. Fresh root yield of simulated and observed data of Rayong 90 and Rayong 5 during 5 years (1991-1995) of Regional Yield Trials at three locations.*

Model Application

The Climatic Zone Map was taken from the study of climatic zones in the Northeast of Thailand (KKU-FORD Cropping Systems Project, 1982). There are four climatic zones in the Khon Kaen area, which can be differentiated by amount of rainfall, which ranges from 800 to 1,400 mm per year. Soil data were taken from the study of soil series digital base map (Promburom *et al.*, 2002). The two cassava cultivars, Rayong 90 and Kasetsart 50, were simulated on the Oxic Paleustults great group, with fine loamy texture, namely soil series Satuk (Suk), Korat (Kt), and Yasothon (Yt) (Thai Land Development Department).

The results indicate that the potential fresh root yields of Rayong 90 were simulated to be 60.3, 51.8 and 47.2 t/ha on Satuk, Korat and Yasothon soil series, respectively, whereas those of Kasetsart 50 were simulated to be 52.8, 48.1 and 45.3 t/ha on Yasothon, Korat and Satuk soil series, respectively **(Figure 5)**. This means that Rayong 90 is expected to produce higher yields than Kasetsart 50 on Satuk and Korat soil series, while Kasetsart 50 may produce higher yields on the Yasothon soil series. This information may be useful for farmers to make their decision about the most suitable cultivar for a specific area.

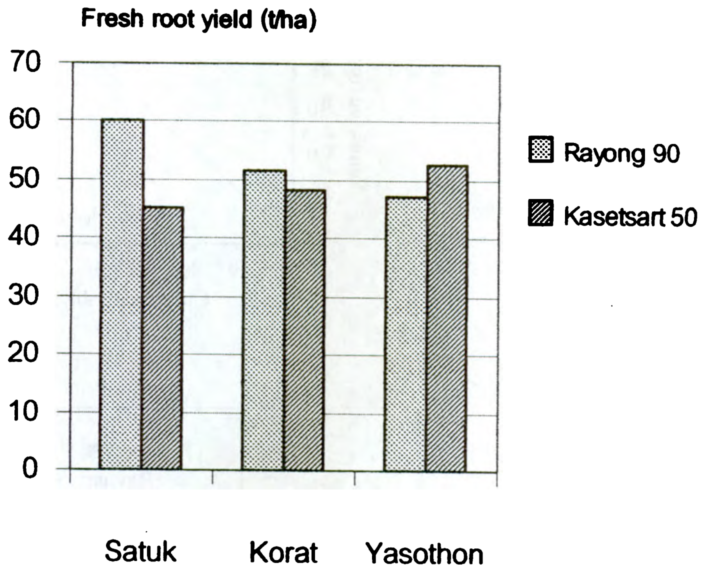

Figure 5. *Yield potential from the cassava simulation model of Rayong 90 and Kasetsart 50 on different soil series.*

CONCLUSIONS

The DSSAT-GUMCAS model was tested against data sets generated from four widely used cassava cultivars during 1996-1999 in Khon Kaen. The model gave a good estimation of phenology, but overestimated the growth and yield of all cultivars. Further testing and development of the model in Thailand should be continued in a network of researchers, both at the national and at the international level. Currently, the model deals with carbon and water balances of cassava production systems, while nitrogen and other nutrients are not part of the model. The model may have great potential to be used as a tool in dealing with large-scale planning issues for linking between farm and policy levels.

It is clear that the development and testing of Agricultural Decision Support Systems based on a simulation model for cassava production in Thailand is still in its early stage. None of the existing institutions has the resources or the expertise to develop this system alone; thus researchers must work together. A formal network of crop model evaluators should be established to link various individuals and institutions, both inside and outside Thailand to make improvements in the model.

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The research team thanks cassava growers in all experimental sites for their understanding and cooperation. We would like to express our sincere thanks to Khon Kaen Field Crops Research Center and Roi-Et Field Crops Experiment Station for the use of their facilities and to allow us to carry out this work.

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THE DEVELOPMENT OF A CASSAVA GROWTH MODEL IN INDIA

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ABSTRACT

The slow advancements in the research and development of cassava is aggravating poverty in many poor countries. Achieving higher yields in a shorter time can help solve this problem. Cassava simulation models are one of the tools to improve the situation. A model to simulate cassava growth is presently being developed at CTCRI. In the model the cassava plant system is simulated by considering all the attributes, as well as the relationships between these attributes. Plant attributes, like formation and falling of leaves, leaf area, leaf area index (LAI), leaf longevity, net assimilation rate (NAR), height of the stem, root development, rate of synthesis of dry matter, partitioning of dry matter into different plant parts etc., were included. Weather variables such as the minimum and maximum temperature and rainfall, are driving the model. Genetic coefficients for each variety should be computed before using the model.

The plant system functions in relation to the temperature as well as the rainfall received by the plant. The atmospheric temperature directly influences the height of the plant (HT), the rate of formation of leaves (LFMD), potential and actual leaf age (PLFAGE and LFAGE) and the average leaf area (ALA). LFAGE is used to compute the number of leaves fallen (LFLLN) and from that the total number of leaves retained by the plant (TLF) is determined. From TLF and ALA, total leaf area (TLA) can be calculated. This dry matter is partitioned into the different plant parts, and equations are developed to compute these values. The computations are continued for the entire growth period. Such simulation experiments can partially substitute for laborious field experiments and thus save resources. The same plant model can be tested for different soil and weather conditions by suitably inputting the required soil and weather parameter values in the model. The model is now in the first phase of development. Once equations for water use, soil nutrient uptake and plant protection are included, the model will be completed. The model is presently being tested under different environmental conditions.

INTRODUCTION

Cassava is the fourth most important source of food energy, and is produced and consumed mainly in the tropics (Cock, 1984). It is an important food crop in many poor countries. Achieving higher productivity of the crop in a shorter time, will contribute to the alleviation of poverty. But to develop improved cassava technologies through field experiments requires a lot of time and resources. With the help of computers the growth of cassava can be studied. A reduced number of trials can be conducted without spending the enormous amount of resources and time, which are otherwise required for field experiments. Different soil and weather conditions can be simulated very easily and the performance of the crop under these varying conditions can be studied easily and quickly. The development of a growth model is the first and most important task. All attributes of the cassava plant system and the relationships between them should be properly understood for developing a sound model (Santhosh Mithra, 2002). A good model will help to identify the various components in the growth of the crop and the interaction among them and with the environment.

The Use of Models

Seligman (1990) lists the following uses of models in research:

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- Identification of gaps in our knowledge
- Generation and testing of hypothesis, and an aid to the design of experiments
- Determination of the most influential parameters of a system (sensitivity analysis)
- Provision of a medium for better communication between researchers in different disciplines
- Bringing of researchers, experimenters and producers together to solve common problems

To increase the efficiency of research, modeling should become a part of it. Knowledge gained should be able to refine the models, and the models should serve as a tool for identifying critical gaps and the potentialities.

Cassava Growth Models Developed Outside India

Several cassava growth models are already developed outside India. These models can be classified into two groups:

1. Those in which dry matter is partitioned according to a fixed pattern
2. "Spill-over" models, in which leaf or stem growth is calculated independently and is assumed to have "first call" on newly produced assimilate, while storage roots receive any that is remaining (Matthews and Hunt, 1994)

Fixed pattern models
1. Boerboom(1978)
2. Connor *et al.* (1981)
3. Gutierrez *et al.* (1988)
4. Gijzen *et al.* (1990)

Spill-over models
1. Cock *et al.* (1979)
2. Fukai and Hammer (1987)
3. GUMCAS by Mathews and Hunt (1994)

The GUMCAS model provides the basis for the CROPSIM-Cassava model, which is included in the DSSAT set of crop models. An improvement is made in this model over the existing models by including an additional component called "Vapor Pressure Deficit."

Cassava Growth Models Developed In India

Proper understanding of the cassava growth system and the physiological processes involved in the growth of cassava are important while developing such models. The structure of the model differs because of differences in the growth systems considered. The entities and the interactions between the entities differ in each of these systems and thus the model structure also differs. Three cassava growth models, which were developed in India are discussed below

Model 1

A cassava growth model was developed for some specific varieties, i.e. Sree Sahya, Sree Visakham and M-4, to understand the growth pattern at different ages of the crop (Santhosh Mithra *et al.*, 1999). The growth of cassava was described with the following components:
1) Age (AG), 2) Height (HT), 3) Leaves formed till date (LFMD), 4) Leaves fallen till date (LFLLN), 5) Total number of leaves (TL), 6) LBN, 7) Average leaf size (ALS), 8) Total leaf area (TLA), 9) Net assimilation rate (NAR), 10) Crop growth rate (CGR), 11) Total dry

matter (TDM), 12) Dry matter in shoot (DMSHT), 13) Dry matter in root (DMRT), 14) Harvest index (HI), and 15) Leaf area index (LAI)

Regression equations were fitted for predicting HT, LFMD, LFLLN and HI as a function of AG, and ALS was fitted as a function of LBN, where LBN is the product of length and breadth of the middle lobe and the number of lobes of any randomly selected three leaves of the plant. All these equations gave very good fit and the R^2 values are shown in **Table1.**

Table 1. Correlation coefficients of the regression between various growth parameters of cassava. Data are the average values of three varieties.

Sl. No	Dependent variable	Independent variable	R^2
1.	HT = height	AG = age	0.950
2.	LFMD = leaves formed till date	AG = age	0.935
3.	LFLLN = leaves fallen till date	AG = age	0.922
4.	HI = harvest index	AG = age	0.984
5.	ALS = average leaf size	LBN = length x breath x no. lobes	0.990

This model helps in understanding the pattern of growth of stems and leaves of the crop. The effect of weather or soil parameters on the growth of the crop is not included in this model. There is no scope for calibrating this model to be used under different environments. So this model does not help in making predictions about cassava under different growing conditions.

Model 2

This model was developed using data collected from CTCRI during 1981 to 1984 (Santhosh Mithra *et al.,* 2001). Weather parameters like maximum and minimum temperature and rainfall were used for modeling. Among the biometric parameters, the number of leaves and nodes, and height and girth of the stem were collected. Three leaves were randomly selected from each plant and the length and breadth of the middle lobe and the number of lobes of each of those leaves were recorded. The biometric observations were taken at monthly intervals from three varieties, i.e. H-1687, H-2304 and M-4. Weather data were collected daily. The relationship between different physiological processes and parameters were taken into consideration while developing the model (Ramanujam, 1991).

The cassava plant growth system was developed with the following components:

a) Rate of formation of leaves–dLFMD/ dTU
b) Rate of falling of leaves–dLFELL/ dTU
c) Total number of leaves formed till "d" days after planting (DAP) –$LFMD_d$
d) Total number of leaves fallen till "d" days after planting (DAP) –$LFELL_d$
e) Total number of leaves on "d" days after planting (DAP) –TLF_d
f) Total leaf area on "d" days after planting (DAP) –TLA_d
g) Leaf area index on "d" days after planting (DAP) –LAI_d
h) Optimum leaf area index–LAI_{opt}
i) Effective leaf area index on "d" days after planting (DAP) –$ELAI_d$
j) Net assimilation rate on "d" days after planting (DAP) –NAR_d
k) Total dry matter on "d" days after planting (DAP) –TDM_d

l) Dry matter apportioned to stem on "d" days after planting (DAP) –$DMST_d$
m) Dry matter apportioned to leaves on "d" days after planting (DAP) –$DMLF_d$
n) Dry matter apportioned to roots on "d" days after planting (DAP) –$DMRT_d$
o) Matter in dry leaves on "d" days after planting (DAP) –$DMDLF_d$
p) Branching.

The three varieties were found to differ in their ability to utilize the temperature. A maximum value of mean temperature (T_{opt}) which can be effectively utilized by the crop was identified and this value depends on the average yield of the variety under that environment. T_{opt} is also dependent on the total rainfall received by the crop. If the mean temperature (t) goes beyond T_{opt}, each unit increase was found to reduce the temperature utilizing ability of the crop (TU).

$$TU_d = \sqrt{(AGE.\, T_{opt} - \sqrt{(\Sigma t - AGE.\, T_{opt})^2})^2}$$

TU_d = Temperature utilizing ability on "d" DAP.

The height of the plant on "d" DAP (HT_d), rate of formation of leaves (dLFMD/ dTU) and rate of falling of leaves (dLFELL/ dTU) were computed as functions of TU_d

$$HT_d = f(TU_d)$$

$$dLFMD/\, dTU = f(TU_d).$$

The number of leaves formed between "d-1" and "d" DAP (dLFMD) and the number of leaves formed till "d" DAP ($LFMD_d$) was obtained as follows:

$$dLFMD = dLFMD/\, dTU\ .\ (TU_d - TU_{d-1}).$$

$$LFMD_d = LFMD_{d-1} + dLFMD.$$

Under field conditions $LFMD_d$ was found to have a lot of variability ($LFSDV_d$) even under the same climatic condition. This is found to be a function of $LFMD_d$

$$LFSDV_d = f(LFMD_{d-1} / LFMD_d)$$

$LFMD_d$ was modified using the variability $LFSDV_d$. This is done by generating pseudo-random numbers in normal distribution (Gordon, 1992) with mean $LFMD_d$ and standard deviation $LFSDV_d$. The average of this random value and the computed $LFMD_d$ is the final value of $LFMD_d$.

$$dLFELL/\, dTU = f(TU_d)$$

The number of leaves fallen between "d-1" and "d" DAP (dLFELL) and the number of leaves fallen till "d" DAP ($LFELL_d$) was obtained from:

$$dLFELL = dLFELL/\, dTU\ .\ (TU_d - TU_{d-1}).$$

$$LFELL_d = LFELL_{d-1} + dLFELL.$$

Under field conditions $LFELL_d$ was found to have a lot of variability ($LFLSDV_d$) even under the same climatic conditions. This is found to be a function of $LFELL_d$

$$LFLSDV_d = f(LFELL_{d-1} / LFELL_d)$$

$LFELL_d$ was modified using the variability $LFLSDV_d$. This is done by generating pseudo-random numbers in normal distribution with mean $LFELL_d$ and standard deviation $LFLSDV_d$. The average of this random value and the computed $LFELL_d$ is the final value of $LFELL_d$.

From $LFMD_d$ and $LFELL_d$, TLF_d was computed as follows:

$$TLF_d = LFMD_d - LFELL_d$$

Average leaf area (ALA) was computed as a function of the average yield of the variety (Y)

$$ALA = f(Y)$$

Total leaf area on "d" DAP (TLA_d) was computed from ALA and TLF_d as follows:

$$TLA_d = TLF_d . ALA$$

From the TLA_d (in cm^2), the leaf area index on day "d" (LAI_d) was calculated by dividing it by the space occupied by each plant.

The value of optimum leaf area index (LAI_{opt}) beyond which the increase in leaf area won't make any increase in the economic yield was computed as follows:

$$LAI_{opt} = I_{v1} . e^{Iv2.LFMD62/62.}$$

$$I_{v1} = 1.17. Y - 15.5$$

$$I_{v2} = -0.0768 .Y + 0.63317$$

Where $LFMD_{62}$ = Number of leaves formed in 62 days.

If the age of the crop is less than 62 days LAI_{opt} is assumed to be equal to LAI_d.

LAI of the crop, which is optimum for the growth and development of the crop ie. effective leaf area index ($ELAI_d$) can be computed using LAI_{opt}

$$ELAI_d = \sqrt{(LAI_{opt} - \sqrt{(LAI_{opt} - LAI_d)^2})^2}$$

$ELAI_d$ determines the net assimilation rate (NAR_d) in gms/cm^2/day on "d" DAP.

$$NAR_d = \frac{(A_1 . ELAI_d + A_2 . ELAI_d{}^2 + Ac)^2}{(LAI_d . 100)^2}$$

Dry matter production and partitioning

Total dry matter produced by the plant each day ($dTDM_d$), is obtained by multiplying NAR_d with TLA_d

$$dTDM_d = NAR_d . TLA_d$$

$$TDM_d = TDM_{d-1} + dTDM_d .$$

TDM_d = Total dry matter in the plant on "d" DAP

The dry matter produced is partitioned into different plant parts. First part is distributed to leaves and then to stem. Whatever is remaining is stored in roots.

Dry matter partitioned into leaves on "d" DAP ($dDMLF_d$) is obtained as follows:

$$dDMLF_d = dTDM_d . (DMLF_{d-1} / TDM_{d-1}) . (TLF_d / TLF_{d-1})$$

$$DMLF_d = DMLF_{d-1} + dDMLF_d .$$

where $DMLF_d$ = Dry matter in leaves on "d" DAP .

Dry matter partitioned into stem on "d" DAP ($dDMST_d$) is obtained as follows

$$dDMST_d = dTDM_d . (DMST_{d-1} / TDM_{d-1}) . (HT_d / HT_{d-1})$$

$$DMST_d = DMST_{d-1} + dDMST_d .$$

where $DMST_d$ = Dry matter in stem on "d" DAP.

The remaining dry matter is stored in the roots

$$DMRT_d = TDM_d - (DMST_d + DMLF_d)$$

$DMRT_d$ = Dry matter stored in the roots on "d" DAP.

Matter is stored in dry leaves on "d" DAP ($DMDLF_d$) as follows:

$$dDMDLF_d = C_d . e^{dx} . dTDM_d$$

where C_d and d are coefficients.

$$x = DMLF_d / TDM_d$$

$$DMDLF_d = dDMDLF_{d-1} + dDMDLF_d$$

Some of the results of simulations done using this model are given in the **Tables 2-10.**

Table 2. Average values of four simulation runs for the variety H-1687.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	37.63	7.71	29.92	33.45
74	86.21	23.44	62.71	68.03
97	116.15	37.52	78.63	87.06
156	203.58	94.17	109.42	137.20
190	258.83	140.75	118.08	166.26
228	320.84	202.11	118.72	197.30
265	377.34	265.90	111.44	224.47
323	462.58	375.48	87.10	263.82

LFMD = number of leaves formed up to a certain age
LFELL = number of leaves dropped up to a certain age
TIF = number of leaves at a certain age
HT = plant height in cm

Table 3. Average observed values for the variety H-1687.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	14.30	0.00	14.30	13.55
74	61.60	5.00	56.60	71.45
97	75.50	18.80	56.70	97.82
156	133.20	55.30	77.90	168.45
190	168.70	92.10	76.60	198.27
228	200.12	139.12	61.00	219.56
265	231.86	163.00	68.86	281.78
323	319.25	169.38	149.88	367.56

Table 4. Average values of four simulation runs for the variety H-2304.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	46.78	9.77	37.02	37.50
74	100.42	32.86	67.57	73.49
97	131.24	52.62	78.62	93.00
156	214.25	128.03	86.22	143.04
190	263.06	186.90	76.16	171.28
228	315.81	262.12	53.62	201.08
265	363.12	339.80	23.32	227.28
323	434.54	433.54	1.00	266.04

Table 5. Average observed values for the variety H-2304.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	20.25	0.00	20.25	12.56
74	69.80	2.10	67.70	54.30
97	94.00	15.20	78.80	99.20
156	181.10	59.20	121.90	190.40
190	205.60	117.20	88.40	202.00
228	254.60	202.90	51.70	221.80
265	319.50	212.30	107.20	243.80
323	416.22	223.78	192.44	270.11

Table 6. Average values of four simulation runs for the variety M-4.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	33.28	8.19	25.09	39.18
74	84.17	29.75	54.42	74.99
97	118.58	51.34	67.24	95.27
156	216.71	139.16	77.56	145.09
190	280.44	214.74	65.70	173.66
228	358.74	325.71	33.04	206.19
265	440.96	439.96	1.00	238.09
323	542.80	541.80	1.00	275.21

Table 7. Average observed values for the variety M-4.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	20.20	0.00	20.20	18.00
74	85.80	10.70	75.10	105.40
97	109.00	27.30	81.70	148.90
156	198.90	85.30	113.60	241.00
190	219.40	142.80	76.60	259.40
228	268.20	213.00	55.20	299.50
265	326.40	238.10	88.30	361.70
323	462.00	250.90	211.10	449.00

Table 8. Predicted distribution of dry matter (gm) in different plant parts at the time of harvest of the three varities by the simulation model.

Variety	DMLF(gm)	DMST(gm)	DMRT(gm)
H-1687	330.71	968.57	793.49
H-2304	281.81	103.39	1,208.14
M-4	125.68	240.75	978.67

DMLF = dry matter in leaves
DMST = dry matter in stems
DMRT = dry matter in roots

Table 9. Distribution of dry matter (gm) observed in different plant parts at the time of harvest in the three varieties.

Variety	DMLF(gm)	DMST(gm)	DMRT(gm)
H-1687	112.13	371.04	733.91
H-2304	201.23	525.76	1,122.92
M-4	213.67	754.29	1,005.48

Table 10. Simulated values of the fresh root weight (gm/plant) yield at time of harvest, and the corresponding values observed in the field.

Variety	Simulated	Observed
H-1687	2,602	2,406
H-2304	3,138	2,917
M-3	2,497	2,565

Coefficients used in these models represent the influence of both the varieties and the environment. So, these are to be computed for each variety and locality. Initial calibration is an essential step before using this model. The model gives fairly accurate predictions, but there is always scope for improvement. This model is helpful mainly for simulating in the computer the various cassava growth parameters.

Model 3

Including the effect of environment in the coefficients makes computer simulation more environment-specific. To develop a growth model, which is more general, the environmental effect should be removed from MODEL 2. The cassava plant system was redesigned with the following components:

a) Total number of leaves formed - LFMD
b) Total number of leaves fallen - LFLLN
c) Total number of leaves - TLF
d) Total leaf area - TLA
e) Leaf Area Index - LAI

f) Net Assimilation Rate - NAR
g) Total dry matter - TDM
h) Dry matter apportioned to stem - DMST
i) Dry matter apportioned to leaves - DMLF
j) Dry matter apportioned to roots - DMRT
k) Matter in dry leaves - DMDLF
l) Branching
m) Potential leaf age - PLFAGE
n) Leaf age - LFAGE

New variables were derived as functions of rainfall and temperature and its effects on the growth of the crop are being investigated. The coefficients, which are more general in all the environments, will give a model which is more general in nature. For using such models, computation of genetic coefficients alone will be sufficient before using such models.

The system starts with the computation of temperature during the growth of the crop and it depends on the rainfall received during the same period.

HT, LFMD, PLFAGE and ALA are the functions of total temperature during the growth of the crop.

LFAGE is calculated from PLFAGE and total temperature during the growth of the crop.

LFAGE is used to compute LFLLN

TLF is calculated as follows:

TLF = LFMD - LFLLN

From TLF and ALA, TLA is calculated as follows:

TLA = TLF * ALA

From TLA, LAI is calculated as follows

LAI= TLA/Spacing

NAR is calculated as a function of LAI

TDM is calculated as follows:

TDM = TLA * NAR

This dry matter is partitioned into the different plant parts and equations are developed to compute these partitioned dry matter values. The computations are continued for the entire growth period.

This model is now in the first stage of development. In subsequent stages, the effect of water, nutrients and pests and diseases will be included to make improvements. The ultimate aim of developing this model is to develop a perfect system for simulating the growth of cassava using a computer.

CONCLUSION

The development of cassava growth models is very important for making more rapid progress in research and development of this crop. Like any other biological system the cassava growth system is very complicated (Santhosh Mithra, 2002). A good understanding of the processes involved is very important for the correct development of the model. So, efforts should be made for the modeling process and the research on this crop to progress simultaneously. Models, which are not specific to any particular cultivar or environment, are very essential for reaping the full advantages of computer simulation,

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CONTRIBUTION OF CASSAVA LEAVES USED AS A VEGETABLE TO IMPROVE HUMAN NUTRITION IN INDONESIA

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ABSTRACT

Young cassava leaves are a popular vegetable in Indonesia due to their high content of protein, minerals and vitamins compared to those in other vegetables. Malnutrition, such as anemia, vitamin A and protein deficiencies, affect one hundred million, nine million and twelve million people, respectively. These nutritional problems could be reduced by introducing young cassava leaves as a vegetable in the diet. Production of cassava leaves as a vegetable for human consumption in Indonesia is estimated at 0.5-0.7 million tonnes/year. Removing some young leaves every week did not affect the cassava root yield, so cassava leaves for use as a vegetable could be available after the first five months. Consumption of 400 g cassava leaves per capita per day would be equivalent to a protein intake of 45-50 g. Utilization of cassava leaves as a supplement in the diet to solve nutritional problems, methods of cooking, as well as cropping patterns, will be discussed.

INTRODUCTION

Malnutrition, especially protein and vitamin A deficiencies and anemia, is a serious public health problem in Indonesia. During the last decade, there is an indication that the prevalences of protein malnutrition and anemia were declining. However, the economic crisis of 1997 resulted in a progressive reduction in food consumption and procurement of nutritious food (Untoro, 2002).

Among the interventions aimed at promoting increased availability of protein and micronutritients in the diet, fortifying common food items with high content of protein, micronutrients and vitamins have proved to be the most sustainable and cost-effective strategy for delivering these nutritients to people in industrialized countries. In Indonesia, rural, remote and marginal populations, who are most vulnerable to protein and micronutrient deficiencies, do not have access to manufactured or processed foods. Technological initiatives for rural communities, such as small-scale fortification using several vehicles, like composite flour products, indicate their important role in the fight against deficits of energy, protein as well as micronutrients. It also includes diversification of food to include vegetables which are high in protein and micronutrients, such as leaves of cassava as well as legumes. Young cassava leaves are a popular food in Indonesia because of their high content of protein, iron and vitamins A and C; they are also cheap and available in rural, remote and marginal communities. Therefore, production of cassava leaves, and their utilization as a supplement in the diet, will be discussed in this paper.

Young Cassava Leaves Contribution in the Human Diet

Malnutrition resulting from inadequate levels of energy and protein in the diet, and anemia are serious public health problems in Indonesia. A survey in various regions of Indonesia indicate that the consumption of non-animal protein varied from 17 to 37 g/person/day (**Table 1**), while that of iron was 13 g/person/day (Untoro, 2002). Among vegetables, cassava leaves have a high content of protein, micronutrients such as iron, and vitamins (**Table 2**). The protein supplied by young cassava leaves in the diet depends on

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the type of staple food consumption: when rice is the staple food, about 75% of the protein requirement is supplied already; on the other hand 75% of the iron requirement should be met from cassava leaves if 20% of rice is substituted by cassava roots. The amount of cassava leaves increase when the staple food has an increasing proportion of cassava roots (**Table 3**). As cassava roots are low in protein content; therefore, the higher the proportion of cassava roots in the diet the more cassava leaves are needed to increase the protein required. In general, consumption of 75 to 100 grams of cassava leaves/capita/day is advised to supply the protein and iron required in the diet.

The benefit of consuming cassava leaves as a protein source, especially of varieties with yellow roots such as Adira 1, is their high content of vitamins A and C as well as iron (Dit Gizi, 1987). **Table 2** shows that consumption of cassava leaves and fermented soybean can supply the protein and iron required in the diet (CBS, 2000; Untoro, 2002). **Table 4** shows that the protein content of cassava leaves depends on the variety: Adira 1 (yellow fleshy roots) had the highest protein content, followed by BIC 137.

The advantage of using young cassava leaves in the diet are: 1. cassava is able to produce high yields in infertile soils, so it is available for farmers in remote and marginal conditions; 2. it has a higher content of protein, iron, calcium and, vitamins A and C as compared to other vegetables; 3. it can be grown in small areas for daily supply; and 4. it can also be grown commercially to increase farmer's income.

Table 1. Total protein consumed and the proportion as vegetable protein in various regions of Indonesia.

	Daily protein consumed in the diet		
	Total protein	Vegetable protein	
Region	(g/person)	g/person	(% of total)
Sumatra	49.45	33.25	67.25
Java	47.81	31.08	65.00
Bali & Nusa Tenggara	49.67	36.76	74.01
Kalimantan	51.36	30.94	60.25
Sulawesi	52.25	31.74	60.75
Maluku & Irian Jaya	39.96	17.17	42.96

Source: *CBS, 2000.*

Table 2. Nutritional content of some vegetables and staple foods.

	Nutritional content (per 100 g edible portion)				
Vegetables/Staple foods	Calories (cal)	Protein (g)	Iron (mg)	Vit. A (SI)	Vit C (mg)
Cassava leaves	131	12.7	3.9	13,000	58
Spinach	30	3.5	3.9	6,090	80
Fermented soybean	149	18.3	10.0	50	50
Rice	360	6.8	0.8	0	0
Cassava roots	145	0.8	0.7	385	30

Source: *Dit Gizi, 1987.*

Table 3. Nutritional status of several food scenarios in the per capita daily diet.

Staple food/ vegetable	In proportion (%)	Available		Substituted by cassava leaves [1)]	
		Protein (g)	Iron (mg)	Protein (g)	Iron (mg)
Rice	100	30.94	3.64	-	100
Rice + cassava roots	80 + 20	26.50	4.49	·35	75
	60 + 40	20.74	5.34	80	30
	40 + 60	17.70	6.55	104	0
Cassava roots	100	9.03	7.91	170	0

[1)] ***Source:*** *calculated from CBS, 2000 and Dit Gizi, 1987.*

Table 4. Protein content of young cassava leaves of ten varieties, harvested at four months after planting in Bogor in 2002.

Varieties	Protein content (% of dry matter)
No. 40.3.3	24.68
No. 50.2	32.86
No. 39.1.1	33.12
BIC 319	33.09
BIC 109	32.69
BIC 137	35.49
BIC 317	33.35
BIC 323	32.20
Adira 1	35.86
Adira 4	32.12

Production of Young Cassava Leaves

The actual yield of young cassava leaves to be used as a vegetable and a source of protein and micronutrients in the diet depends on the way the leaves are harvested and on the cultural practices used. There are basically two ways of harvesting young cassava leaves as a vegetable: one is at weekly intervals and the other at root harvest.

The growth rate of cassava increases rapidly between four and seven months after planting. During the first six months, dry matter accumulated is used mainly for growth of leaves and stems, while after six months it is used mainly for the development of roots (Hozyo, 1984; Wargiono, 1986). The reasons why farmers harvest cassava young leaves weekly between four and seven months after planting are: 1. easy to harvest (plant height is 0.75 to 1.5 meters); 2. good quality (large leaf blades); and 3. no branches. Farmers do not harvest young cassava leaves weekly after seven months because: 1. difficult to harvest (plant height more than 1.5 meters); 2. not good quality leaves (fewer and smaller); and 3. the number of branches per plant increases. Cassava grown under intercropping systems is normally planted at a population of 5,000 to 10,000 plants/ha, while for monoculture 10.000 to 12.000 plants/ha. In Indonesia cassava is generally managed so as to leave two shoots or stems per plant. The estimated weekly production of leaves harvested before seven months old, based on the plant population of intercropped and monoculture cassava, will be 4.45 million tonnes and 5.67 million tonnes of fresh young leaves, respectively, while young cassava leaf production when harvested at the time of root harvest will be only 0.37 million tonnes of fresh young leaves. So, the total production of young cassava leaves to be used as vegetable could be as high as 6.04 million tonnes/year. This would be equivalent to 78.8 g/capita/day. The problem is that good quality young leaves for vegetables are available for only three months, from the 4th to the 7th month. Since the requirement for non-animal protein is about 35 g/capita/day, this could be achieved by growing cassava in the backyard or in other unused land. Using young cassava leaves in the diet will help to reduce the prevalence of protein deficiency and anemia.

Contribution of Young Cassava Leaves to Farmers' Income

Results of a study on young cassava leaves used as vegetable in Bogor, West Java, indicate that farmers divide their upland areas into two parts for planting cassava. One part for commercial production of young leaves as vegetable and the other for commercial production of both roots and young leaves at the harvesting of roots.

Planting cassava for commercial vegetable production

Information on the planting of commercial vergetable is based on a case study at Bogor, West Java, in 2002. The planted area varied from 200 to 500 m^2. Cassava was planted in strips of four rows, each strip one meter wide and 10 to 20 meter long; the 40 cm space between strips was used as a drainage canal. Shoots with five leaves are harvested daily.

The cultural practices are:

- Plant spacing : 25 x 25 cm
- Fertilization : 4 kg urea/400 m^2 applied monthly after each harvest of young leaves, and 40 kg cattle manure at time of soil preparation (depends on farmer's capital)
- Harvesting : Daily/2 strips starting at 2 months after planting, followed by application of urea.
- Daily yield : 6 bundles/2 strips with the price Rp 400,-/bundle at the farmer's field
- Harvesting duration : 1-1.5 years (depends on water availability)
- External input : Urea = 11 x 4 x Rp 1200 = Rp 52,800 per year/400 m^2
- Cattle manure : 40 x Rp 400 = Rp 16,000
- Cost of production without labor (family labor): Rp 78,800
- Gross income : 6 x 30 x 11 x Rp 400 = Rp 792,000
- Net income : Rp 792,000 - Rp 78,800 = Rp 713,200/year/400 m^2 or Rp 59,433/month/400 m^2

When this production system is calculated on a hectare basis using external labor the production costs are Rp 7,625,000, the gross income is Rp 19,800,000 and the net income Rp 12,175,000/ha/month or only Rp 40,583/400 m^2/month. This is the reason that farmers plant cassava for vegetable in only small areas without using external labor. Planting 500 to 1000 m^2 can be managed with family labor and this system produces a high income.

Planting cassava for root yield

Most farmers that plant cassava for root yield on an area of more than 0.25 ha use external labor for land preparation and harvest. The production cost and net income shown in **Table 5** are based on the case study in Bogor, West Java, in 2002.

Table 5. Production costs and gross and net income (Rp/ha/year) from the production of either cassava roots and leaves (at root harvest) or from the continuous harvests of young leaves as a vegetable in Bogor, W. Java, Indonesia in 2002.

Items	Commercial roots and leaves	Commercial vegetable
Land preparation	Rp. 420,000	Rp 420,000
Stake preparation	Rp. 70,000	Rp 100,000
Planting	Rp. 113,500	Rp 227,000
Fertilizer application	Rp. 196,000	Rp 217,000
Weeding	Rp. 342,000	Rp 634,000
Harvest	Rp. 295,000	Rp 4,320,000
Fertilizers : Urea	Rp. 240,000	Rp 1,707,000
SP36	Rp. 170,000	
Total production costs	Rp 1,846,500	Rp 7,625,000
Gross income - roots	Rp 4,589,000	
-leaves	Rp 320,000	Rp 19,800,000
-total	Rp 4,909,000	
Net income (per ha/year)	Rp 3,062,500	Rp 12,175,000
Net income (per ha/month)	Rp 255,208	Rp 1,014,583
B/C Ratio	1.66	1.60

Theoretically, growing cassava as a vegetable is more profitable than commercial root and leaf production. The problems are that farmers have limited capital for production (external inputs) and the marketing of a daily yield of 300-400 bundles of young leaves is difficult. Each seller at the city market can only sell 10 to 15 bundles/day, while traditional restaurants buy about 4-6 bundles/day. B/C ratio of planting cassava for both commercial vegetable and root yield were 1.60 and 1.66 respectively. It means that planting cassava for both root yield and leaves as vegetable are feasible to be developed.

Young cassava leaves harvested daily from their commercial root production field is suitable for farmers living in the village because: 1. available from their upland production area or backyard; 2. they are in fresh condition; 3. have high quality (young, large leaf blades); and 4. cheap. The demand of cassava young leaves for each family is about 300 g/day, which is equivalent to 38 plants. To supply that demand about 200-300 plants/family are needed, with the upper leaves of each plant harvested at weekly intervals. By using cassava leaves as vegetable the family's expenditure for protein can be reduced.

Protein and Iron Contribution of Cassava Leaves in the Diet

The implementation of introducing young cassava leaves to solve malnutrion of protein and anemia due to iron deficiency will be through a food diversification program that promotes the planting of about 300 cassava plants as vegetable in the backyard or in upland areas. This program should be promoted through the media such as TV, newspapers and others.

To produce the necessary amounts of staple food (rice and cassava flour), soybean or fermented soybean and young cassava leaves, the following cropping patterns could be established

- Cassava intercropped with rice, followed by soybean
- Cassava intercropped with maize, followed by soybean
- Cassava intercropped with soybean

Young cassava leaves and fermented soybean are popular vegetable and side-dishes in Indonesia. Young cassava leaves can be prepared as soup, or made into a ball with a small dry fish inside which are boiled together to produce a popular dish that is high in both animal and vegetable protein. In general, cooking young cassava leaves as a soup, a fish ball and just boiled are:

- Water + baking powder or salt (0.5 g/ kg of leaves to maintain the green color of cassava leaves), heat until boiling point, put in the young cassava leaves, wait for about 15 minutes (make sure that the color does not change to brown), and wash in cold water to reduce the HCN content.
- These washed and boiled cassava leaves are made into a ball with a small dry fish inside; these are cooked in coconut milk + spices (shallots, garlic, coriander powder, curcuma, sugar and salt with the amount dependent on personal taste) until just boiling. Fermented soybean can be cooked as a soup (same process as cassava leaves) or fried dry in small or big size.

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CASSAVA LEAF PRODUCTION RESEARCH IN THAILAND

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ABSTRACT

The unlignified upper part of the cassava plant is potentially a good source of protein for animal feed rations because of its high yield and nutritive value. Several experiments have revealed that the dry matter of these plant tops contains 20-32% crude protein, which consists of various essential amino acids in proportions close to those of soybean meal. Most research conducted in Thailand in the past focussed mainly on the utilization of cassava foliage to partially substitute for soybean meal in the feeding of different types of animals, such as cows, pigs, and poultry, in order to reduce the import of soybean meal. If only 10% (0.14 million tonnes) of soybean meal in animal feed is substituted by cassava leaf meal, the country would be able to save 900 million baht or 21 million U.S. dollars per year.

According to previous research conducted in Thailand, the annual yield of dry cassava foliage varied from 3.6 to 12.6 t/ha. Both yield and nutritive value depend to a large extent on both genetics and the environment. Hence, factors affecting yield and protein content of cassava foliage are presently being researched at different locations in order to determine the appropriate practices in cassava foliage production for each part of the country. A preliminary trial conducted in 2001/02 at Rayong Field Crops Research Center indicates that the total cassava dried foliage yields from 3 cuttings of 16 varieties and their protein contents were in the range of 4.0 to 7.7 t/ha and 19.7 to 26.8%, respectively, while root yields and starch contents at 12 months after planting ranged from 11.9 to 29.1 t/ha and 19.0 to 26.4%, respectively. A similar trial conducted at TTDI in Nakhon Ratchasima province resulted in total dry foliage yields of 2.6 to 8.2 t/ha with 11.5 to 34.3% protein, and 6.77 to 22.7 t/ha of fresh roots with 11.3 to 29.1% starch.

INTRODUCTION

Most research related to cassava leaves recently conducted in Thailand has focused on the utilization of cassava leaves or cassava hay to partially substitute for soybean meal in the feeding of dairy cows, cattle, pigs, and poultry, in order to reduce the importation of soybean meal. If only 10%, or 0.14 million tonnes, of soybean meal in animal feed is substituted by cassava leaf meal, the country would be able to save 900 million baht or 21 million U.S. dollars per year. Although the protein content of cassava leaves is not as high as that of soybean meal, it is not much different from those of some other sources of animal feed (**Tables 1, 2** and **3**). Therefore, it can be used to some extent for feeding different types of animals, mainly cattle, pigs and poultry. The role of cassava forage in animal feeding is presented by other authors. Research concerning factors affecting cassava leaf production conducted in the past until recently are presented in this paper.

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Table 1. Chemical composition of cassava leaves and hay compared with other protein sources in animal feed.

Parameter	Concentrate[1)]	Soybean meal[2)]	Dry pigeon pea leaves[2)]	Dry *Leucaena* leaves[2)]	Dry cassava leaves	Cassava hay
Dry matter	88.4	89.0	96.7	90.0	90.0[3)]-92.1[4)]	86.3[3)]
Composition (% of DM)						
Crude protein	17.7	49.0	19.8	22.4	20.6[4)]-24.7[3)]	23.6[1]-25.0[3)]
Crude fiber		8.2	23.2	20.0	17.3[3)]	
Neutral Detergent Fiber	48.7				29.6[3)]	44.3[1]-58.8[3)]
Acid Detergent Fiber	35.9				24.1[3)]	30.3[3]-32.0[4)]
Ether extract		0.9	7.3	3.9	5.9[3)]	
Nitrogen-free extract		32.7	43.7	43.9	44.2[3)]	
Ash	26.6	8.8	6.0	9.8	7.9[3)]	6.8[4]-17.5[3)]

Sources: [1)] *Metha Wanapat, 1999;* [2)] *Vimolruth Sukarinth, 1998;*
[3)] *Metha Wanapat, 2002;* [4)] *Onanong Poungchompu et al., 2001.*

Table 2. Chemical composition of various cassava products, sorghum and alfalfa hay.

Parameter	Cassava products: Dry leaves	Dry forage	Fresh roots	Ensiled roots	Root meal	Sorghum	Alfalfa hay
Dry matter	89-90	91-92	35-40	40-45	90	88-89	89-90
Composition(% of DM)							
Crude protein	21	17-18	1-2	2-3	3.1	11	15
Crude fiber	20-24	17-18	1.5-2.0	3-4	3.4	2.0	29
Ether extract (fat)	6-7	5-6	0.2-0.5	1-2	1.3	2.8	1.7
Non-Nitrogen extract	27-35	39-44	30-36	30-32	80	70-71	34-35
Ash	8-10	9-10	1-2	2-3	2.1	1.7	9
Ca	1-1.4	1.75	0.05		0.12	0.04	1.4
P	0.25-0.28	0.32	0.07		0.16	0.29	0.20

Source: *Gomez et al., 1985.*

Table 3. Amino acid contents of various protein sources of animal feed (gm/16 gm N).

Amino acid	SM[1)]	CL[2)]	CH[3)]	AH[4)]	Amino acid	SM[1)]	CL[2)]	CH[3)]	AH[4)]
Alanine	4.4	5.7	6.3	na	Arginine	7.5	5.3	2.4	3.8
Asparagine	Na	Na	6.8	na	Aspartic acid	11.9	9.8	na	na
Cystine	1.6	1.4	0.3	0.2	Glutamine	19.0	12.3	9.6	na
Glycine	4.4	4.8	2.6	1.9	Histidine	2.8	2.3	1.5	1.2
Isoleucine	4.7	4.5	13.1	0.7	Leucine	7.1	8.2	2.9	1.1
Lysine	6.5	5.9	1.7	0.6	Methionine	1.6	1.9	0.6	0.2
Proline	5.6	Na	2.9	na	Phenylalanine	5.6	5.4	1.9	0.8
Serine	5.5	Na	2.8	na	Threonine	4.2	4.4	na	na
Tryptophan	Na	2.0	na	na	Tyrosine	4.7	4.0	1.8	0.4
Valine	5.1	5.6	2.4	0.7					

[1)] SM = soybean meal; [2)] CL = dry cassava leaves; [3)] CH = cassava hay; [4)] AH = alfafa hay.
Source: *Metha Wanapat, 2002.*

FACTORS AFFECTING CASSAVA FOLIAGE YIELD AND PROTEIN CONTENT

Cassava dried foliage yields reported from former research conducted in Thailand were in the range of 3.6 to 12.6 t/ha/year. Both yield and nutritive value depend considerably on genetics and the environment. Hence, factors affecting yield and protein content of cassava foliage, i.e. variety, plant age, fertilization, spacing, cutting frequency and cutting height, are being researched under different conditions in order to determine the most appropriate techniques for cassava foliage production for each part of the country.

1. Yield Potential and Varietal Difference in Yield and Protein Content

a. Cassava tops collected at root harvesting time

i) 12 months harvest

In May 1998, the foliage yields were determined of 119 clones planted in the Preliminary Yield Trial for root production at Rayong Field Crops Research Center. The varieties were planted in 5x10 m plots at a spacing of 1x1 m. Twenty four plants of each clone were harvested at 12 months after planting (MAP). Fresh foliage production of Rayong 1 and Rayong 90 were 4.31 and 2.91 t/ha while that of the most leafy one in the trial was 7.70 t/ha. In this case, most of the erect types had a thicker leaf canopy but fewer branches than the branchy types, which had a lower foliage production. Under Rayong's conditions the fresh foliage yield of an erect type is usually around 4 t/ha. The dry foliage weight is usually 25-30% of fresh weight, depending on varietal differences in dry matter content and the intensity of the sunlight during the drying process.

ii) 8 months harvest

Vicharn Vichukit (1979) harvested cassava leaves (without petioles) from an eight month old crop and indicated that fresh leaf and dried leaf production was 5.78 and 1.92 t/ha respectively. Sunee Kittivorawate (1996) also reported that the dry leaf yield from an eight month crop was as high as 2 t/ha.

Compared to the 12 month crop, cassava foliage production derived from the 8 month crop seemed to be not much different. In tropical countries, the season of harvest (wet or dry) has more effect on leaf yield than plant age, due to leaf shedding during the dry season.

Chareinsuk Rojanaridpiched (1988) reported that the protein content in the leaves of 13 cassava varieties harvested at 8 months varied from 21.6 to 26.7%. Rayong 1 and Rayong 3 had 22.2 and 22.6% crude protein in their leaves' dry matter, respectively.

b. Cassava tops collected at 3-4 month intervals

Metha Wanapat (1997) reported that the production of dry cassava hay could reach 12.6 t/ha/year when cassava was planted at narrow spacing and with the first harvest at 3 MAP, and thereafter every two months. Cassava tops were chopped and sun dried for 1-3 days before feeding to animals or keeping for later use. Protein production was 2.5 t/ha/year or about 20% of the dry weight.

2. Effect of Varieties on Leaf Production

Between May 2001 and May 2002, an experiment was conducted at Rayong Field Crops Research Center (RFCRC) in Rayong and at TTDI Research and Training Center in Nakhon Rachasima provinces to evaluate the potential of 16 cassava varieties for foliage production. Stakes were planted at 60x60 cm in RCB design with 4 replications in 3.6x3.6

m plots. Fertilizers were applied three times i.e. 500 kg/ha of 15-15-15 at planting, and 25 kg N/ha as urea after each of the first two cuttings. The plants were cut at 3 ½, 5 ½ and 12 months after planting at a height of 50-60 cm above the soil surface. Dry foliage yields and dry matter and protein contents varied among varieties and cuttings in both locations. Fast growth or higher leaf production seemed to result in lower protein contents (**Table 4**). Total production of dried leaves, protein and fresh roots are shown in **Tables 5** and **6**. The highest dry leaf yields at RFCRC and TTDI were 7.77 and 8.24 t/ha, respectively. The highest protein yields at the same two locations were 1.93 and 1.90 t/ha respectively. Root yield and starch content of some varieties were surprisingly high, even though they had had to regenerate leaves continuously.

Table 4. Dry leaf yields, dry matter contents and protein contents of three cuts of cassava leaves at RFCRC and TTDI, Thailand, in 2001/02.

	Cut 1 (3½ MAP)	Cut 2 (5½ MAP)	Cut 3 (12 MAP)
RFCRC			
Dry leaf yield (t/ha)	1.4-2.9	2.2-3.3	0.4-1.8
% D.M.	22-25	22-25	25-30
% protein (DM basis)	21-27	19-25	21-26
TTDI			
Dry leaf yield (t/ha)	0.7-2.5	0.9-2.4	1.1-4.0
% D.M.	-	20-24	26-32
% protein (DM basis)	25-37	24-31	11-19

Table 5. Total dry matter and protein yields of three cuts of cassava leaves[1)] as well as the fresh root yield and starch content at harvest at 12 MAP in Rayong Field Crops Research Center, Rayong, Thailand in 2001/02.

Variety/line	Leaf production (t DM/ha)				Crude protein yield (t/ha)				Root yield (t/ha)	Starch content (%)
	1st cut	2nd cut	3rd cut	Total	1st cut	2nd cut	3rd cut	Total		
1. Rayong 1	1.700	3.074	0.985	**5.759**	0.367	0.740	0.222	1.329	23.87	21.4
2. Rayong 5	2.151	2.617	0.794	**5.562**	0.592	0.648	0.184	1.424	29.12	25.6
3. Rayong 60	1.922	2.207	0.396	**4.525**	0.500	0.541	0.094	1.135	20.27	20.6
4. Rayong 90	1.172	2.349	0.522	**4.043**	0.290	0.514	0.125	0.929	16.49	25.1
5. Rayong 72	1.962	2.389	0.514	**4.865**	0.528	0.599	0.107	1.234	25.96	23.7
6. KU 50	1.985	2.234	0.908	**5.127**	0.532	0.563	0.179	1.274	21.31	25.5
7. Hanatee	1.580	2.459	0.452	**4.491**	0.358	0.549	0.103	1.010	11.98	19.8
8. OMR 39-42-54	1.396	2.965	0.718	**5.079**	0.373	0.778	0.152	1.303	16.19	23.3
9. CMR 40-84-154	1.725	3.101	1.337	**6.163**	0.377	0.591	0.328	1.296	15.54	20.1
10. CMR 41-42-3	1.741	3.394	1.205	**6.340**	0.477	0.891	0.301	1.669	21.79	26.4
11. CMR 41-60-24	2.987	3.219	1.562	**7.768**	0.670	0.852	0.402	1.924	23.78	25.1
12. CMR 41-61-59	2.025	3.010	0.797	**5.832**	0.457	0.691	0.187	1.335	23.79	19.0
13. CMR 41-61-118	2.118	2.832	1.126	**6.076**	0.501	0.627	0.283	1.411	21.14	22.0
14. CMR 41-111-129	1.979	3.128	0.926	**6.033**	0.485	0.773	0.222	1.480	22.39	23.7
15. CMR 41-114-125	1.704	3.369	1.631	**6.704**	0.446	0.737	0.349	1.532	25.00	25.7
16. CMR 41-23-41	1.373	3.035	1.791	**6.199**	0.365	0.664	0.357	1.386	20.61	25.2
Average	1.845	2.836	0.979	**5.660**	0.457	0.672	0.225	1.354	21.20	23.3

[1)]Young stems, leaves and petioles cut at 3½, 5½ and 12 months after planting.

Table 6. Total dry matter and protein yields of three cuts of cassava leaves[1)] as well as the fresh root yield and starch content at harvest at 12 MAP in the Thai Tapioca Develop. Institute (TTDI) in Huay Bong, Nakhon Ratchasima, Thailand in 2001/02.

Variety/line	Leaf production (t DM/ha)				Crude protein yield (t/ha)				Root yield (t/ha)	Starch content (%)
	1st cut	2nd cut	3rd cut	Total	1st cut	2nd cut	3rd cut	Total		
1. Rayong 1	0.721	1.507	2.291	**4.519**	0.237	0.424	0.444	1.105	9.63[2)]	15.0[2)]
2. Rayong 5	1.660	1.478	3.443	**6.581**	0.487	0.404	0.643	1.534	22.74	27.4
3. Rayong 60	0.626	0.924	1.101	**2.651**	0.232	0.292	0.208	0.732	6.77[2)]	12.8[2)]
4. Rayong 90	1.010	1.075	1.428	**3.513**	0.293	0.289	0.262	0.844	12.50	23.4
5. Rayong 72	1.661	1.527	2.350	**5.538**	0.480	0.462	0.417	1.359	21.35	24.8
6. KU 50	1.617	1.269	2.431	**5.317**	0.359	0.315	0.389	1.063	21.27	26.2
7. Hanatee	1.350	1.748	1.702	**4.800**	0.380	0.505	0.341	1.226	6.77[2)]	11.3[2)]
8. OMR 39-42-54	1.648	2.117	3.330	**7.095**	0.466	0.509	0.610	1.585	16.14	25.4
9. CMR 40-84-154	1.556	2.099	2.766	**6.421**	0.465	0.611	0.387	1.463	12.15[2)]	16.4[2)]
10. CMR 41-42-3	1.857	1.762	3.641	**7.260**	0.466	0.525	0.637	1.628	19.27	26.0
11. CMR 41-60-24	2.380	1.858	3.369	**7.607**	0.628	0.564	0.610	1.802	14.76	29.0
12. CMR 41-61-59	2.560	1.318	3.693	**7.571**	0.701	0.364	0.427	1.492	19.88	20.7
13. CMR 41-61-118	1.748	2.414	4.011	**8.173**	0.498	0.641	0.763	1.902	11.55[2)]	16.9[2)]
14. CMR 41-111-129	2.199	1.743	3.037	**6.979**	0.588	0.465	0.452	1.505	18.31	22.2
15. CMR 41-114-125	2.408	1.982	3.939	**8.239**	0.635	0.494	0.483	1.612	21.35	29.1
16. CMR 41-23-41	1.671	2.285	3.621	**7.577**	0.469	0.626	0.675	1.770	13.45	24.1
Average	1.667	1.694	2.884	**6.246**	0.461	0.468	0.484	1.414	15.49	21.9

[1)] Young stems, leaves and petioles cut at 3½, 5½ and 12 months after planting
[2)] Low yield and low starch content due to very poor growth in one of the four replications, prodably due to Zn deficiency.

In May 2002, similar trials were planted in Rayong, Nakorn Rachasima, Khon Kaen and Songkhla provinces to evaluate the potential of 25 cassava varieties for foliage production. In this case, stakes were planted at a spacing of 30x30 cm corresponding to a population of 111,111 plants/ha, which is four times those of the previous trials; plants were fertilized with 500 kg/ha of 15-15-15 fertilizer at planting and 25 kg N/ha after each cut. The first leaf harvest was at 2.5-3 months after planting by cutting the top parts at 20 cm above the soil surface. Yields varied among varieties and locations (**Table 7**). The highest fresh and dry foliage production at the first cut at Rayong was 15.56 and 3.17 t/ha, respectively. Some of the tested varieties produced 20 tonnes of fresh leaves per ha in some replications. The dry matter contents (determined after 5 days in the oven at 50°C) was 17.5-22.6% of the fresh weight. The protein content has not been analyzed at this moment. Leaf production from the first cut at Songkhla and Khon Kaen are quite high compared to those at Rayong.

3. Fertilizer Application and Ridging

Onanong Poungchompu *et al.* (2001) conducted a trial to determine the effect of cow manure application and ridging on cassava leaf production. KU 50 was planted at a spacing of 50x30 cm in 4x8 m plots, and was first cut at 10-15 cm above the ground at 3 MAP, and every two months thereafter. It was concluded that ridging had no effect, while manure application (1,250 kg/ha) tended to increase cassava foliage yield but not the protein content (**Table 8** and **9**) . The total dry foliage yield reached 4.4 t/ha with ridging and manure application.

Table 7. Range of fresh leaf yields, dry matter contents and dry leaf yields of the first cut of 25 cassava varieties in leaf production trials at Rayong, Khon Kaen and Songkla, Thailand in 2002/03.

	Rayong	Khon Kaen	Songkla
Fresh leaves[1)] (t/ha)	5-15	10-23	13-24
D.M. (%)	17-22	16-18	20-23
Dry leaves (t/ha)	1.4-3.1	1.8-4.2	2.8-5.4

[1)] Includes upper green stem and petioles

Table 8. Effect of ridging and manure application on the foliage yield of cassava (KU 50) cut at 3, 5 and 12 MAP at Khon Kaen in 2000/01.

	With ridging		Without ridging	
	without manure	with manure	without manure	with manure
Fresh yield (t/ha)				
Cutting: 1st	3.71	3.99	3.79	3.46
2nd	3.06	3.12	3.12	3.27
3rd	6.02	7.66	5.71	7.77
Total	**12.79**	**14.77**	**12.62**	**14.50**
Dry yield (t/ha) and D.M. (%)				
Cutting: 1st	1.12 (30)	1.20 (30)	1.14 (30)	1.04 (30)
2nd	0.95 (31)	0.94 (30)	0.97 (31)	1.02 (31)
3rd	1.80 (29)	2.27 (29)	1.54 (27)	2.17 (27)
Total	**3.87 (30)**	**4.41 (30)**	**3.66 (29)**	**4.23 (29)**

Source: *Onanong Poungchompu et al., 2001.*

Table 9. Effect of ridging and manure application on the chemical composition of cassava dry Foliage, cut at 3, 5 and 12 MAP at Khon Kaen in 2000/01.

	With ridging		Without ridging	
	without manure	with manure	without manure	with manure
Dry matter content (%)	92.0	91.9	92.1	91.8
Composition (% of DM)				
Ash	7.1	6.8	7.1	6.9
Crude protein	22.0	20.6	20.9	20.6
NDF	58.1	58.8	58.5	57.6
ADF	31.7	32.0	31.0	31.0
Condensed tannins (mg/kg)	40.0	38.0	38.0	42.0

Source: *Onanong Poungchompu et al., 2001.*

In 2002, a trial was conducted at Rayong and Khon Kaen Field Crops Research Centers to determine the fertilizer requirements for cassava leaf production by planting Rayong 5 and Rayong 72 in plots of 2.1x3 m with a plant spacing of 30x30 cm. Twelve combinations of four levels each of N, P and K fertilizers were applied. The crop was first cut at 2.5 months after planting, and thereafter at 2 months intervals.

The data from the first cutting indicates that the two varieties responded differently to fertilizer application and the response varied between locations according to the climate and the fertility of the soil (**Figure 1**).

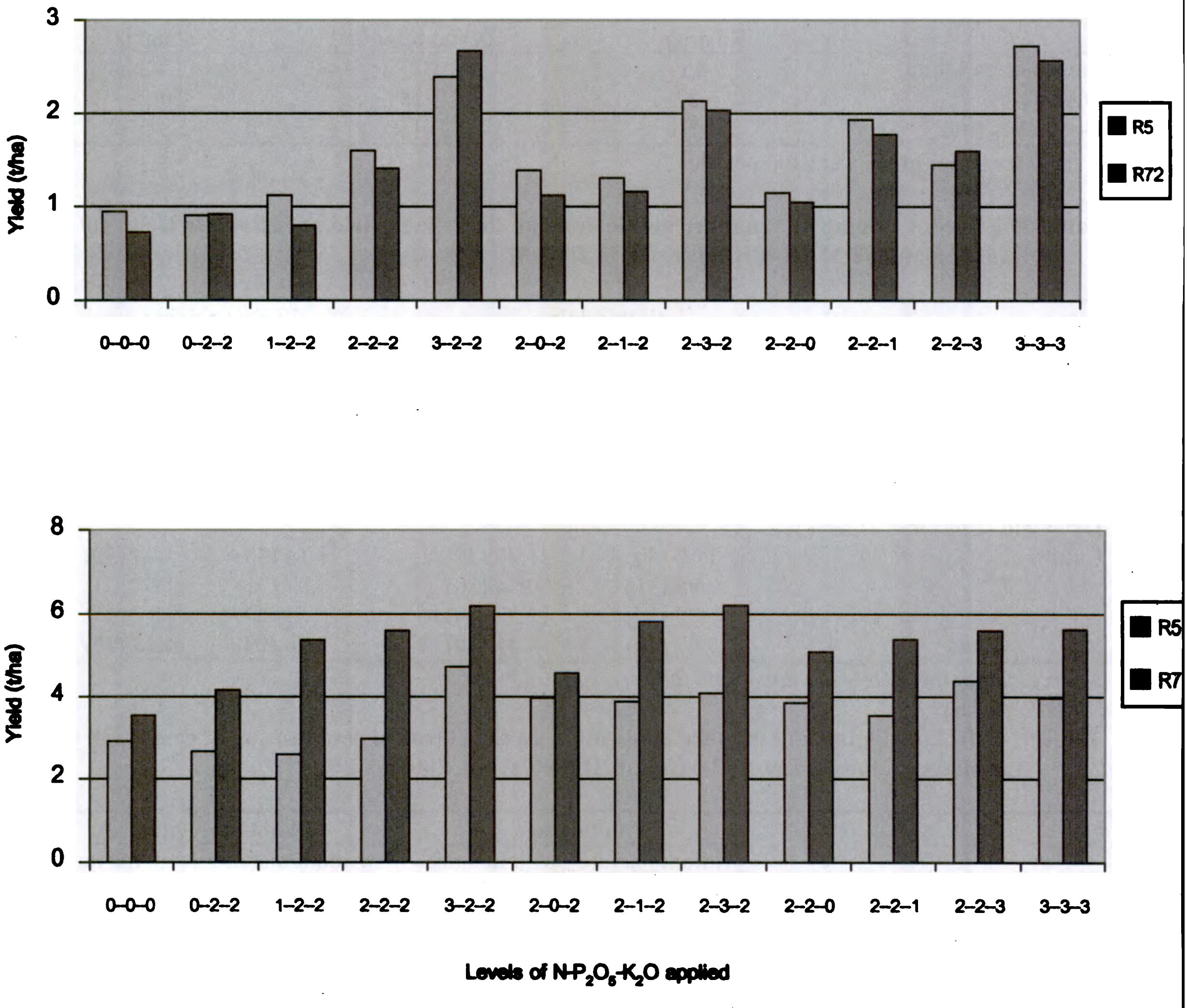

Figure 1. The effect of various combinations of N, P and K on the dry foliage yield of two cassava varieties planted at Rayong (top) and Khon Kaen (bottom) Field Crops Research Centers in Thailand in 2002. Data correspond to the first cut at 2 MAP.

4. Plant Spacing and Cutting Height and Frequency

Somsak Thongsri, Kumpol Narintaraporn and Utai Cenpukdee conducted several experiments to determine the effect of plant spacing and cutting frequency on fresh leaf yield and root yield of Rayong 1 (RFCRC Annual Reports for 1977, 1978 and 1979). The following conclusions could be drawn ;

1) spacings had no significant effect on leaf yield, but did have an effect on root yield (**Table 10**)
2) leaf yield increased but root yield decreased as cutting frequency increased (**Table 11**)
3) plant spacing and cutting frequency had no significant interaction effect on leaf yield.

Table 10. Effect of plant spacings on leaf and root yields of Rayong 1 at Rayong Field Crops Research Center during 1977-1979.

Spacing	Fresh leaf yield (t/ha)				Root yield (t/ha)			
(cm)	1977	1978	1979	**Av.**	1977	1978	1979	**Av.**
40x40	7.06	7.50	7.19	**7.25**	7.75	21.06	12.94	**13.92**
40x50	8.25	8.12	7.87	**8.08**	9.81	25.12	15.00	**16.64**
50x50	6.37	8.06	6.94	**7.12**	9.69	23.00	14.62	**15.77**
80x40	7.81	10.37	8.37	**8.85**	12.37	28.37	18.12	**19.62**
100x50	6.87	8.19	7.31	**7.45**	12.25	27.75	18.69	**16.56**
100x100	6.50	7.31	7.00	**6.94**	14.50	31.50	21.62	**22.54**

Source: *Rayong Field Crops Research Center, Annual Reports, 1977, 1978, 1979.*

Table 11. Effect of cutting intervals on leaf and root yield of Rayong 1 at Rayong Field Crops Research Center during 1977-1979.

Cutting frequency	Fresh leaf yield (t/ha)				Root yield (t/ha)				(%)
	1977	1978	1979	**Av.**	1977	1978	1979	**Av.**	starch
1x (at harvest)	5.31	4.00	4.75	**4.69**	13.25	31.31	19.81	**21.46**	17.5
2x (at 6 and 12 MAP)	5.19	4.19	4.81	**4.73**	12.19	29.00	18.50	**19.90**	17.3
3x (every 4 months)	7.56	11.44	8.50	**9.17**	11.06	23.12	16.06	**16.75**	18.6
6x (every 2 months	10.56	13.50	11.62	**11.89**	7.62	13.50	12.94	**11.35**	17.4

Source: *Rayong Field Crops Research Center, Annual Reports, 1977, 1978, 1979.*

The effect of cutting frequency and cutting height are again being investigated at Rayong and Khon Kaen in 2002/03. In this trial, Rayong 5 is planted with a spacing of 30x30 cm and first cut at 2.5 months after planting at different cutting height, i.e. 15, 20 and 25 cm above the soil surface. Cutting frequency of the next cuttings are every 1.5, 2 , 2.5, and 3 months. Effect of cutting height on dry leaf yield from the first cutting at Rayong and Khon Kaen Center are shown in **Table 12**, but other results will be reported when the trial has finished.

Table 12. Effect of cutting height on the dry leaf yield at first cutting (2½ MAP) of Rayong 5 at Rayong and Khon Kaen Field Crops Research Centers, Thailand in 2002/03.

Cutting height	Dry leaf yield (t/ha)	
(cm)	Rayong	Khon Kaen
15	2.65	4.20
20	2.62	3.59
25	2.38	3.57

CONCLUSIONS

Cassava leaf production research in Thailand was initiated 30 years ago but the results were not utilized due to lack of demand for cassava leaves in the country. It is now national policy to try to utilize all parts of many crops to increase the economic returns to farmers. Current research to optimize cassava leaf production is in response to the potential utilization of cassava leaves for animal feeding, and cassava stems for paper making. Definite results on the best varieties, the fertilizer requirements and the optimum plant spacing, cutting height and frequency should be available during the next four years. CIAT has played an important role in this project by initiating strategic research on cassava leaf production in some parts of the country, which can later be applied to other areas.

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RESEARCH ON CASSAVA FOLIAGE PRODUCTION IN COLOMBIA

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ABSTRACT

Cassava cultivation in Colombia has been increasing recently due to its multiplicity of uses and markets. One of the most important uses for the crop is the foliage in animal feeding, as a source of protein in balanced feeds for monogastrics and ruminants. In Colombia, the animal production sector is growing very fast and domestic production of cereals such us maize and soybean that are used in balanced feeds is not sufficient to meet the increased demand. To meet this demand, the country has been importing cereals at levels that by the end of 2002 will be over 2 million tonnes of maize per year.

With the objective of identifying alternative sources of raw material for animal feeding, CLAYUCA has been conducting adaptative research on the potential of intensive cassava foliage production systems. The results obtained so far indicate that the development of parameters such us variety, plant population and harvesting period are very important as well as the climatic conditions of the region in which the foliage is produced. A comparison was made of three different regions of Colombia, using different varieties and different plant populations. The best results were obtained using a plant spacing of 30 x 30 cm which gives a plant population of around 111,000 plants/ha. The total yield obtained after 12 months was 91 t/ha of fresh cassava foliage. These results were obtained in the region Ayapel, Cordoba, a dry savanna characterized by a dry season of four months. During the dry season, with zero rainfall, cassava plants were able to survive, and with the onset of the rains they recovered normally and produced acceptable yields. The plants tops were harvested every three months.

A similar experiment was conducted in Caicedonia, Valle, a region characterized by a better rainfall distribution and soil fertility status. In this region, although the crop was maintained for two years and the plants were harvested six times, the yields obtained were lower, around 81 t/ha of fresh foliage. These differences in yield could be explained by the physical characteristics of the soils, which makes crop management more difficult. Additionally, with the aim of facilitating the management of the crop in activities such us planting, weeding, fertilization and harvesting, CLAYUCA has conducted some work with different plant spacing, using raised beds separated 70 cm and with 30 cm distance between plants. This arrangement gives a plant population of 48,000 plants per hectare. This experiment is being conducted in the Valle region, with harvest at 3, 7 and 9 months. Yields obtained in those three harvests was 98 t/ha of fresh foliage. This arrangement looks very promising for reducing labor requirements for cassava foliage production.

Another important aspect of cassava foliage production systems is the management of soil fertility. These systems extract more nutrients than normal root production systems. Data obtained by CLAYUCA indicates that with a planting density of 48,000 plants per hectare and with three harvests in a nine month period, each tonne of fresh cassava foliage harvested represents an extraction of 9.26 kg of N. This amount is considerably higher that the 4.42 kg N extracted per tonne of fresh cassava roots (including foliage) in the root production system.

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CLAYUCA is also looking at the viability of using mechanical harvesters to reduce the cost of labor in the intensive cassava foliage production systems. Some prototypes have been identified and are currently under evaluation.

INTRODUCTION

The use of cassava in animal feeding in Colombia is generally restricted to the roots that are used as a source of energy. The top part of the cassava plant has had very limited use. The importance and value that the use of cassava leaves, petioles and stems can have in animal feeding has not received adequate recognition.

During the last five years, cassava cultivation in Colombia has been expanding rapidly, due to its specific characteristics that allows the crop to be used in different markets. One of these markets, perhaps the one with the greatest potential, is the use of cassava in animal feeding, as a source of energy (the roots) and as a source of protein (the leaves). Casava leaves can be used with excellent results in the feeding of monogastrics (poultry and swine) and ruminants (cattle).

The high nutritional value of cassava leaves and the great adaptation of the crop to different types of soils and climates make it a very feasible option for animal nutrition programs.

In many regions of the world, Colombia among them, animal production has increased considerably in recent years and this growth has created an increased demand for raw materials for the elaborations of animal balanced concentrates, most of which have to be imported (maize, sorghum, soybean). This dependency on imported raw materials has increased the cost of animal production. This growing demand for raw materials opens up an opportunity for the use of cassava foliage as a protein supplement in nutrition programs for different types of animals.

CLAYUCA has conducted during the past three years some adaptative research aimed at promoting a more intensive use of cassava leaves in animal feeding programs in Latin America and the Caribbean region. This paper presents a brief summary of this work.

Nutritional Quality of Cassava Foliage

The nutritional composition of cassava foliage is affected by factors such us varieties, soil types and climatic conditions, especially rainfall, age of plant, period of harvest and proportion of stem, petioles and leaves. With older plants, the protein content is lower and the fiber and dry matter contents are higher. The protein and fiber contents determine the nutritional quality of the cassava foliage in animal feeding, specially for monogastrics.

Cassava roots contain on average 2.0% crude protein whereas cassava foliage can have protein contents between 20 to 26% (**Table 1**). Also, when compared with some grains, the nutritional value of cassava foliage in terms of protein content and digestible energy content are higher, thus making it a very attractive option for animal feeding (**Table 2**).

Table 1. Average content of dry matter, crude protein and digestible energy of some foliage crops.

	Dry matter		Crude protein		Digestible energy	
Legumes	%	t/ha/year	%	kg/ha/year	Mcal/kg	Mcal/ha/year
Kudzú	24	10.0	21.0	2,100	2.20	22,000
Desmodium ovalifolium	21	4.5	15.0	675	1.90	8,550
Gliricidia sepium	25	12.0	21.2	2,544	2.10	25,200
Leucaena leucocephala	35	15.2	25.7	3,906	1.90	28,880
Hay	26	24.0	22.5	5,400	1.47	35,280
Cassava foliage	25	25.0	22.0	5,500	1.70	42,500

Source: *Adapted from Chamorro et al., 1998; Gonzalez et al., 1969.*

Table 2. Average contents of dry matter, crude protein and digestible energy of some foliage crops.

	Dry matter		Crude protein		Digestible energy	
Grains	%	t/ha/year	%	kg/ha/year	Mcal/kg	Mcal/ha/year
Imperial grass	22	19.8	8.0	1,584	2.36	46,728
King grass	22	30.8	6.0	1,848	2.09	64,372
Elefant grass	22	26.4	7.0	1,848	1.98	52,272
Guinea grass	20	18.5	9.8	1,813	2.00	37,000
Star grass	20	20.0	10.5	2,100	2.20	44,000
Brachiaria decumbens	20	12.0	8.5	1,020	2.00	24,000
Sorghum	33	12.3	10.9	1,345	2.96	36,408
Maize (whole plant) (100 days)	32	14.5	8.8	1,268	3.22	46,690
Cassava foliage[1)]	25	25.0	22.0	5,500	1.70	42,500

[1)] assuming an annual production of fresh cassava foliage of 100 t/ha.
Source: *Adapted from Chamorro et al., 1998*

Buitrago (1990) considers fiber, protein, fat and ash as the principal elements in the composition of cassava foliage for preparation of balanced animal feeding diets (**Tables 3 and 4**).

Table 3. Nutritional composition of some foliage raw materials used in animal feeding (dry matter basis).

Component	*Manihot esculenta*	*Zea mays*	*Medicago sativa*	*Pueraria phaseoloides*
Crude protein %	18.1	7.3	20.2	16.3
Ether extract %	3.7	2.2	3.0	3.9
Ash %	11.2	6.7	11.7	8.0
Crude fiber %	21.0	33.9	25.9	37.1

Source: *McDowell et al., 1974, reported by Rosero, 2002.*

MATERIALS AND METHODS

The technology adaptation work that CLAYUCA has done during the last four years, has been implemented in three different regions of Colombia. **Table 5** describes the types of soils and the varieties used in each region. Different planting distances and plant densities were tested, ranging from 48,000 to 112,000 plants per ha with periodical harvests every three monts. Parameters evaluated included fresh and dry foliage weight, as well as crude protein, crude fiber, fat and ash contents.

Table 4. Nutritional quality of cassava foliage.

Component	Leaves	Leaves and petioles	Leaves, petioles and stems
Crude protein %	22.7	21.6	20.2
Ash %	10.9	9.8	8.5
Ether extract %	6.3	6.3	5.3
Crude 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

Source: *Van Poppel, 2001, reported by Buitrago et al., 2001.*

Table 5. Type of soils, and cassava varieties and plant population used in the cassava foliage technology adaptation research conducted in three regions of Colombia.

Region	Type of soil	Varieties used	Plant population (plants/ha)	Period (months)
Santander de Quilichao (Cauca)	clay	CMC-92	62,500	24
Ayapel (Cordoba)	sandy clays	CMC 4843-1	112,000	12
Buga (Valle)	calcareous clay	CM 2758	112,000	24
Buga (Valle)	calcareous clay	CM 523-7	112,000	24
Caicedonia (Valle)	sandy clays	CM 2737	112,000	24
Candelaria (Valle)	-	HMC-1	48,000	11

RESULTS

CIAT (1985) and Cadavid (2002), working under conditions of clay type soils in Colombia, and using plant densities ranging from 20,000 to 62,000 plants/ha reported yields of dry foliage of around 24 t/ha, with seven periodic harvests, every three months, over a 2-year period (**Table 6**).

Table 6. Production of fresh cassava foliage (t/ha) with the cultivar CMC 92 (Algodona) in soils of Santander de Quilichao, Cauca, Colombia with a planting density of 62,500 plants/ha , during a 2-year growing cycle.

	Age (months) at cutting							Total yield (t/ha)
	3	6	9	12	15	18	24	
Fresh foliage (t/ha)	24.5	5.0	15.0	6.0	8.6	16.8	8.7	84.6
Crude protein (%)		24.8	13.6	22.7	20.2	17.4	14.8	
Crude fiber (%)		20.8	34.4	16.1	22.9	31.6	32.7	
Ash (%)		6.4	4.8	4.3	5.3	3.2	3.8	

Source: *Cadavid, L., personal communication, 2002.*

Climatological factors are very important, especially rainfall. When the cassava plant tops are harvested, the growth of the plant suffers a stress period and the availability or lack of a following rainfall period determines to a large extent the recovery of the plant and the subsequent production of acceptable foliage yields. This effect of rainfall was demontrated recently in a trial conducted in the region of Ayapel, Cordoba, Colombia, in a sandy clay soil, with average temperature of 27 ^{0} C and average annual rainfall of 2,600 mm (**Figure 1**). It can be seen that during the dry months, the growth of the plant almost stopped, but the plants did not die. When it started to rain again, the plants recovered and achieved again acceptable yields. The time of planting and of the successive harvests, in relation with the rainfall distribution, becomes a critical factor in the yields obtained in cassava leaf production systems.

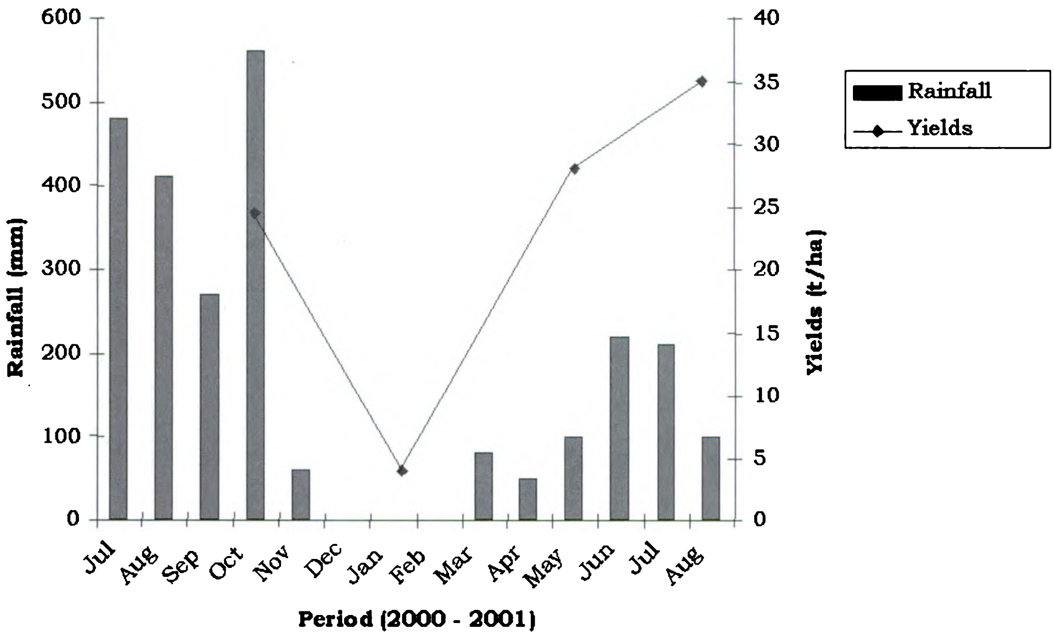

Figure 1. Effect of precipitation on the yield of fresh cassava foliage of cv CM 4843-1 in Ayapel, Córdoba in 2001/02.

In other trials conducted by CLAYUCA in various regions of Colombia, the varietal effect as well as the effect of plant age at harvest were analyzed. The results are presented in **Tables 7, 8, 9** and **10**. In general, it can be observed that in some regions, leaving the crop for two consecutive years in the field, is not a very good option. The yields obtained were the same as those obtained in another location in just one cropping cycle. The low yields obtained could be due to the fact that the varieties used were not adapted very well to consecutive harvests and high planting densities.

Using high planting densities (112,000 plants/ha) makes the leaf harvest very difficult and the plants are damaged by the workers that have to enter the plots to harvest. Seeking an alternative planting arrangement, another trial was conducted using a different planting density, in a region with better climatic conditions. **Table 11** presents the results obtained in Candelaria, Valle de Cauca. It can be observed that with only 11 months of growing period and three harvests, almost 100 t/ha of fresh cassava foliage were obtained. The planting density used was low (48,000 plants/ha), which facilitates the mechanization of the harvest operation, thus reducing the total cost of cassava foliage production.

Table 7. Production of fresh cassava foliage of cv CM 4843-1 in sandy clay soils of Ayapel, Córdoba, Colombia, with a planting density of 11,2000 plants/ha and a growing cycle of 12 months.

	Age (months) at cutting				
	3	6	9	12	**Total**
Fresh foliage (t/ha)	24.45	4.80	27.20	34.96	**91.4**
Crude protein (%)		18.6	22.2	11.8	

Source: *Adapted from Rosero, 2002.*

Table 8. Production of fresh cassava foliage of cv CM 2758 (Parrita) in calcareous clay soils of Buga, Valle, Colombia, with a planting density of 112,000 plants/ha and a growing cycle of 24 months.

	Age (month) at cutting							**Total**
	3	6	9	12	18	21	24	
Fresh foliage (t/ha)	8.87	25.60	12.99	10.02	8.95	8.82	7.76	**83.01**
Crude protein (%)	16.4	14.6	12.0	8.9	14.6	12.1		
Crude fiber (%)	21.5	27.4	26.3	21.9	20.3	26.0		

Source: *Completed and adapted from Rosero, 2002.*

Table 9. Production of fresh cassava foliage of cv CM 523-7 (Catumare) in calcareous clay soils of Buga, Valle, Colombia, with a planting density of 112,000 plants/ha and a growing cycle of 24 months.

	Age (months) at cutting							
	3	6	9	12	18	21	24	**Total**
Fresh foliage (t/ha)	7.31	21.88	14.12	9.44	12.37	12.11	9.58	**86.81**
Crude protein (%)	17.5	17.0	12.0	11.9	14.2	10.6		
Crude fiber (%)	25.1	25.9	28.1	19.2	22.2	23.1		

Source: *Adapted from Rosero, 2002.*

Table 10. Production of fresh cassava foliage of cv MCol 2737 (Brasilera) in calcareous sandy clay soils of Caicedonia, Valle, Colombia, with a planting density of 112,000 plants/ha and a growing cycle of 24 months.

	Age (months) at cutting							
	3	6	9	12	18	21	24	**Total**
Fresh foliage (t/ha)	16.7	23.1	11.7	5.1	11.1	15.3	19.9	**102.9**
Crude protein (%)	14.2	12.6	10.5	13.6	18.5	17.5		
Crude fiber (%)	35.2	35.5	35.5	24.6	27.6	25.1		

Source: *Adapted from Rosero, 2002.*

Table 11. Production of fresh cassava foliage of cv HMC 1 in Candelaria, Valle, Colombia, with a planting density of 48,000 plants/ha and a growing cycle of 11 months.

	Age (months) at cutting			
	3	7	9	**Total**
Fresh foliage (t/ha)	18.0	53.5	26.7	**98.2**
Crude protein (%)	26.7	18.3	20.5	
Crude fiber (%)	29.6	32.0	25.9	
Fat (%)	5.5	4.8	4.3	

Source: *CLAYUCA, 2002. (unpublished data)*

The results obtained in this trial conducted in a region with good quality soils and a good rainfall distribution give an idea of the potential that this type of arrangement can have for a sustainable, profitable production of cassava foliage. Fresh foliage yields of almost 100 t/ha per season are excellent. This particular trial was planted with a plant spacing of 70 cm between rows and 30 cm between plants, an arrangement that facilitates mechanization of the harvest operations. Another important result of this trial was the reduction of the number of stakes to be planted, a time and money consuming operation, with a consequent reduction in total production costs.

A topic that has to be considered with extreme caution in the promotion of intensive cassava leaf production systems is the fertility management of the soils. This factor is critical, especially in soils that are not very fertile. It is a well-known fact that high yields of cassava foliage result in a high nutrient extraction from the soil, especially nitrogen, potassium and calcium (Cadavid, 2002). It is therefore necessary to make specific adjustments to the fertilization of the soils when the area is used for intensive cassava leaf production. These adjustments can not be the same ones that are used for production of cassava roots.

In the trial conducted in Candelaria, Valle, Colombia (**Table 11**), the amount of nutrients extracted after each cutting was determined. **Table 12** indicates that for each tonne of fresh cassava foliage harvested, 8.42 kg of N were removed, whereas in the case of cassava root production, the removal is around 4.42 kg of N (Cadavid, 2002).

This information is important for the determination of fertility management practices in intensive cassava foliage production systems; if not properly managed, the high extraction of nutrients in several succesive leaf harvests could make the production system unsustainable.

Another important aspect in the establishment of intensive cassava foliage production systems is the cost of labor. If the harvest is done using manual labor, the costs of cassava foliage per tonne could be very high. Almost 25 man-days are required per hectare for each cutting. One option is the mechanization of the harvests. There are various types of mechanical cutters that can be used for this purpose. CLAYUCA has tested some of these machines and the best results have been obtained with a mechanical slicer (**Photos**

1 and 2), that can be attached to a tractor and allows regulation of the cutting height. Also, the foliage is cut, chopped and discharged into a trailer in one single operation.

Table 12. Concentration and content of nutrients in the harvest of three cuts of foliage of variety HMC-1 grown in Candelaria, Valle, Colombia were planted at 48,000 plans/ha.

	Nutrient concentration (%)						Nutrients removed (kg/ha)					
Age at cutting	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
3 months	4.27	0.32	2.28	1.70	0.47	0.29	230.6	17.3	123.1	91.8	25.4	15.7
7 months	2.92	0.36	1.99	1.25	0.42	0.24	307.5	37.9	209.5	131.6	44.2	25.3
9 months	3.28	0.36	1/82	1.40	0.54	0.24	178.8	19.8	100.1	77.0	29.7	13.2
Total							716.9	75.0	432.7	300.4	99.3	54.2
Mean extraction per tonne fresh forage harvested							**8.42**	**0.80**	**4.83**	**3.48**	**1.12**	**0.61**

Source: *CLAYUCA, 2002*

CONCLUSIONS

1. Cassava foliage is a good alternative resource for balanced animal feeds, due to its high content of crude protein.
2. High planting densities (between 50,000 to 112,000 plants/ha) could be employed for intensive cassava foliage production systems, depending on factors such as plant type, fertility of the soils, and the rainfall pattern.
3. Fresh cassava foliage yields could be as high as 100 tonne per ha per year depending on the fertility of the soil and rainfall.
4. Harvest intervals could be reduced to 45-60 days after the first cut, which is made when the plants are three months old.
5. High removal of nutrients in the foliage harvests, especially N and K, makes it necessary to increase the application of these nutrients in intensive cassava foliage production systems.

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Photo 1. Mechanized harvesting of cassava foliage.

Photo 2. Cassava field after the mechanical harvest, Candelaria, Valle, Colombia.

CASSAVA LEAF PRODUCTION RESEARCH IN CHINA

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ABSTRACT

Cassava leaves are a very important protein source, and the yield of fresh stems and leaves can be as high as that of fresh roots in many varieties. How to increase cassava leaf production and use it as a forage for animal feeding? Eleven high-yielding clones that have been recommended for root production were evaluated to select the best cassava varieties for forage use. In addition, various agronomic practices were also evaluated using the orthogonal experimental method.

The results showed that two new clones, ZM9036 and ZM8639, were equal to, and/or exceeded, the control variety SC 205 in the main agronomic characteristics, such as the yield of roots, young stems and leaves, their crude protein content, as well as wind-resistance. Pruning during the crop cycle (at 4-8 months after planting) had a significant negative effect on cassava root yield. The earlier the plants were pruned, the lower the root yield. However, pruning not only increased substantially the dry matter and crude protein yield of young stems and leaves, but it also improved the wind resistance of the plants.

INTRODUCTION

Cassava is the fifth most important crop in southern China, following rice, sweetpotato, sugarcane and maize. It is used mainly as animal feed and for starch manufacturing, which both play an important role in the upland agricultural economy. Also, cassava leaves are a very important protein feed resource, the fresh yield of young stems and leaves is often equal to the fresh root yield in many varieties. However, cassava leaves are seldom used in China. The objective of the research, therefore, was to find ways to increase cassava leaf production and to use it as a forage for animal feeding by evaluating a number of cassava varieties for forage production.

MATERIALS AND METHODS

Varieties and breeding lines were selected from the existing clones with high root yield and high total biomass production, in comparison with the local variety, SC 205:

V_1 = ZM 8229	V_5 = SM 1592-3	V_9 = SM 1860
V_2 = ZM 9111	V_6 = SM 1595-2	V_{10} = ZM 9266
V_3 = ZM 9036	V_7 = SM 1113-1	V_{11} = ZM 9057
V_4 = ZM 8639	V_8 = SM 1542-3	V_{12} = SC 205(check)

These 12 clones were planted in 72 plots using an orthogonal experimental design with three plant spacings:

S_1 = 60x60 cm
S_2 = 80x80 cm
S_3 = 100x100 cm

Combined with three levels of application of 15:15:15 compound fertilizers:

F_1 = 225 kg/ha
F_2 = 450 kg/ha
F_3 = 900 kg/ha

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And three dates of pruning of young stems with leaves and petioles (hereafter called "leaves")

P_1 = at 4 months after planting
P_2 = at 5 months after planting
P_3 = at 8 months after planting (just before root harvest);

This resulted in 36 treatments with 2 replications. The plot size was 4x5m.

RESULTS

Statistical analysis of the results, shown in **Tables 1, 2** and **3,** indicate that there were no significant differences among cassava varieties in terms of fresh root yield, dry root yield or crude protein content of "leaves", but there were highly significant differences among varieties in terms of root dry matter content, dry leaf yield and crude protein yield of those "leaves". Time of pruning had a significant effect on cassava fresh and dry root yields, but not on the dry matter content of the roots; the earlier plants were pruned, the lower the fresh and dry root yields. For practically all varieties, highest root yields were obtained when plants were pruned just before the root harvest at 8 months after planting (MAP). For some varieties pruning at 4 MAP had very little effect on final root yield, but for other varieties root yields were reduced as much as 60%. On average, fresh root yields were reduced by 37% when plants were pruned at 4 MAP, and by 24% when pruned at 5 MAP. However, pruning at either 4 or 5 MAP significantly increased the dry "leaf" yield, the crude protein content of those "leaves" and the crude protein yield of the "leaves". Pruning at 5 MAP produced the highest dry "leaf" yields and protein yields, but the protein content were slightly higher in "leaves" harvested at 4 MAP. Pruning plants just before the root harvest resulted in "leaves" with very low protein contents, and thus a low protein yield.

Data shown in **Table 3** indicate that plant spacing had only a statistically significant effect on the "leaf" protein content and protein yield. The intermediate spacing of 80x80 cm resulted in the highest "leaf" protein content and protein yield. Other measured yield parameters were not significantly affected by plant spacing. The rate of application of 15-15-15 fertilizers had a signification effect on the dry "leaf" yield, "leaf" protein content and protein yield, but not on any of the three measured root yield parameters. The intermediate level of 450 kg/ha of 15-15-15 fertilizers produced the highest " leaf" yield, protein content and protein yield; this was followed by the highest level of application of 900 kg/ha of 15-15-15 **(Table 3**).

All factors also had a significant effect on plant wind resistance. However, pruning time had the closest relation to wind resistance.

DISCUSSION

1. The results showed that two new clones, ZM9036 and ZM8639, were equal to and/or exceeded the control variety SC205 in the main agronomic characteristics, such as yield of roots and young stems and leaves, "leaf" crude protein content, and wind-resistance.
2. Pruning at 4 or 5 MAP significantly reduced cassava root yields. The earlier the plants were pruned, the lower the root yields. However, pruning not only increased substantially the yield of young stems and leaves and their crude protein contents, but also improved the

wind resistance of the plants.

3. This trial is a preliminary study, there are many tests to be done in the future.

Table 1. Effect of cassava variety (V) and time of pruning (P) of young plant tops on the fresh and dry root yield and root dry matter content in a leaf production experiment conducted at CATAS, Danzhou, Hainan, China in 2000/01.

	Fresh root yield (t/ha)				Root DM content (%)				Dry root yield (t/ha)			
Variety	P_1[1)]	P_2[1)]	P_3[1)]	Av.	P_1	P_2	P_3	Av.	P_1	P_2	P_3	Av.
V_1	12.5	9.5	15.3	**12.4**	31.9	31.8	31.4	**31.7cd**	3.99	3.02	4.81	**3.94**
V_2	31.3	30.8	42.8	**35.0**	31.7	30.3	30.0	**30.7cd**	9.91	9.34	12.85	**10.70**
V_3	15.0	16.3	32.5	**21.3**	31.4	32.3	33.6	**32.4bc**	4.72	5.27	10.91	**6.97**
V_4	15.8	33.8	40.5	**30.0**	26.9	28.8	25.7	**27.2cd**	4.25	9.74	10.42	**8.14**
V_5	27.0	24.5	29.3	**26.9**	32.8	31.3	32.9	**32.3bc**	8.86	7.67	9.63	**8.72**
V_6	18.5	18.0	33.3	**23.3**	32.3	30.2	30.4	**31.0cd**	5.97	5.45	10.12	**7.18**
V_7	14.3	14.8	22.3	**17.1**	35.0	30.9	34.6	**33.5abc**	5.00	4.57	7.72	**5.76**
V_8	20.3	24.8	37.8	**27.6**	32.2	35.5	33.8	**33.8abc**	6.53	8.82	12.78	**9.38**
V_9	19.8	20.3	23.3	**21.1**	32.7	31.0	31.4	**31.7cd**	6.48	6.30	7.32	**6.70**
V_{10}	15.8	23.5	24.0	**21.1**	33.4	34.0	34.8	**34.0abc**	5.28	7.98	8.34	**7.20**
V_{11}	14.5	29.5	28.5	**24.2**	30.3	31.3	31.3	**31.0cd**	4.40	9.23	8.93	**7.52**
V_{12}	15.3	24.8	30.5	**23.5**	34.0	33.3	32.4	**33.2abc**	5.20	8.25	9.89	**7.78**
Av.	**18.3bc**	**22.6bc**	**30.0a**	**23.6**	**32.0**	**31.7**	**31.9**	**31.9**	**5.88c**	**7.14b**	**9.48a**	**7.50**
f-test Variety (V)				NS				**				NS
Pruning time (P)				*				NS				*

[1)] P_1 = young tops pruned at 4 MAP; P_2 = at 5 MAP; P_3 = at 8 MAP (before root harvest).

Table 2. Effect of cassava variety (V) and time of pruning (P) of young plant tops on the dry yield of young stems and leaves, their crude protein content and the protein yield in a leaf production experiment conducted at CATAS, Danzhou, Hainan, China in 2000/01.

	Dry yield of leaves+stems (t/ha)				Protein content (%)				Protein yield (t/ha)			
Variety	P_1[1)]	P_2[1)]	P_3[1)]	Av.	P_1	P_2	P_3	Av.	P_1	P_2	P_3	Av.
V_1	2.37	5.00	2.96	**3.44bcd**	18.69	17.39	12.90	**16.33**	0.43	0.87	0.39	**0.56bc**
V_2	2.02	2.65	1.80	**2.16cd**	17.30	20.24	15.76	**17.77**	0.37	0.54	0.28	**0.40c**
V_3	4.05	5.36	3.94	**4.45abcd**	17.50	18.88	12.50	**16.29**	0.73	1.01	0.56	**0.76abc**
V_4	3.60	6.78	4.99	**5.12abcd**	16.54	17.51	12.47	**15.51**	0.59	1.17	0.66	**0.81abc**
V_5	2.93	5.44	1.84	**3.40bcd**	16.93	14.05	15.88	**15.62**	0.53	0.73	0.32	**0.53bc**
V_6	2.47	3.33	1.75	**2.52cd**	20.11	19.11	15.46	**18.23**	0.47	0.50	0.26	**0.41c**
V_7	1.62	2.24	1.79	**1.88cd**	21.30	19.81	13.20	**18.10**	0.32	0.56	0.25	**0.38c**
V_8	1.94	3.16	1.78	**2.29cd**	20.63	16.83	15.50	**17.65**	0.40	0.51	0.27	**0.39c**
V_9	2.67	2.99	2.24	**2.63bcd**	18.84	18.97	13.98	**17.26**	0.50	0.53	0.29	**0.44c**
V_{10}	3.12	2.93	1.64	**2.56cd**	20.91	19.85	11.62	**17.46**	0.65	0.56	0.20	**0.47bc**
V_{11}	2.50	3.28	3.08	**2.95bcd**	16.27	17.55	14.26	**16.03**	0.43	0.55	0.43	**0.47bc**
V_{12}	2.44	2.60	1.17	**2.07cd**	16.85	18.74	11.75	**15.78**	0.41	0.49	0.14	**0.35c**
Av.	**2.64bc**	**3.81ab**	**2.42c**	**2.96**	**18.49ab**	**18.24ab**	**13.77c**	**16.84**	**0.49ab**	**0.67ab**	**0.34b**	**0.55**
f-test Variety (V)				**				NS				**
Pruning time (P)				**				**				**

[1)] P_1 = young tops pruned at 4 MAP; P_2 = at 5 MAP; P_3 = at 8 MAP (before root harvest).

Table 3. Effect of plant spacing (S) and fertilizer rates (F) on dry yield of cassava leaves + stems, on crude protein content and on protein yield in a leaf production experiment conducted at CATAS, Danzhou, Hainan, China in 2000/01.

Spacing	Dry "leaf" yield (t/ha)	"Leaf" protein content (%)	"Leaf" protein yield (t/ha)	Fertilizer	Dry "leaf" yield (t/ha)	"Leaf" protein content (%)	"Leaf" protein yield (t/ha)
S_1	2.95	15.45 c	0.46 a	F_1	2.65 de	15.82 c	0.42 b
S_2	3.04	17.95 abc	0.54 a	F_2	3.27 abc	17.74 abc	0.57 b
S_3	2.88	17.10 bc	0.49 a	F_3	2.96 c	16.95 bc	0.51 b
f-test	NS	**	**		**	*	**

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CASSAVA LEAF PRODUCTION RESEARCH IN VIETNAM

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ABSTRACT

Cassava is an annual root crop and it provides food for hundreds of millions of people in the tropical and sub-tropical areas of the world. The crop has a reputation of producing high yields and being tolerant to poor soil. The yield of dry cassava leaves, also known as cassava "hay", which includes the young stem and leaves, can be quite high if the crop is pruned every 2-3 months. This "hay" is a good source of protein and also contains many nutrients such as nitrogen, phosphorus, potassium, calcium and magnesium.

Experiments on the production of cassava hay have been conducted in Hung Loc Agricultural Research Center and at Hue University with the purpose of determining cassava hay yield by four different varieties as affected by different planting densities. The results of this research indicate that:

-among four cassava varieties, the new line KM 140-2 produced both the highest cassava root and hay yield.

-between two plant populations used, the population of 22,222 plants/ha (0.9 x 0.5 m plant spacing) resulted in the highest cassava hay yield.

INTRODUCTION

In Vietnam the roots of cassava are an important source of energy for human consumption and in animal feeding. However, the young foliage, including the green stem, leaves and petioles, cut two or three times at 15-20 cm above the ground can become an important and cheap source of protein for animal feeding.

This research was undertaken to identify the best varieties and plant spacing for maximizing both root and forage yields as well as the economic benefits for farmers.

MATERIALS AND METHODS

Four cassava varieties, i.e. KM94, KM140-2, KM98-5 and SM937-26, were planted at two spacings of 0.9x0.9 m and at 0.9x0.45 m. Treatments were arranged in a split-plot design with varieties in main plots and plant spacing in subplots. Thus, there were in total eight treatment combinations.

Young tops of cassava, including leaves, petioles and green stem were cut three times: at five and seven months after planting and at time of root harvest. Cassava tops were harvested by breaking the stems at 15 cm above the ground. Fresh weight of tops was measured and samples were taken for dry matter determination and chemical analysis.

CONCLUSIONS

Based on the results of the experiment (**Tables 1and 2**) it was found that plant spacing and varieties both had significant effects on cassava root yield, and cassava dry forage yield as well as on net income. Among the four cassava varieties, KM140-2 produced the highest root yield but KM98-5 produced the highest forage yield and net income at both plant spacings. Between the two plant spacings, the narrower spacing of

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0.45x0.90 m (= 24,690 plants/ha) resulted in higher cassava forage yields than the wider spacing at 0.90x0.90 m (= 12,345 plants/ha).

Table 1. Effect of plant spacing on the fresh root and total dry forage yield, as well as the total amounts of N, P and K removed in the leaf harvest when four cassava varieties were planted at Hung Loc Agricultural Research Center in Dong Nai, Vietnam in 2001/02.

Treatments[1)]	Fresh root yield (t/ha)	Total dry forage yield (t/ha)	N	P (kg/ha)	K
S-1 - KM 94	8.68	4.63	181.5	12.1	63.2
- KM 98-5	7.91	5.33	216.4	13.1	97.3
- KM 140-2	11.29	3.39	87.8	6.1	61.8
- SM 937-26	8.49	3.79	151.2	9.3	70.8
S-2 - KM 94	8.39	9.17	359.5	24.0	125.3
- KM 98-5	7.33	9.74	395.4	23.0	177.8
- KM 140-2	9.22	6.86	177.7	12.3	130.9
- SM 937-26	5.88	7.37	294.1	18.0	137.6

[1)] S-1 = spacing at 0.90x0.90 m; S-2 = spacing at 0.90x0.45 m.

Table 2. Effect of plant spacing on the fresh root and total dry forage yield, as well as the gross and net income obtained when four cassava varieties were planted at Hung Loc Agricultural Research Center in Dong Nai, Vietnam in 2001/02.

Treatments[1)]	Fresh root yield (t/ha)	Total dry forage yield (t/ha)[2)]	Gross income[3)]	Production costs[4)] ('000 dong/ha)	Net income
S-1 - KM 94	8.68	4.63	10,764	6,723	4,041
- KM 98-5	7.91	5.33	11,475	6,723	4,752
- KM 140-2	11.29	3.39	10,053	6,723	3,330
- SM 937-26	8.49	3.79	9,421	6,723	2,698
S-2 - KM 94	8.39	9.17	17,447	9,323	8,124
- KM 98-5	7.33	9.74	17,835	9,323	8,512
- KM 140-2	9.22	6.86	14,347	9,323	5,024
- SM 937-26	5.88	7.37	13,642	9,323	4,319

[1)] S-1 = spacing at 0.90x 0.90 m; S-2 = spacing at 0.90x0.45 m.

[2)] The unlignified upper part of the stem with leaves and petioles were cut two times during the growing cycle as well as at harvest; dry forage is the sum of these 3 cuts after drying.

[3)] Prices: cassava dong 440/kg fresh roots
cassava dry forage 1,500/kg

[4)] Labor costs cassava production S_1 3.1 mil. dong/ha
S_2 4.0 mil. dong/ha
Planting material: S_1 = 12,345 plants/ha 0.5 mil. dong/ha
S_2 = 24,690 plants/ha 1.0 mil. dong/ha
Labor for leaf cutting (3x): S_1 1.2 mil. dong/ha
S_2 2.4 mil. dong/ha
Fertilizer costs: 175 N+ 75 P_2O_5 +75 K_2O /ha 1.623 mil. dong/ha
Labor for fertilizer application (3x) 0.3 mil. dong/ha

CASSAVA LEAVES AND FORAGE CROPS FOR RUMINANT FEED IN THE ESTABILISHMENT OF SUSTAINABLE CASSAVA FARMING SYSTEMS IN INDONESIA

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ABSTRACT

Most of the cassava production areas in Indonesia are on marginal soils, which are characterized by a low content of nutrients and organic matter, and are susceptable to erosion. Increasing the nutrients and organic matter content as well as controlling erosion is needed to maintain soil productivity. Soil erosion, the main cause of soil degradation, could be reduced effectively by such cultural practices as contour ridging, the planting of contour hedgerows of forage crops, and intercropping cassava with upland rice or peanut. The organic matter content of soil could be increased by applying organic fertilizers such as cattle manure and mulch. Contour hedgerows of forage crops planted in cassava fields will reduce erosion effectively, while the pruning of the forage crops is a potential source of feed for ruminants. Using the prunings of forages of *Gliricidia, Leucaena*, elephant grass, and the residues of food crops such as cassava leaves, cassava root skin, rice straw and maize stalks as feed of ruminants is able to increase their weight significantly. The ruminants are main organic manure producers and are used for soil preparation. Therefore, the development of this integrated crop-livestock system is advised to maintain soil fertility and increase its productivity. On the other hand, the production of cassava leaves, which is estimated to be 1.5 million tonnes per year, is an excellent protein supplement in the rations of ruminants. The main problems of cassava leaves are their low neutral-detergent fiber (NDF) and hight HCN contents. NDF can be increased by supplementing with elephant grass or napier grass, while HCN can be reduced by chopping the harvested leaves and letting them wilt for 24 hours before feeding.

INTRODUCTION

Most cassava production areas in Indonesia are located on marginal mountainous soil on Java island and undulating Ultisols of the other islands. These soils are characterized by their low contents of nutrients and organic matter; they also tend to be susceptible to erosion (Wargiono,1995). Erosion and the low contents of nutrients and organic matter are the main factors affecting the productivity of crops. Therefore, controlling erosion by growing contour hedgerows of forage crops and increasing both soil nutrients and organic matter by establishing integrated crop-livestock systems is the way to maintain the sustainability of cassava-based farming systems. Most farmers in these areas have limited capital and labor; it is estimated that they have on average 1.1 to 2.2 ruminants/household (**Table 1**).

A cheap and effective way of controlling erosion, suitable for most soils and farmers, is the planting of contour barrier strips of grasses such as elephant grass, vetiver grass, napier grass, or the planting of contour hedgerows of *Leucaena* and *Gliricidia*. Another advantage of these practices is that grasses and prunings of *Leucaena* and *Gliricidia* can be used for either ruminant feeding or for mulch, which is able to supply aditional N to the crops and inprove the soil organic matter content as well as their physical characteristics (Wargiono, 1995).

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Table 1. Ruminant population and amount of cassava leaves used for feed per farmer household[1] in several regions of Indonesia.

Regions	Ruminant [2] population (animal/family)	Cassava leaf production (kg/family)
Sumatera	1.4	114
Java	1.1	98
Bali + Nusa Tenggara	2.2	158
Kalimantan	0.3	61
Sulawesi	1.5	89
Maluku & Irian	1.0	151

[1]Farmer households are asumed to be 60% of all households
[2]Consists of cattle, buffalo, goat and sheep
***Source:** CBS, 2000.*

Ruminants are useful as producers of manure, they also function as a household bank and some are used for soil preparation. Ruminants fed with elephant grass, napier grass, prunings of *Leucaena* and *Gliricidia* as well as cassava leaves increased their daily weight gain (Budiman and Djamal, 1994; Ludgate and Scholz, 1992). Increasing the daily weight gain of ruminants depends on the year-round availability of forage crops. The better the availability of the feed, the greater the weight gain. The higher the weight gain of the ruminants, the greater the production of manure and therefore, the more manure can be applied to cassava. By applying this manure annually, it is possible to maintain a low external input integrated cassava-livestock farming system.

Applying ruminant manure increases the yield of cassava leaves and thus the amount of protein supplement in the ration of ruminant feed, as the protein content of cassava leaves is higher than that of other forage crops (Ludgate and Scholz, 1992). More than 70% of cassava leaves are used for ruminant feeding in Indonesia (Sudaryanto, 1992). Cassava fresh leaf production, estimated at 5.7 million tonnes/year in Indonesia (BPS, 2000), will be a potentially important protein source for ruminants in the next decade.

Cassava Leaves as a Protein Feed Supplement for Ruminants

1. Potential and Production of Cassava Leaves

The actual yield of cassava leaves depends on the way these leaves are harvested. Maximum stem growth is at six months after planting, after which DM accumulation is redirected from growing stems and leaves to that of roots (Wargiono, 1986). As a new leaf is initiated every two days, therefore, four leaf blades/plant can be harvested a week during 3 to 4 months when plants are 3 to 7 months old, without any reduction in root yield (Sugito, 1990; Sudaryanto, 1992). By estimating an average plant population of 8,000 plants/ha, a harvested area of 1.275 million ha and a weight of each four leaf blades of 15 grams (harvested at weekly intervals for 4 months between 3 and 7 months old of 10 varieties at Bogor, W. Java), about 2.4 million tonnes of cassava leaves can be harvested during that period. Stem and leaf production decreases steadily after the seventh month (Hozyo, 1984); so, harvesting four leaf blades weekly after 7 months is not recommended, because it can reduce root yields.

The population of large ruminants in Indonesia (cows, buffaloes and horses) is about 15 million, while that of small ruminants (goats and sheep) is about 16.3 million

(BPS, 2000). Based on that ruminant population and estimating that farmers' households comprise about 60% of the total number of households, indicates that each farmers' household has between 1.0 to 2.2 ruminants. **Table 1** shows that cassava leaf production is not in line with the number of ruminants per farmer's household. Demand for cassava leaves is generally higher than production, so we have to find a way to increase cassava production or substitute cassava leaves with other forage crops.

Harvesting leaves + young stems for ruminant feeding at nine months after planting or later yielded about 20.2% of root yield weight. Using this ratio the estimated amount of harvested leaves will be 3.5 million tonnes, with the availability of those leaves per household varying from 13 to 223 kg in the various provinces. It means that production of cassava leaves should be increased as demand increases, or other forage crops that can be used as potential protein supplements, such as *Leucaena, Sesbania, Calliandra* and peanut, should be established.

2. Nutritive Value of Cassava Leaves

The protein content of cassava leaves is affected by the variety used and its age (**Table 2**). The protein content of young leaves (five blades starting from the top) varied from 24.7% to 35.5%, while for older leaves this varied from 20.2% to 30.8% (Ludgate and Scholz,1992). The protein content of leaves + petiole + young stem of Adira-1 was 23.4% (Sudaryanto, 1992). This protein content is lower than the average protein content of old and young leaves as reported by Ludgate and Scholz (1992).

Table 2. Protein content of young and old cassava leaves, Bogor 2002.

	Crude protein content (%)	
Varieties	Young leaves	Old leaves
Adira-1	35.86	30.79
Adira-4	32.12	30.23
No.50.2	32.86	23.88
No.39.1.1	33.12	27.17
No.40.3.3	24.68	20.16
BIC 319	33.09	26.53
BIC 317	33.35	29.14
BIC 323	32.20	28.68
BIC 109	32.69	27.07
BIC 137	35.49	28.61

Source: *Ludgate and Scholz, 1992.* Harvesting leaves at 8 months old.

The main problem of cassava leaves used for ruminant feed is their low level of neutral-detergent fiber (NDF) and high HCN. Therefore, the daily weight gain of ruminants fed only with cassava leaves is lower as compared to that of cassava leaves supplemented with high NDF feed. Supplementing cassava leaves with high NDF feed such as native grass, elephant grass and rice straw is one way to increase the NDF content in the ration. **Table 3** shows that supplementing cassava leaves with other feed of high NDF content, and using cassava leaves as a supplement to increase the protein intake, increased the ruminant weight effectively.

Table 3. The effect of using cassava leaves as main feed or as suppliment on the daily weight gain of sheep in Indonesia.

Ration	Daily weight gain(g)
Native grass	4
Cassava leaves	-8
Native grass + cassava leaves	31
Elephant grass + cassava leaves	67
Rice straw + cassava leaves	92

***Source:** Ludgate and Scholz, 1992.*

Ruminants are more prone to HCN poisoning than non-ruminants because rumen microbes produce enzymes that hydrolyze cyanogenic-glycosides and release HCN into the bloodstream (Ludgate and Scholz, 1992). In addition to accute poisoning, chronic poisoning can occur from continuous intake of small amounts of cyanic acid over long periods of time. The lethal dose of HCN was found to be 3 mg/kg body weight (Ludgate and Scholz, 1992), but supplementing small ruminant feed with cassava leaves, where the HCN intake was 15 mg/kg body weight, had no significant effect on dry matter intake and average daily weight gain (**Table 4**) This difference may be because of characteristics of certain animals (some are more tolerant to HCN than others). A practical technology to reduce the HCN content is by chopping the leaves and young stems and letting these wilt for 12-24 hours before feeding.

Table 4. Dry matter and HCN intake, the digestibility of feed components and the average daily weight gain at three levels of cassava leaf meal in the ration of sheep.

	Level of cassava leaf meal		
	0%	20%	30%
Intake			
Dry matter (g/day)	751	716	735
HCN (mg/kg body weight)	-	9.4[a]	15[b]
Digestibility (%)			
Dry matter	55	50	56
Crude protein	49	38	45
Organic matter	59	54	59
Energy	52	45	52
Neutral detergent fiber	60[a]	54[b]	53[b]
Average daily weight gain (g/day)	112	87	109

***Source:** Sudaryanto, 1992.*

Note: Means in the same row with different superscript are significantly different

Forage Crops for Erosion Control and Ruminant Feeding

Since most cassava is grown on soils that are susceptible to erosion, and cassava leaf production is generally less than demand, planting contour hedgerows of forage crops that effectively help to control erosion is a way to meet the additional demand for feed. (Sudaryanto, 1992; Wargiono, 1995).

Common forage crops used for erosion control in cassava production areas are elephant grass, *Sesbania*, *Gliricidia* and *Leucena* as well as interplanted crops under intercropping systems with cassava, such as rice, maize and peanut.

1. Forage Crops for Erosion Control

Most cassava production areas are located in mountainous and undulating areas where erosion can be quite severe. Erosion can be reduced substantially by terracing, minimum tillage and mulching. Erosion control by terracing is very expensive, minimum tillage is not often practiced by farmers because it makes weed control more difficult, while mulch is seldom available as crop residues are mostly used for ruminant feeding. Rice straw can be used either as animal feed during the dry season by farmers having ruminants, or used as mulch for cassava to reduce erosion, control weeds and to maintain soil humidity when it is not used to feed ruminants. For most farmers, ruminants are very useful as manure producers, they function as a family bank and are used for soil preparation. Therefore, a cheaper way to control erosion and which has a double function as ruminant feed, is urgently needed.

One way to control erosion, which is very effective and also produces ruminant feed, is the planting of contour hedgerows of forage crops such as elephant grass, *Sesbania* and *Gliricidia*, or intercropping systems of cassava with maize, rice and peanut (Wargiono, 1995). Contour hedgerows of elephant grass reduced soil losses by erosion at Jatikerto, Malang, E. Java by 31% compared to that without contour hedgerows, while contour hedgerows of *Gliricidia* and *Leucaena* with the pruned leaves used as mulch reduced erosion by 60% and 41%, respectively. Intercropping systems of cassava with rice or peanut reduced erosion about 20% compared to monoculture cassava (Wargiono, 1995).

Returning organic matter into the soil as mulch or as ruminant manure increased both the soil organic matter content and improved the physical characteristics of the soil, thus increasing the productivity of crops. Feeding ruminants with the prunings of forage crops such as *Gliricidia* and *Leucaena* or with straw of interplanted crops increased the daily weight gain of ruminants (Ludgate and Scholz, 1992). Therefore, the more feed is available the more manure is produced and can be applied for cassava, and the higher the productivity of both leaves for feed and roots for food. It means that contour hedgerows of forage crops and the use of intercropping systems can be applied by farmers who have or do not have ruminants.

Table 5 shows the nutrient contents of eroded soil with and without contour strips of grasses and both in monoculture and intercropping systems. The nutrient contents of eroded soil at one month after planting (1/3 of N and K applied) were generally lower than in eroded soil collected at four months (2/3 of N and K applied). This is an indication that the nutrient loss by erosion is relatively higher after fertilizers are applied. It means that using forage crops for erosion control on mountainous and undulating cassava production areas is important for maintaining low external input sustainable agriculture.

Table 5. Nutrient content of eroded soil using different erosion control practices, at 1 and 4 months after planting in Tamanbogo, Lampung in 1999.

Cultural practices[1)]	Eroded soil (t/ha/4 months)	Total nutrients content in eroded soil (%)					
		N		P		K	
		1[2)]	2[2)]	1	2	1	2
Cassava monoculture (CM)	8.86	0.146	0.163	0.008	0.014	0.020	0.018
CM + Vetiver grass (Vg) hedgerows	8.49	0.173	0.169	0.017	0.018	0.013	0.018
CM + Contour strip Vg	8.57	0.171	0.156	0.015	0.022	0.019	0.014
Cassava + Rice + Contour strip Vg	7.84	0.174	0.179	0.012	0.019	0.020	0.020
Cassava + Rice + Contour strip Eg	7.21	0.171	0.178	0.015	0.024	0.022	0.019
Cassava + Peanut + Contour strip Eg	6.68	0.162	0.206	0.020	0.023	0.019	0.019

1) Vg= vetiver grass
Eg = elephant grass
2) 1= a month after P + 1/3 NK applied (1 MAP)
2= a month after 2/3 NK applied (4 MAP)

2. Forage Crops for Ruminants Feed

Table 1 shows that the average ruminant population per household varied from 1.0 to 2.2 animals depending on the province. Ruminants produce manure, they can be sold when the family needs cash, and cattle and buffalos are used for soil preparation. Therefore, farmers need a year-round supply of forage crops or food crop residues to feed their ruminants.

Table 6 shows the effect of various rations on the daily weight gain of goats and cattle. Utilization of native grass, elephant grass, leguminous leaves, *Gliricidia* leaves, and food crop residues to feed ruminants on the outer islands is 40%, 4%, 16%, 21% and 19%, respectively (Sudaryanto, 1992). Native grass used as the main feed should be supplemented with cassava leaves to increase the NDF, or native grass need to be supplemented with *Leucaena* or *Gliricidia* to increase the protein in the ration.

Table 6. Effect of feed ration on the daily weight gain of small and large ruminants.

Ration		Ruminants weight gain (gram/day)	
Main feed	Supplement	Goats	Cattle
Native grass	-	4	-
Native grass	cassava leaves	31	-
Gliricidia	-	80	451
Gliricidia	elephant grass	111	-
Leucaena	-	44	-
Leucaena	native grass	69	470
Leucaena	elephant grass	50	570
Elephant grass	-	53	-
Elephant grass	*Gliricidia*	67	-
Elephant grass	cassava leaves	21	-
Rice straw	*Gliricidia*	-	400
Rice straw	elephant grass	67	470

Source: *Ketaren et al., 1993; Budiman and Djamal, 1994; Ludgate and Scholz, 1992.*

Using *Gliricidia* as the main feed resulted in a daily weight gain of 80 and 451 grams for goats and cattle, respectively. The daily weight gain increased 39% when *Gliricidia* was supplemented with elephant grass. Establishing two contour hedgerows of 50 meter length is enough for farmers having two cows, where *Gliricidia* is the supplement (40%) of elephant grass or rice straw. *Gliricidia* can be harvested every three months. The hedgerow should be maintained at about 0.5 meter height to minimize the shading of cassava planted between hedgerows (Wargiono, 1995).

Leucaena has a high protein content (about 24% on DM basis); therefore, this species is suitable both as a main feed and as a supplement. *Leucaena* use as main feed and supplemented with native grass resulted in a daily weight gain of goats and cows of 69 and 470 grams, respectively. An increase in daily weight gain of cattle of 21% was obtained when *Leucaena* was supplemented with elephant grass. *Leucaena* is mostly planted along the border of their land.

Elephant grass is the most common among these forage crops, especially in Java island. The problem of elephant grass is its low protein content and its strong competitive effect on cassava. Elephant grass as the main feed resulted in daily weight gain of goats of 53 grams, and this increased 26% when the grass was supplemented with *Gliricidia.* Intercrops having by-products that can be used as feed and which also reduce erosion effectively, are rice and peanut. Rice straw as the main feed and supplemented with elephant grass resulted in a daily weight gain of goats and cattle of 67 and 470 grams, respectively. Therefore, rice straw can be used as animal feed during the dry season or it can be used as mulch when not used as feed.

The advantages of planting contour hedgerows of *Gliricidia*, *Leucaena* and elephant grass as well as intercropping cassava with other food crops in an integrated cassava-based crop/livestock farming system are shown in **Figure 1**.

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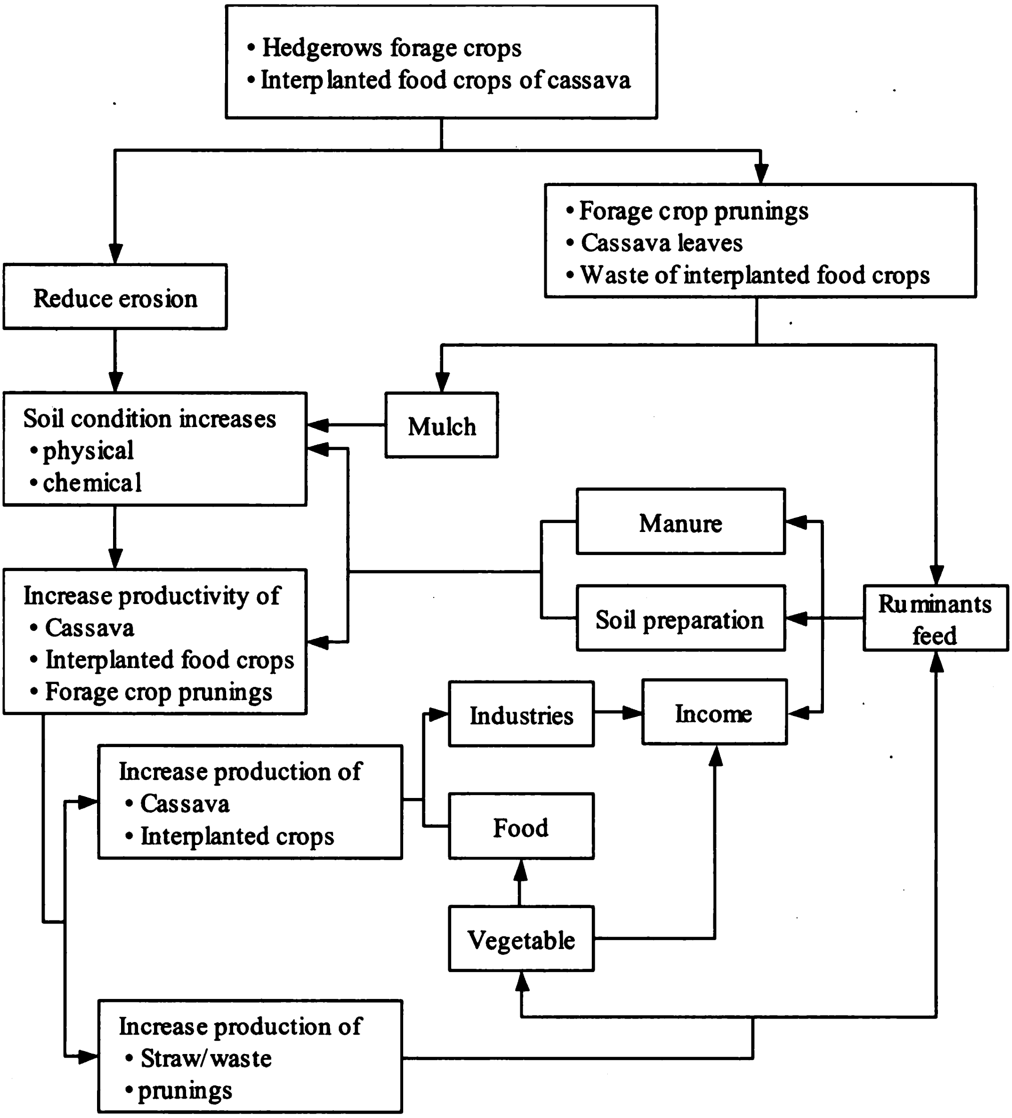

Figure 1. Diagram showing how farmers' income can be increased by an integrated cassava-based crop/livestock farming system.

THE ROLE OF CASSAVA HAY AS ANIMAL FEED

Metha Wanapat[1]

ABSTRACT

Cassava (*Manihot esculenta* Crantz) has been nutritionally evaluated as a protein source for animal feeding. Planting cassava densely and harvesting the unlignified top portion of the plant about 20 cm above the ground at 3-4 months after planting, followed by subsequent harvests every two months for one year could produce high forage biomass. Moreover, intercropping cassava with leguminous crops such us cowpea, peanut or *Leucaena leucocephala* could enrich the soil and further increase cassava leaf biomass. After harvesting, the cassava leaf biomass could be sun-dried for 2-3 days to obtain dry (85% dry matter) cassava forage, also called "cassava hay". Sun drying reduces the hydrocyanic acid content by more than 90% and this results in good quality cassava hay. Cassava hay contains about 25% crude protein with a relatively good profile of amino acids as compared with soybean meal and alfalfa hay. Furthermore, cassava hay contains only 2-4% condensed tannins as compared to more than 6% in mature cassava leaves at time of root harvest. Producing cassava hay as a high-protein fodder is a means of increasing the protein to energy ratio of the whole cassava crop.

Feeding trials with cattle indicate the high levels of dry matter (DM) intake (3.2% of body weight) and high DM digestibility (71%). The hay contains tannin-protein complexes which could act as rumen by-pass protein for digestion in the small intestine. As cassava hay contains condensed tannins, it could have a subsequent impact by changing the rumen ecology, particularly the rumen microbial population. Therefore, supplementation with cassava hay at 1-2 kg/head/day to dairy cattle could markedly reduce the requirements of concentrate and improve the yield and composition of milk. Moreover, cassava hay supplementation in dairy cattle increases the milk thiocyanate content, which could possibly enhance milk quality and milk storage, especially in small-holder dairy farming. Condensed tannins contained in cassava hay have also been shown to reduce gastro-intestinal nematodes in ruminants and therefore could act as an anthelmintic agent. Cassava hay is therefore an excellent multi-nutrient feed resource for animals, and has the potential to increase the productivity and profitability of livestock production systems in the tropics.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an annual root crop grown widely in tropical and sub-tropical areas. It can thrive in sandy-loam soil with low organic matter, receiving low rainfall and high temperatures. It is therefore a cash crop cultivated by small-holder farmers within the existing farming systems in many countries (Wanapat, 1999).

Cassava roots contain high levels of energy and minimal levels of crude protein, and have been used as readily fermentable energy in ruminant rations. Cassava leaves have been used as a protein source when collected at root harvesting time. However, the intake and digestibility was low due to the high level of condensed tannins (Reed *et al.*, 1982; Onwuka, 1992). The role of tannins in tropical animal production has been currently presented (Brooker *et al.*, 2000; Norton, 2000). Harvesting of cassava at an early growth stage (3 months) to make hay could reduce the condensed tannin content and increase the protein content (25% of DM) resulting in a higher nutritive value (Wanapat, 2003; Wanapat *et al.*, 1997).

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Production of Cassava Leaves and Cassava Hay

The studies by Wanapat *et al.* (1997, 2000a, 2000b, 2000c, 2000d) have revealed the details of planting and cassava hay making. Planting cassava for hay making was aimed to increase the whole crop digestible biomass and the roots as a by-product. Earlier work by Wanapat *et al.* (1997) demonstrated that planting cassava at 60x40 cm between rows and intercropping with cowpea or *Leucaena* could enrich soil fertility and the intercrops could be used as food and feed for humans and livestock, respectively. The initial cutting was made at three months and this was followed by subsequent cuttings at two month intervals by breaking of the stem by hand about 20-30 cm above the ground (with 3–5 remaining branches). The fresh tops were directly sun-dried or chopped before sun-drying until a DM content of 80-90%. This might take 2-3 days, but chopping helps to shorten the drying process. Sun-drying also eliminated more than 90% of hydro-cyanic acid (HCN) and enhanced the palatability and long-term storage. Intercropping cassava with leguminous crops such as cowpea could improve soil fertility and provide food for human consumption, while the residue could be used as supplemental feed, especially during the dry season (Polthanee *et al.*, 2001). Plant spacing and frequency of cuttings have been shown to have a significant affect on the combined yield of cassava hay (Petlum *et al.*, 2001). Furthermore, planting pattern, either with or without ridging as well as manure fertilization, could affect cassava hay production (Puangchompoo *et al.*, 2001) (**Table 1**). Protein yield of cassava hay has been reported to range from 1.5–1.7 t/ha from six collective harvests (Wanapat *et al.*, 2002).

Table 1. Effects of planting method and fertilization on cassava hay yield.

	With ridges		Without ridges		
Item	Without manure	With manure	Without Manure	With manure	SEM[1)]
Fresh leaf yield (t/ha)					
First cutting	3.7	4.0	3.8	3.5	0.26
Second cutting	3.1	3.1	3.1	3.3	0.31
Third cutting	6.0	7.7	5.7	7.8	0.54
Fourth cutting	5.6	4.7	5.6	4.6	0.27
Fifth cutting	2.7	3.0	2.8	3.5	0.19
Sixth cutting	0.7	0.8	0.4	0.9	0.11
Total fresh yield	***21.8***	***23.3***	***21.4***	***23.5***	***0.54***
Dry leaf yield (t/ha)					
First cutting	1.1	1.2	1.1	1.1	0.08
Second cutting	1.0	0.9	1.0	1.0	0.09
Third cutting	1.8	2.3	1.5	2.2	0.17
Fourth cutting	1.7	1.4	1.6	1.3	0.08
Fifth cutting	0.9	1.0	0.9	1.1	0.05
Sixth cutting	0.3	0.3	0.2	0.3	0.05
Total dry yield	***6.7***	***7.1***	***6.3***	***7.0***	***0.17***
Crude protein yield (t/ha)	**1.5**	**1.7**	**1.5**	**1.7**	

[1)] SEM = standard error of the mean; there were no significant interactions
Source: *Puangchompoo et al., 2001.*

Table 2 shows the dry matter yield of leaf, petiole and stem when harvested at four months after planting. High levels of DM yield were obtained (Wanapat, 2002, unpublished data).

Table 2. Fresh yield of cassava foliage of Rayong 72[1)] harvested at 4 months after planting at Khon Kaen University, Khon Kaen, Thailand.

		% DM	Fresh weight (g)	Dry weight (g)	% of total cut DM	Dry weight (kg/ha)
Leaf	P1	27.5	16.7	4.6	13.5	120
	P2	30.5	41.9	12.8	37.4	336
	P3	37.9	44.4	16.8	49.1	430
	Total		**103.0**	**34.2**	**61.6[2)]**	**880**
Petiole	P1	14.1	7.7	1.1	9.9	32
	P2	20.4	21.8	4.4	39.6	116
	P3	22.1	25.5	5.6	50.5	142
	Total		**55.0**	**11.1**	**20.0[2)]**	**290**
Stem	P1	10.5	4.5	0.5	4.9	14
	P2	17.4	14.9	2.6	25.5	65
	P3	20.1	35.1	7.1	69.6	185
	Total		**54.5**	**10.2**	**18.4[2)]**	**264**
Grand total			**212.5**	**55.5**		**1,434**

[1)] Cassava tops harvested approximately 40 cm above the ground and separated into three portions:
P1 = light green and reddish colored young leaves, top part
P2 = green leaves, middle part
P3 = dark green leaves, lower part
[2)] Percentage of total biomas/cut
Source: *Wanapat et al., 2002, unpublished data.*

The chemical composition of leaves and hay are presented in **Table 3**. It can be seen that cassava leaves/hay contain high levels of nutrients, especially high levels of protein. Harvesting of tops at an earlier stage, followed by subsequent cuttings at two month intervals resulted in a significantly higher protein to energy ratio **(Tables 3 and 4)**.

Nutritive Value of Cassava Hay

It has been found that cassava hay harvested at a younger stage of growth (three months) had a protein content up to 25% and with a good profile of amino acids. As presented in **Table 3** and **Figure 1**, cassava leaves and cassava hay have relatively high levels of nutrients particularly protein and certain amino acids. Comparing cassava leaves (CL) and cassava hay (CH) with soybean meal (SBM) and alfalfa hay (AH), the amino acid profiles were rather similar. Lysine, glutamine, asparagine and arginine were higher in SBM, but methionine and leucine were higher in CH. Condensed tannins and hydrocyanic acid (HCN) concentrations were low in both CL and CH. Sun-drying remarkably reduced the HCN content (Wanapat *et al.*, 2000a; Wanapat, 2002). Digestibility and intake studies in cattle resulted in relatively high values, which indicate that cassava hay is palatable and highly digestible. Levels of condensed tannins (CT) were generally higher in mature cassava leaves than in cassava hay harvested at a younger stage. Barry and Manley (1984) and Reed (1995) reported that if condensed tannins in the feed exceeded 6% of dry matter, it would reduce feed intake and digestibility. If the level of condensed tannins was between 2 and 4% of DM, it would help to protect protein from rumen digestion and thus increase by-pass protein.

Table 3. Chemical compositions of dried cassava leaves and hay[1].

Item	Dried cassava leaves	Cassava hay
Dry matter, DM (%)	90.0	86.3
	% of DM	
Digestible protein, DP	18.3	22.0
Total digestible nutrient, TDN	60.0	65.0
Crude protein, CP	20-30	25.0
Neutral detergent fiber, NDF	29.6	44.3
Acid detergent fiber, ADF	24.1	30.3
Acid detergent lignin, ADL	4.7	5.8
Ether extract, EE	5.9	6.2
Nitrogen-free extract, NFE	44.2	48.0
Ash	10.0	12.5
Ca	1.5	2.4
P	0.4	0.03
Secondary compounds:		
-Condensed tannins (%)	4.3	3.9
-Hydrocyanic acid (mg/kg DM)	46.0	38.0

[1] Leaves and whole tops harvested at 3-4 months after planting.
Source: *Wanapat, 1999; Wanapat, 2001; Wanapat et al., 2000a.*

Table 4. Comparison of energy and protein obtained from the traditional cassava cultivation and the new method of consecutive harvests of plant tops at two month intervals.

Item[1]	Method of cultivation: Traditional[2]	Method of cultivation: Consecutive harvests
Crude protein (CP), kg/ha	550	3,125
Total digestible nutrient (TDN), kg/ha	21,250	18,125 (10,625+7,500)
CP/TDN	0.026	0.172
Efficiency CP/E, %	10	90

[1] Includes roots and leaves harvested
[2] Harvest of remaining leaves at time of root harvest.
Source: *Wanapat, 2001.*

Cassava hay contains condensed tannins (CT) and proanthocyanidin (PC) which are commonly found in tropical plants. CT are polyphenolics that are easily solubilized in water, which may result in precipitation of protein. Condensed tannins and protein could form a tannin-protein complex (TPC) by hydrogen bonding, especially under alkaline conditions. TPC is stable at pH 3.5-7, but the complex will dissociate at pH<3.0 and pH >8.0 (Jones and Mangan, 1977). Condensed tannins have been found to increase N-recycling in the rumen as well as salivation (Reed, 1995), and also improve rumen microbial protein synthesis (Makkar, 2000). McSweeney *et al.* (2000) found lower rumen cellulolytic bacteria in sheep that were fed tannin-containing diets, but microbial protein synthesis was not affected. However, the exact mode of action of CT on rumen fermentation is yet to be elucidated.

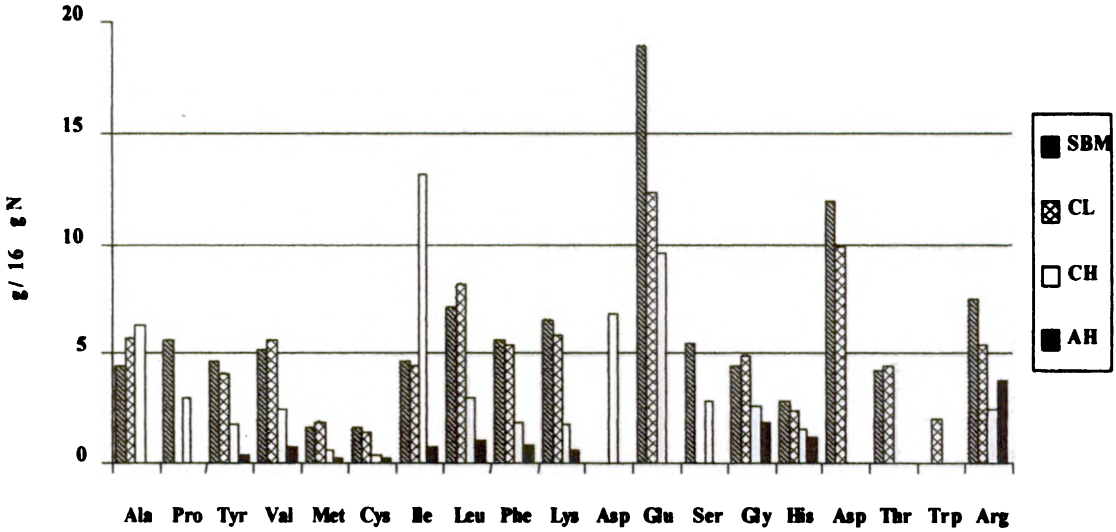

Figure 1. Amino acid profiles in cassava leaves (CL), cassava hay (CH), soybean meal (SBM) and alfalfa hay (AH)
***Source:** Wanapat, 2002.*

Effect of Residual Hydrocyanic Acid (HCN) as Thiocyanate in Cassava Hay on Milk Preservation

Claesson (1994) reported that milk thiocyanate was required in the lactoperoxidase system in milk to help increase its shelf-life, and that the optimal range of milk thiocyanate should not exceed 20 ppm. Feeding dairy cows with cassava hay as a supplement resulted in a thiocyanate level of 19.5 ppm in the milk; however, more research is needed in order to pinpoint the role of residual HCN in cassava on milk thiocyanate.

Effect of Condensed Tannins as a Gastrointestinal Anthelmintic Agent

Gastrointestinal (GI) parasites or nematodes are very common and result in poor performance of ruminants in the tropics. Common GI nematodes found include *Trichostrongylus colubriformis, Ostertagia circumcincta, Haemonchus centortus and T. vitrinus.* Nematode-infected animals had higher requirements of protein and minerals due to loss of endogenous nitrogen (blood, plasma, mucin and sloughed cells) and a lower P adsorption (Poppi *et al.*, 1985; Kahn and Diaz-Hernandez, 2000). Research by Netpana *et al.*, (2001) showed that the fecal parasitic egg counts in cattle and buffaloes were significantly lower when fed with cassava hay which contained condensed tannins, and were similar to the group of animals receiving a drenching treatment. Recent work by Granum *et al.* (2002) revealed that supplementation of CH at 1 kg/head/day significantly reduced the fecal egg counts in both buffaloes and cattle (**Table 5**). The reason may be that the animals received supplemental protein, and/or the CT could have a direct affect on the internal parasites. Possible mechanisms thorough which CT may reduce larval migration and development remain to be elucidated, but the process may involve interactions of CT with the external surface of larvae (Kahn and Diaz-Hernandez, 2000).

Table 5. Effect of cassava hay supplementation on fecal egg counts (FEC).

	Buffaloes		Cattle		
Parasitic egg counts/g DM feces	C	S	C	S	SEM
Preliminary period (grazing only)	1,552	1,243	1,189	1,462	82.2
Experimental period	918 [a]	579 [b]	951 [a]	747 [c]	77.4
Reduction from preliminary period (%)	31.7 [a]	57.6 [b]	24.7 [a]	45.0 [c]	6.2

Values in the same row with different superscripts are significantly different ($P<0.05$)
Values are the mean of six animals; C = control; S = cassava hay supplementation;
SEM = standard error of the mean
Source: *Granum et al., 2002.*

Feeding Trials Using Cassava Hay

Cassava hay has been used successfully as a source of high protein roughage in lactating dairy cows (Wanapat *et al.*, 2000a; Wanapat *et al.*, 2000b). **Table 6** shows that increasing levels of CH from 0.56 to 1.70 kg/head/day could reduce levels of concentrate from 0.1 to 1.6 kg/head/day, respectively, without affecting milk yield. Moreover, feeding CH at *ad libitum* basis resulted in similar results and could further reduce the need for concentrates. A study was conducted on supplementation levels of cassava hay (CH) in dairy cows. Six multiparous Holstein-Friesian crossbreds were paired and randomly assigned in a change-over design to receive three levels of CH supplement at 0, 0.8 and 1.7 kg DM/head/day. Concentrate was supplemented at the same level (concentrate:milk yield=1:2), while urea-treated (5%) rice straw was offered on *ad libitum* basis. **Table 7** shows that supplementation of CH could significantly reduce concentrate use resulting in similar milk yields, and significantly enhanced 3.5% fat-corrected milk (FCM). Moreover, CH supplementation significantly increased milk fat and milk protein percentages, especially when supplemented at 1.70 kg/head/day. Concentrate use could be significantly reduced by 27% at 1.7 kg/head/day CH supplementation.

In a later experiment (Wanapat *et al.*, 2000b), supplementation of cassava hay to replace concentrate was studied using lactating Holstein-Friesian crossbreds grazed on Ruzi grass. Six multiparous cows in mid-lactating periods were paired and randomly assigned according to a change-over-design to receive three dietary treatments: T_1=0 kg cassava hay (CH) in 1:2 concentrate supplementation (CS) to milk yield (MY); T_2=1.0 kg DM CH/head/day in 1:3 CS to MY; T_3=1.7 kg DM CH/head/day in 1:4 CS to MY, respectively. **Table 8** shows that milk yields were similar among treatments while protein, lactose and solids-not-fat percentages were highest ($P<0.05$) in cows receiving CH at 1.0 kg/head/day. The most significant improvement from CH supplementation was the ability to reduce concentrate use by 42%, which could provide a higher income for small-holder dairy farmers. In addition, milk thiocyanate was enhanced from 5.3 in the control to 17.8 ppm ($P<0.05$) in the CH supplemented group (1.7 kg/head/day). Moreover, **Table 9** shows in more detail that CH supplementation significantly reduced the need for concentrate for dairy feeding, thus resulting in greater economic returns. These results are in agreement with those of Woodward *et al.* (1999), who reported that dairy cows fed with *Lotus corniculatus,* containing condensed tannins, had contributed to a 42% improvement in milk yield and 57% increase in protein percentage without changing feed intake.

Table 6. Effects of cassava hay (CH) supplementation levels on ruminal pH, NH_3-N, milk yield and milk composition in late-lactating cows fed urea-treated rice straw (UTRS) as a roughage.

Item	T1[1)]	T2	T3	T4	T5	SEM[2)]
Cassava hay DM intake (kg/day)	-	0.56	1.13	1.70	5.20	0.20
Condensed tannin intake (g/head/day)	0	1.44	2.90	4.37	13.36	5.26
Concentrate saving (kg/head/day)	-	0.10	1.30	1.60	3.10	-
Urea-treated rice straw						
DM intake						
kg/day	6.8	6.4	6.7	8.0	-	0.28
$g/kgw^{.75}$	86	69	84	98	-	2.82
% body weight	2.0	1.8	2.0	2.3	-	0.06
Ruminal pH	7.2	7.0	7.0	7.0	6.8	0.13
Ruminal NH_3-N (mg%)	17	13	13	16	7.0	0.52
Milk yield (kg/day)	6.3	6.1	5.4	6.1	5.4	0.24
3.5% FCM (kg/day)[3)]	6.8^{ac}	6.2^{ab}	6.0^{b}	7.1^{c}	6.4^{ab}	0.13
Milk fat (%)	4.0^{a}	3.6^{b}	4.2^{a}	4.5^{c}	4.6^{c}	0.11
Milk protein (%)	4.4^{a}	4.0^{a}	3.8^{a}	4.1^{a}	5.3^{b}	0.17
Solids-not-fat (%)	8.6	8.8	8.4	8.6	8.4	0.12
Total solids (%)	12.6	12.3	12.0	12.2	12.6	0.18

[1)] T1 = Urea-treated rice straw (UTRS) *ad lib.* + Concentrate*: Milk yield (1:2) + 0 CH.
T2 = UTRS *ad lib.* + Concentrate : Milk (1:2) + CH at 0.56 kg DM/head/day
T3 = UTRS *ad lib.* + Concentrate : Milk (1:3) + CH at 1.13 kg DM/head/day
T4 = UTRS *ad lib.* + Concentrate : Milk (1:2) + CH at 1.70 kg DM/head/day
T5 = Cassava hay *ad lib.* + Cassava supplement (97% cassava chips + 3% urea) at 2 kg/head/day
*Concentrate mixture contained 95% cassava chips, 3% urea, 1% sulfur and 1% mineral mix in T_1 to T_4

[2)] SEM = Standard error of the mean
Values with different superscipts within the some row are significantly different ($P<0.05$)

[3)] FCM = fat corrected milk

***Source:** Wanapat et al., 2000b.*

In recent trials in Vietnam, Nguyen *et al.* (2002) obtained results that were similar to those earlier reported by Wanapat *et al.* (1997, 2000a, 2000b) that cassava hay could be produced from an initial harvest of plant tops at four months after planting and subsequent harvests at one month intervals. Supplementation of cassava hay could lower concentrate use and improve milk yield and milk composition (**Tables 10, 11** and **12**).

Koakhunthod *et al.* (2001) used CH as a major source of protein in high-quality feed blocks used as a supplement for lactating dairy cows. The results (**Table 13, 14, 15, 16, 17**) indicate that rumen ecology, milk yield and milk composition were significantly improved.

Table 7. Effect of level of chopped cassava hay supplementation on milk yield and composition of Holstein-Friesian crossbreds fed urea-treated (5%) rice straw on *ad libium* basis.

Item	Chopped cassava hay (kg/head/day)			SEM[1)]
	0	0.8	1.70	
Concentrate DM intake (kg/day)	5.53	5.00	4.03	0.25
Concentrate saving (kg)	0	0.53	1.50	0.30
Milk yield (kg/day)	12.50	12.12	12.62	0.57
3.5% FCM (kg/day)[2)]	14.21[a]	15.70[c]	14.93[b]	0.67
Milk composition:				
Fat (%)	4.06[a]	4.15[a]	4.61[b]	0.19
Protein (%)	3.40[a]	3.34[b]	3.50[c]	0.08
Lactose (%)	4.64[a]	4.82[b]	4.62[a]	0.05
Solids-not-fat (%)	8.74	8.80	8.81	0.09
Total solids (%)	13.56	13.18	13.76	0.32

[1)] SEM = Standard error of the mean
Values with different superscripts within the same row are significantly different (P<0.05)
[2)] FCM = fat corrected milk
Source: *Wanapat et al., 2000a.*

Table 8. Effect of cassava hay (CH) supplementation on concentrate use, milk yield and composition.

Concentrate : Milk yield ratio	1:2	1:3	1:4	SEM[1)]
CH supplementation (kg DM/day)	0	1.0	1.7	
Concentrate DM intake (kg/day)	4.56[a]	3.20[b]	2.64[c]	0.25
Concentrate saving (kg)	0	1.36	1.92	-
Milk yield (kg/day)	10.72	10.19	10.42	0.58
3.5% FCM (kg/day)[2)]	12.65	12.51	12.64	0.75
Milk composition:				
Fat (%)	4.61[a]	4.98[b]	4.80[ab]	0.13
Protein (%)	3.36[a]	3.60[b]	3.45[ab]	0.10
Lactose (%)	4.47[a]	4.66[b]	4.53	0.07
Solids-not-fat (%)	8.80[a]	8.95[b]	8.68[c]	0.09
Total solids (%)	13.41	13.54	13.50	0.24
Thiocyanate (ppm)	5.3[a]	13.3[b]	17.8[b]	0.77

[1)] SEM = Standard error of the mean
Values with different superscripts within the same row are significantly different (P<0.05)
[2)] FCM = fat corrected milk
Source: *Wanapat et al., 2000a.*

Table 9. Effect of cassava hay supplementation on the economic return of milk yield per cow.

Concentrate : Milk ratio	1:2	1:3	1:4
CH Supplementation (kg DM/day)	0	1.0	1.7
3.5% FCM (kg/day)	12.65	12.51	12.64
Milk sale (baht)	141.68	140.11	141.57
Concentrate intake (kg/day)	5.15	3.62	2.97
Concentrate cost (baht/day)	30.90	21.72	17.82
Cassava hay intake (kg/day)	0	2.85	4.02
Cassava hay cost (baht/day)	0	1.92	2.01
Total feed cost (baht/day)	30.90	23.64	19.83
Income over feed (baht/day)	110.78	116.47	121.74
Income over feed (baht/month)	3,324	3,494	3,652
Income over feed ($US/month)	92.3	97.1	101.4

1 kg milk = 11.20 baht; 1 kg concentrate = 6.00 baht; 1 kg cassava hay = 0.50 baht; 1US$ = 36 baht
Source: *Wanapat et al., 2000a.*

Table 10. Fresh and dry fodder and protein yield of cassava (t/ha) with different cutting regimes.

Item	T1[1)]	T2	T3	T4	SEM[2)]	Contrast[3)] IC	SC	X
Fresh fodder yield (t/ha)	27.89[a]	37.58[b]	33.51[b]	35.91[b]	1.14	NS	*	*
Dry fodder yield (t/ha)	4.25[a]	6.86[b]	6.49[b]	7.90[c]	0.35	**	**	*
Protein yield (t/ha)	1.16[a]	1.60[b]	1.55[b]	1.54[b]	0.06	**	NS	**

[1)] T1: IC = 2 months and SC = 1 month; total 11 cuts
T2: IC = 2 months and SC = 2 months; total 6 cuts
T3: IC = 4 months and SC = 1 month; total 9 cuts
T4: IC = 4 months and SC = 2 months; total 5 cuts
[2)] SEM = Standard eror of the mean
Values in the same row with different superscipts are significantly different (P<0.05)
[3)] IC = Initial cutting, SC = Subsequent cutting, X = Interaction between IC and SC.
*, ** = Significant at 0.05 and 0.001% probability level, respectively, NS = Non-significant.
Source: *Nguyen et al., 2002.*

Table 11. Effect of different cuttings regimes on chemical composition of cassava foliage.

Items	T1	T2	T3	T4	SEM
DM (%)	16.41[a]	18.80 [b]	18.89[b]	22.40[c]	0.60
			% of DM		
NDF	42.70[a]	48.27[b]	49.16[b]	56.04[c]	1.26
ADF	25.93[a]	31.02[b]	32.06[b]	37.97[c]	0.14
ADL	10.44[a]	11.83[b]	12.59[b]	13.60[c]	0.32
CP	28.51[a]	24.23[b]	28.65[a]	20.79[c]	0.87
Total Ash	7.72[a]	6.66[b]	6.97[b]	5.21[c]	0.25
Condensed tannins	5.00	5.15	4.87	5.48	0.85

[1)] T1: IC = 2 months and SC = 1 month; total 11 cuts
T2: IC = 2 months and SC = 2 months; total 6 cuts
T3: IC = 4 months and SC = 1 month; total 9 cuts
T4: IC = 4 months and SC = 2 months; total 5 cuts
[2)] SEM = Standard error of the mean
Values in the same row with different superscripts are significantly different (P<0.05)
Source: *Nguyen et al., 2002.*

Table 12. Effect of cassava hay supplementation on milk yield and composition.

Item	T1[1)]	T2	T3	T4	T5	SEM[2)]
Milk yield (kg/day)	7.48	8.42	7.70	8.00	7.90	0.12
4% FCM (kg/day)[3)]	7.79	9.53	8.76	9.10	8.87	0.16
Milk DM (%)	12.72	13.52	13.76	13.60	13.86	0.13
Milk fat (%)	4.32	4.90	4.90	5.04	4.90	0.09
Milk CP (%)	3.46[a]	3.76[b]	3.78[b]	3.94[b]	3.74[b]	0.03
Milk SNF (%)[4)]	8.40	8.62	8.86	8.56	8.96	0.07

[1)] T1: No cassava hay supplementation, supplementation of concentrate : milk yield at 1:2
T2: Supplementation of 1 kg DM of CH/h/d; supplementation of concentrate : milk yield at 1:2
T3: Supplementation of 1 kg DM of CH/h/d; supplementation of concentrate : milk yield at 1:3
T4: Supplementation of 2 kg DM of CH/h/d; supplementation of concentrate : milk yield at 1:2
T5: Supplementation of 2 kg DM of CH/h/d; supplementation of concentrate : milk yield at 1:2
[2)] SEM = standard error of the mean
Values in the same row with different superscipts are significantly different (P<0.05)
[3)] FCM = fat corrected milk, 4% FCM = 0.4 x(kg of milk)+15x(kg of fat); SNF = solids non-fat

Table 13. Composition of high-quality feed block (HQFB).

Ingredients	HQFB1	HQFB2
	(% by weight)	
Molasses	40	42
Coarse rice bran	30	0
Cassava hay	0	30
Urea	13	11
Sulfur	1	1
Mineral mix	1	1
Salt	1	1
Tallow	2	2
Cement	12	12

Source: *Koakhunthod et al., 2001.*

Table 14. Chemical composition of (as% of dry matter) urea-treated rice straw (UTRS), concentrate and high-quality feed block with (HQFB-CH) or without (HQFB) cassava hay (CH).

	Dry matter	Organic matter	Crude protein	NDF	ADF
UTRS	55.2	83.6	6.8	83.0	58.1
Concentrate	85.0	92.2	13.6	24.3	10.7
HQFB	79.8	76.4	36.0	26.2	20.2
HQFB-CH	80.2	76.1	33.2	23.2	17.2

Source: *Koakhunthod et al., 2001.*

Table 15. Effect of cassava hay in a high-quality feed block on feed intake and dry matter digestibility in lactating dairy cows fed a basal diet of urea-treated rice straw(UTRS).

Item	Control	HQFB	HQFB-CH	SEM
UTRS DM intake				
kg/day	5.44	5.61	6.20	0.17
% of body weight	1.44	1.55	1.57	0.03
HQFB DM intake				
kg/day		0.65	0.79	0.03
% of body weight		0.18	0.20	0.01
Total DM intake				
kg/day	9.18[a]	10.1[ab]	11.1[b]	0.31
% of body weight	2.43	2.82	2.78	0.07
Dry matter digestibility %	48.4[a]	51.1[ab]	53.4[b]	0.76

[1)] SEM = Standard error of the mean

Values in the same row with different superscripts are significantly different (P<0.05).

Source: *Koakhunthod et al., 2001.*

Table 16. Effect of cassava hay in the feed block on rumen pH, NH3-N and rumen microbes.

	Dietary treatments			
	Control	HQFB	HQFB-CH	SEM
pH	6.64	6.50	6.59	0.07
NH_3-N (mg %)	7.95	8.61	9.14	0.71
Bacteria (x 10^9 cells/ml)	6.56	6.74	7.25	3.05
Protozoa (x10^5 cells/ml)	6.30	6.20	6.10	0.34
-holotrich (x10^5 cells/ml)	2.30	2.30	2.40	0.52
-entodiniomorp (x10^5 cells/ml)	4.00	3.90	3.70	0.83
Fungal zoospore (x10^7 cells/ml)	3.02	3.75	4.16	3.87
Total viable count (x10^{10} CFU/ml)	2.51	2.86	3.16	0.23
Cellulolytic bacteria (x10^9 CFU/ml)	3.04	3.21	3.48	0.27
Amylolytic bacteria (x10^8 CFU/ml)	1.60	2.22	2.19	0.15
Proteolytic bacteria (x10^8 CFU/ml)	1.71	2.02	2.13	0.19

Source: *Koakhunthod et al., 2001.*

Table 17. Effect of cassava hay (CH) in the feed block (HQFB) on milk yield and milk composition in lactating dairy cows fed urea-treated rice straw.

Items	Dietary treatments			
	Control	HQFB	HQFB-CH	SEM
Milk yield (kg/day)	7.58[a]	8.85[b]	9.36[b]	0.44
3.5% FCM (kg/day).	7.66[a]	8.43[b]	9.94[c]	0.46
Fat (%)	0.27[a]	0.29[a]	0.37[b]	0.02
Protein (%)	0.23[a]	0.25[a]	0.31[b]	0.02
Milk compositions (%):				
Fat	3.39[a]	3.53[ab]	4.08[b]	0.16
Protein	2.87	2.96	3.32	0.11
Lactose	5.01	4.85	5.00	0.04
Solids-not-fat	7.98	8.01	8.01	0.42
Total solids	12.11[a]	12.03[a]	13.09[b]	0.25

[1)] SEM = Standard error of the mean
Values in the same row with different superscripts are significanty different (P<0.05).
Source: *Koakhunthod et al., 2001.*

CONCLUSIONS AND RECOMMENDATIONS

Cassava could be cultivated to produce mainly cassava leaves to make hay, which has a high nutritive value. Intercropping cassava with food or feed crops could further increase biomass yield and improve soil fertility. Condensed tannins contained in cassava hay may play an important role forming a tannin-protein complex which increases rumen by-pass protein and reduces GI nematode egg counts. Feeding cassava hay as a supplemental high-protein source could increase milk yield and improve its composition, and significantly reduce concentrate use. On-farm research with small-holder farmers show a promising establishment and development of cassava hay production on farm. Harvesting of whole tops at an earlier stage and subsequent prunings to produce hay resulted in an increased protein to energy ratio in animal feeding. However, further research relating to the role of condensed tannins in cassava hay on rumen ecology, its efficient use for livestock feeding, especially dairy cattle, as well as the utilization levels with other low-quality roughage, still needs to be undertaken. Cassava hay and cassava chips as a complete concentrate could contribute to more sustainable crop/livestock production systems in the tropics.

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THE USE OF CASSAVA ROOTS AND LEAVES FOR FEEDING PIGS IN VIETNAM

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ABSTRACT

In Vietnam, cassava (*Manihot esculenta Crantz*) is the second most important food crop after rice in terms of total production; annual root production is about 2 million tonnes, the majority of which is used for animal feeding. Cassava is also an important source of income for poor farmers.

Making silage is an appropriate method to preserve cassava roots to be used for pig feeding and is applicable under village conditions. After harvest, fresh roots are cleaned, grated finely and mixed with 0.5% salt. The mixture is put into plastic bags of 20-30 1, pressed tighty to expel all air and tied; it is then let to ferment naturally. The mixture could be used after 2-3 weeks of ensiling and can be kept for at least 3-4 months.

Research has shown that including about 40% ensiled cassava roots (ECR) in diets for growing pigs does not affect their growth performance. Under village conditions, the inclusion of 30% ECR of DM of diet improved the daily weight gain and decreased feed cost by 7%. However, a higher proportion of ECR in the diet may cause an imbalance in amino acid concentrations, particularly low methionine.

A higher level of digestibility of organic material and crude protein was obtained when including levels of 0.1, 0.2 and 0.3% (as DM) DL-methionine in ECR-based diets for pigs. Inclusion of DL-methionine in the diet significantly reduced the amount of N secreted in urine, increased the retention of N and improved the performance of growing pigs. Although inclusion of DL-lysine (0.1%) and DL-methionine (0.05%) in 30% ERC-based diets did not increase performance, it reduced the feed cost by 3%.

At root harvesting time, about 5-7 t/ha of fresh leaves can also be collected. However, leaves are seldom used for feeding animals. The high crude protein content of cassava leaves (20-30%) makes these a very useful feed resource.

Making silage of cassava leaves reduces the toxicity of HCN and this is a very practical and applicable method. Additives used in the ensiling process are readily available in the village, such as salt, rice bran, molasses and cassava root meal.

In diets for growing pigs, inclusion of 15% (as DM) ensiled cassava leaves (ECL) improved daily weight gains and the food conversion ratio, as well as reduced the feed cost by 25%. Additionally, for pregnant sows the feeding with 15% ECL improved their piglet live weight gain at weaning time.

In conclusion, cassava roots and leaves can be used effectively for feeding growing pigs and pregnant sows. However, a low protein content of the roots and an imbalance of essential amino acids in the leaves could limit their inclusion in pig diets.

INTRODUCTION

In Vietnam, cassava (*Manihot esculenta* Crantz) is the second most important food crop after rice in terms of total production; annual fresh root production is about 2 million tonnes (GSO, 2001), most of which is used for animal feeding. Cassava is also an important source of income for poor farmers.

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Ensiled Cassava Roots as Pig Feeds

Sun-drying of cassava roots is the method of processing commonly used by Vietnam farmers. After harvesting, the roots are cleaned, chopped by hand or by machine into small pieces, sun-dried and stored. However, it is difficult to sun-dry cassava roots in the rainy season.

Making silage is an appropriate alternative method to preserve cassava roots to be used for pig feeding, and this can be done under village conditions (Loc, 1996). After harvest, fresh roots are cleaned, grated finely, and mixed with 0.5% salt. The mixture is put into plastic bags of 20-30 liters, pressed tightly to expel all air and then tied; it is then let to ferment naturally. The mixture could be used after 2-3 weeks of ensiling, and can be kept for at least 3-4 months. The pH of the mixture decreases after the first week of ensiling and then remains constant, while the HCN content is reduced to about 35% after 150 days of ensiling **(Table 1).**

Table 1. Effect of time of ensiling on pH and the HCN content of cassava roots.

Day of ensiling	DM (%)	pH	HCN (mg/kg fresh roots)
0	37.5	6.6	112
30	37.8	4.1	77
60	37.4	3.8	59
90	37.3	3.8	51
120	37.3	3.8	44
150	37.4	3.8	39

***Source:** Nguyen Thi Loc et al., 2001.*

The present study has shown that including about 40% ensiled cassava roots (ECR) in diets for growing pigs did not affect their growth performance **(Table 2).**

Table 2. Effect of different levels of ensiled cassava roots in the diets of growing pigs on their performance.

	Treatments[1]					
Item	Control	20 ECR	40 ECR	60 ECR	SEM[2]	P[2]
No. of pigs (head)	9	9	9	9		
Live weight (kg)						
- initial	18.6	18.7	18.5	18.6	0.36	0.9
- final	89.2a	89.6a	86.5a	70.2b	0.84	0.001
Daily weight gain (g/day)	588a	591a	567a	428b	11.1	0.001
Feed in take (kg/day)	2.07a	2.09a	2.02a	1.78b	0.01	0.001
Feed conversion ratio[3]	3.52a	3.54a	3.56a	4.16b	0.09	0.001

[1] 20 ECR, 40 ECR, 60 ECR, diets containing 20, 40 and 60 % ensiled cassava roots (as DM)
[2] SEM= Standard error of the mean; P=Probability
[3] Feed conversion ratio= Feed intake/weight gain;
***Source:** Nguyen Thi Loc et al., 2000.*

Under village conditions, the inclusion of 30% ECR (as DM) increased the daily weight gain by 5.7% and reduced feed cost by 7.3 % **(Table 3).**

Table 3. Effect of using 30% ECR (as DM) in diets of growing pigs on their performance under village conditions.

Item	Control	ECR
Live weight (kg)		
- intitial	27.79	28.75
- final	61.90	64.68
Daily weight gain (g/day)	378.90	400.50
Feed conversion ratio (FCR)	4.34	4.10
Feed cost/kg gain (VND)	7,237	6,711

Source: *Nguyen Thi Hoa Ly et al., 2001.*

However, a higher proportion of ECR in the diet may cause an imbalance in amino acid concentrations, particularly methionine. Studies on supplementation of methionine show that inclusion of 0.1, 0.2 and 0.3% (as DM) could increase the daily weight gain and reduce the feed conversion ratio (FCR) and feed cost **(Table 4).**

Table 4. Effect of DL-methionine supplementation in ECR-based diets on performance of pigs and feed cost.

	DL-methionine inclusion (% as DM)					
Item	0	0.1	0.2	0.3	SEM	P[1)]
Daily weight gain (g/day)	568	661	649	628	12.05	0.01
Daily feed intake (kg)	2.09	2.12	2.09	2.10	0.02	0.42
Feed conversion ratio	3.67	3.47	3.21	3.34	0.03	0.001
Feed cost/kg gain ('000 VND)	8.4	7.9	7.7	8.8	0.06	0.001
Feed cost (% of control diet)	100	95	91	97		

[1)] SEM = Standard error of the mean; P = Probability

Source: Nguyen Thi Loc *et al.*, 2001.

A higher level of digestibility of organic material and crude protein was obtained with supplementation of 0.1, 0.2 and 0.3% (as DM) DL-methionine in ECR-based diets for pigs. Inclusion of DL-methionine in the diet significantly reduced the amount of N secreted in the urine, increased the retention of N and improved the performance of growing pigs **(Table 5)**.

Table 5. Effect of DL-methionine in ECR-based diets on ileal and total tract digestibility, and N-retention in growing pigs.

	DL-methionine inclusion (% as DM)					
Item	0	0.1	0.2	0.3	SEM[1)]	P[1)]
Ileal digestibility of DM (%)	78	80	82	82	1.04	0.07
Total tract digestibility of DM (%)	86	87	90	90	0.21	0.26
Daily N-retention (g)	19.3	20.1	21.9	20.8	0.49	0.02
N-retained/N-digested (%)	58	59	63	62	0.77	0.002

[1)] SEM =Standard error of the mean; P = Probability

Source:*Nguyen Thi Loc et al., 2001.*

Ensiled Cassava Leaves for Feeding Growing Pigs and Sows

1. Making silage

At root harvesting time, about 5 t/ha of fresh leaves and about 7 t/ha of total foliage (Ngoan and Duong, 1993) can be harvested. However, cassava leaves are seldom used for feeding animals. Cassava leaves have high levels of crude protein (20-30%) and are a good source of protein for animals, but their high content of cyanide limits their use as an animal feed.

Making silage of cassava leaves reduces their HCN content and this was found to be a practical method (Loc, 1996). Trials on the use of various additives for ensiling the leaves indicate that inclusion at 5% of rice bran, molasses or cassava root meal, which are common feed sources in the market, enhanced the natural fermentation process (Loc, 1996; 2000). The authors reported that the pH of the silage decreased quickly within one week after ensiling and that the HCN content decreased about 50% after 56 days of ensiling (**Table 6**).

Table 6. Effect of various additives on the pH and HCN (ppm) content at different times (days) after ensiling.

	Days of ensiling											
Treatments[1)]	0	7	14	21	28	56	0	7	14	21	28	56
	pH						HCN (ppm on fresh basis)					
T_1	6.7	4.3	4.1	4.1	4.2	4.2	302	284	226	192	189	141
T_2	6.6	3.7	3.7	3.6	3.6	3.6	291	250	233	164	126	120
T_3	6.6	3.7	3.7	3.6	3.6	3.6	276	220	212	177	106	102
T_4	6.7	4.1	3.9	3.8	3.8	3.8	287	258	237	171	143	110
T_5	6.7	4.0	3.9	3.8	3.8	3.8	274	235	221	192	125	112
T_6	6.7	4.1	4.0	3.8	3.8	3.8	283	231	215	172	137	103
T_7	6.7	4.2	3.9	3.9	3.9	3.9	269	240	217	134	130	91

[1)] T_1 = Cassava leaves + 0.5% NaCl; $T_2 = T_1$ + 5% molasses; $T_3 = T_1$ + 10% molasses; $T_4 = T_1$ +5% cassava root meal (CRM); $T_5 = T_1$ + 10% CRM; $T_6 = T_1$ + 5% rice bran; $T_7 = T_1$ + 10% rice bran.

In diets for growing pigs, inclusion of 15% (as DM) of ensiled cassava leaves (ECL) increased the daily weight gains, and reduced FCR by 6.1% and feed cost by 25% (**Table 6**).

Table 7. Effect of using 15% ensiled cassava leaves in the diet of growing pigs on their performance.

Item	Control	15% ECL
Live weight (kg)		
- initial	24.2	24.3
- final	58.6	60.8
Daily weight gain (g/day)	382	405
Feed conversion ratio (FCR)	4.9	4.6
Feed cost/kg gain (VND)	7,904	5,879

Source: *Nguyen Thi Hoa Ly et al., 2001.*

Additionally, pregnant sows fed 15% ECL improved the live weight gain of piglets at weaning time (**Table 8**).

Table 8. Effect of using ensiled cassava leaves during pregnancy on reproductive traits of Mong Cai sows under farm conditions.

	Control	15 ECL	SEM[1)]	P[1)]
No. of live piglets born	11.3	10.3	1.06	0.535
Average piglet weight (kg)	0.68	0.70	0.015	0.209
No. of piglets weaned	9.75	9.14	0.925	0.632
Average weight of weaned pigs (kg)	6.9	7.5	0.11	0.010

[1)] SEM = Standard error of the mean; P = Probability

CONCLUSION

Cassava roots and leaves can be used effectively for feeding growing pigs and pregnant sows. However, the low protein content of roots and an imbalance of essential amino acids in leaves could limit their inclusion in pig diets.

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CASSAVA ROOT AND LEAF MEALS AS THE MAIN INGREDIENTS IN POULTRY FEEDING: SOME EXPERIENCES IN COLOMBIA

Julián Buitrago[1], Bernardo Ospina[2], Jorge Luis Gil[3] and Hernando Aparicio[4]

ABSTRACT

Cassava roots provide usable feed energy, while cassava leaves provide fiber and protein. In a conventional cassava crop, the root to leaf ratio as dried ingredients offers a balanced mixture (10:1) to optimize their inclusion in swine and poultry diets. In a non-conventional crop, root or leaf production can be directed to maximize either energy or protein/fiber depending on the final use as ruminant or monogastric feeds.

Cassava root meal can be used to substitute the total energy needs in swine and poultry feeds. This type of diets requires a protein and essential fatty acid supplementation, which can be provided by full-fat soybeans. Cassava root meal mixed with full-fat soybeans becomes an excellent feed to cover the nutritional needs of energy, aminoacids and essential fatty acids for swine and poultry. High performance diets can contain up to 95% of a cassava root, cassava leaf and full-fat soybean mixture.

Pig pre-starter and starter diets may be based on cassava root meal and full-fat soybeans. Growing and finishing diets can contain up to 10% cassava leaf meal in addition to root meal and soybeans. Higher (15%) leaf meal inclusion may be provided during gestation and lactation. On-farm equipment to process cassava and full-fat soybeans has been developed in Colombia as a practical tool for farmers in order to obtain the total energy and protein sources for animal feeds at the farm level. Raw cassava and soybean contain anti-nutritional factors (cyanides and antitripsins), which are destroyed by heat through processing using semi-industrial equipment.

INTRODUCTION

The animal production sector in Colombia is an economic activity with great development potential. During the last decade, this sector, especially the poultry production area (eggs, chicken), has had a dynamics of constant growth that has converted it into an efficient source of animal protein at low cost. Today, at the beginning of the third millennium, the poultry industry in Colombia is one strategic sector that provides the country with food security, employment and income.

Despite the increased growth of the poultry sector in the last decade, there are profound structural problems that affect this activity and that are limiting its contribution to the generation of employment, expansion of the agricultural frontier, technological modernization, exports and even the strategic goal of producing chickens and eggs at lower costs to attend the increasing food needs of the Colombian population.

Among these problems, the principal one is the dependency of imported raw materials that accounts for 80% of the total raw materials used. In a tropical country like Colombia, the poultry production sector is not tropicalized, which means that it is not working with raw materials that are produced under the specific conditions of the country. This situation creates a heavy dependency on imported products to produce the animal feed concentrates. The maize crop is the best example. During the last two years, the amount of maize

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imported for the animal and balanced feeds sector has reached the level of 2 million tonnes per year. The national production is not capable of attending the increasing demand, also affected by the increasing demand for human consumption. Under these circumstances, the steady, increasing growth tendency of the Colombian poultry sector offers the possibility of implementing an agricultural development policy based on the intensified production of raw materials that can be used as substitute of imported cereals like maize. Cassava is one of the crops best suited for expanding the agricultural frontier and at the same time, offers an alternative to the animal and balanced feeds industries. This paper describes some policies that have been implemented recently in Colombia, with the aim of promoting a more intensive use of cassava roots and leaves in balanced feeds for poultry and swine.

The Poultry Sector in Colombia

The poultry sector in Colombia generates approximately 170,000 permanent direct jobs per year, including poultry producers that produce their own balanced feeds, egg hatcheries, egg producers, broiler and reproduction poultry farms, processing plants, and distribution and commercialization points and networks. If the backward and forward linkages of the poultry sector with other sectors are included, such as the production of raw materials (soybean, sorghum, maize), the poultry chain generates more than 300,000 direct jobs per year. The poultry sector in Colombia has been presenting a steady growth during the last decade. In 1999, its contribution to the Colombian GNP was 5.1 times greater than that of the plantain/banana sector and 1.45 times greater than that of the coffee sector (**Figure 1**).

These impressive trends are a consequence of various factors, among which could be mentioned the increased urbanization and the changes that this rural to urban migration causes in the nutritional habits of the population. Traditional foods are replaced by processed, convenience foods that are more easily obtained in urban areas. For example, in just about every corner of the cities, it is possible to find small grocery stores that sell eggs and chicken. The consumption of these two items has been growing steadily during the last two decades (**Figures 2** and **3**).

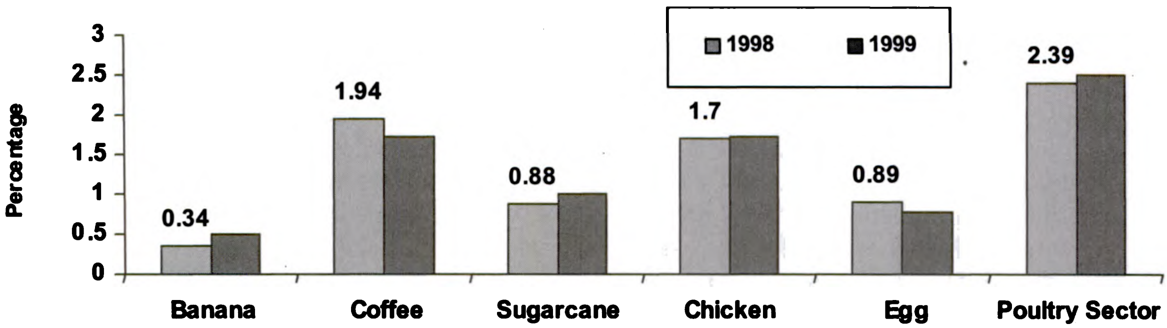

Figure 1. Contribution of some agricultural activities to Colombia's total GNP.
***Source:** FENAVI-FONAV- Economic Studies Program.*

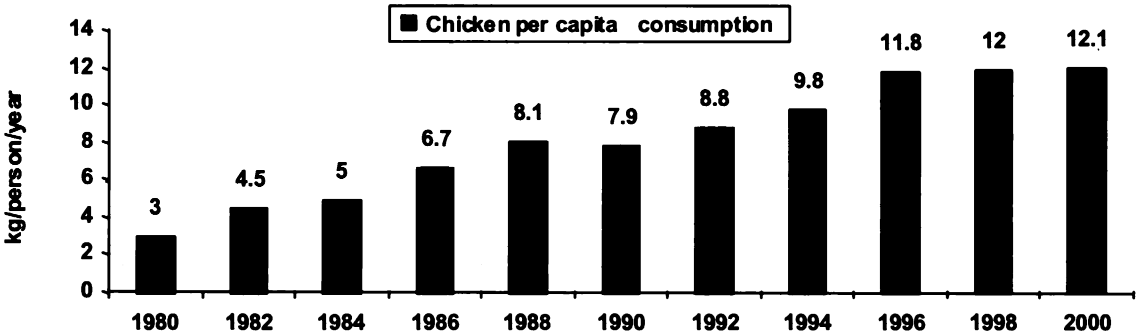

Figure 2. Per capita consumption of chicken in Colombia: 1980-2000.
***Source:** FENAVI-FONAV- Economic Studies Program.*

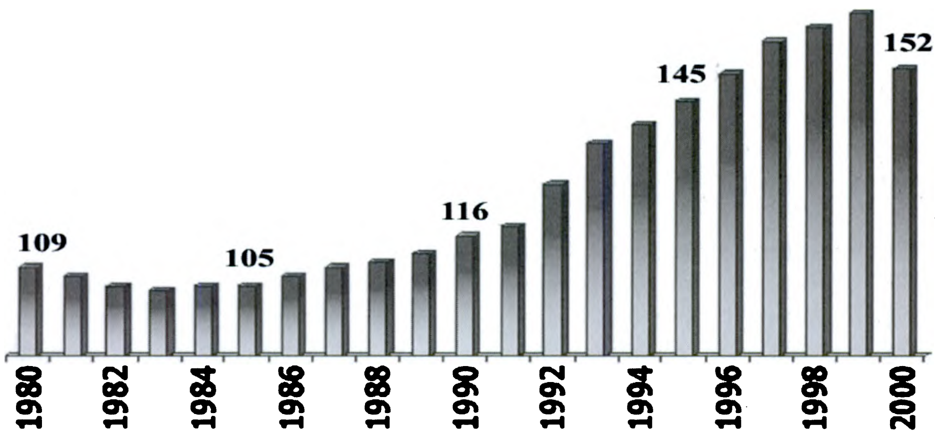

Figure 3. Per capita consumption of eggs in Colombia: 1980-2000.
***Source:** FENAVI-FONAV- Economic Studies Program.*

The poultry sector (eggs, chicken) is affected by some problems that pose a great risk for the continuous development of the activity. The principal risk is related to the dependency on imported raw materials for the production of the balanced feeds that are needed in the production of chickens and eggs. For example, in the total cost of production of one egg, nearly 70% is represented by the cost of maize. The importations of maize in Colombia are now reaching the level of more than 2 million tonnes per year **(Figure 4)**.

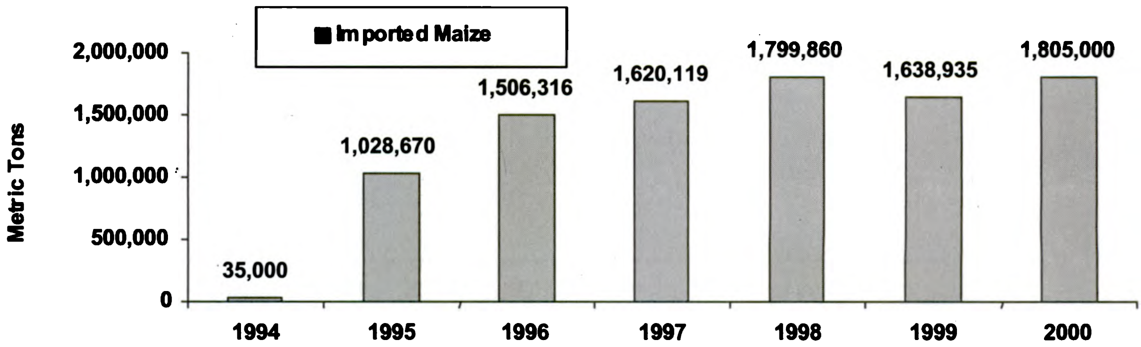

Figure 4. Maize imports in Colombia. 1995-1999.
Source: *FENAVI-FONAV- Economic Studies Program.*

This situation has motivated the poultry sector to look for alternative options that can help them to reduce the dependency on imported cereals. Cassava appears to be one of the most promising alternatives. The sector has called this movement, the "tropicalization of the poultry sector in Colombia". In this context, tropicalization is understood as the promotion and intensification of the use of raw materials that can be produced locally, such us cassava and sweet potato.

The Balanced Feeds Sector in Colombia

The production of balanced feeds in Colombia has experienced a very dynamic growth during the last two decades as a consequence of the increasing demand. **Table 1** presents data on this evolution. It can be observed that on average, growth rates were around 5% per year. From 1990 to the year 2000, the size of the market increased by 50%. This growth has also contributed to the increasing dependency on imported grains to satisfy the requirements for raw material, especially maize **(Figure 4)**

The Market for Cassava in the Balanced Feeds Industry in Colombia

Cassava has a great potential to be developed in Colombia and other countries in the region as a raw material for the growing balanced feed industry. Factors such as the positive growth rates of the sector during the last two decades, the increasing dependency on imported grains to meet this demand for raw materials and the low productivity of domestic cereal production, create an excellent opportunity for cassava to be used intensively as an energy component in animal nutrition programs. The substitution of maize by cassava in balanced feeds for animals is a well-known practice that has had good experiences in many countries such us Holland. **Table 2** shows a typical example of an alternative diet for poultry, based on the partial substitution of maize by cassava flour. The data presented in **Table 2** indicates the potential of the market for cassava flour in the balanced feeds industry. An increment in the use of cassava flour from 0 to 20% in poultry diets implies a reduction of 40.7% in the amount of maize used in the balanced diets.

Table 1. Evolution of the balanced feeds market in Colombia and projections up to 2010 (average for 4 year periods).

Years	Broilers (t/year)	Layers (t/year)	Pigs (t/year)	Cattle (t/year)	Others (t/year)	Total (t/year)
1990/93	942,839	688,941	329,462	154,298	210,450	2,325,990
1994/97	1,198,317	822,853	361,482	157,653	284,401	2,824,706
1998/01	1,453,004	909,686	395,465	170,956	343,067	3,272,178
2002/05*	1,777,968	1,082,971	472,472	202,550	414,428	3,950,389
2006/09*	2,161,131	1,316,358	574,293	246,201	503,740	4,801,723
2010*	2,437,858	1,484,914	647,829	277,726	568,242	5,416,569

*estimates

Source: *FENAVI-FONAV- Economic Studies Program*

Table 2. Balanced feeds for poultry with 20% cassava root flour substituting for maize.

	Broilers		Layers	
Raw Material	Commercial	20% cassava	Commercial	20% cassava
Maize	60.4	35.8	60.4	35.9
Cassava root flour	0	20.0	0	20.4
Soybean cake	11.6	8.9	20.4	17.1
Full-fat soybean	24.8	32.2	8.3	16.3
Oil	0	0	0	0
Carbonate	1.2	1.0	8.7	8.5
Calcium phosphate	1.3	1.3	1.6	1.6
Salt	0.35	0.35	0.35	0.35
Methionine	0.19	0.18	0.14	0.16
Vitamins, mineral additives	0.20	0.20	0.10	0.10

Source: *FENAVI-FONAV- Economic Studies Program*

Potential for the Use of Cassava in the Animal and Balanced Feed Industries in Colombia

Total production of balanced feeds for animal consumption in Colombia for 2000 was estimated at 3,800,000 tonnes. Annual growth of this sector has been around 4 to 5%, thus creating a great pressure on the supply of raw materials, especially agricultural products such us maize, soybeans and sorghum. National agricultural production of these grains has not been able, and will not be able, to satisfy this increasing demand. The principal deficit occurs in the need for energetic sources of which maize and sorghum account for 50 to 60% of the total final volume of balanced feed. Considering the estimations of future growth for the balanced feed sector in Colombia (**Table 1**), it can be concluded that the demand for maize and sorghum in the coming years will be around 2,200,000 tonnes per year. National production with the current areas planted for both cereals will not be able to contribute more than 600,000 tonnes. The difference will have to be imported from countries that have more competitive production systems.

The dry matter content of cassava roots fluctuates normally between 35 and 38%, which is equivalent to a conversion factor of 2.6 tonnes of fresh roots to obtain 1 tonne of cassava flour. Considering a substitution rate of 20% in animal feed concentrates for monogastrics, the needs for cassava flour in Colombia would be around 800,000 tonnes per year. If we consider a range of 15-30 t/ha as the average yield, then Colombia will need to plant approximately 70,000 to 140,000 new hectares of cassava to satisfy this demand.

Cassava leaves can also be processed to produce cassava leaf flour with a high level of protein and fiber for use in animal feeding. One hectare of cassava, with sound management, could yield both roots and leaves or top parts that can be processed into balanced feeds. This cassava leaf flour has also a good potential for feeding ruminants due to its high fiber content. In feeding monogastrics, its use is more limited due to the low level of energy and high fiber content.

Intensive use of cassava in animal feeding requires the elimination of anti-nutritional factors such as linamarine in cassava roots. This compound acts as a precursor of hydro-cyanic acid. The use of adequate processing methods is sufficient to eliminate this problem. The roots have to be properly dried to a moisture content of 12-13% using processing technologies that allow the elimination of the cyanide. In general, it is considered that a level below 100 ppm of hydro-cyanic acid in the final product (cassava flour) is safe for use in animal feed diets.

Cassava flour can be used to partially substitute cereals used in animal feeding for the different species (poultry, swine, cattle, fish). When the proper nutritional adjustments are made in the diet that contains cassava products, the performance of the animals is comparable with the performance obtained in animal feeding programs based on cereals. Most of the research that has been conducted in the world on this subject indicates that cassava flour can be used in levels between 20-40% in the total diet for poultry and swine.

The principal characteristic of cassava flour is the high carbohydrate content (starch) that gives an energy level slightly lower than that of maize and sorghum. The principal limiting nutritional factor in cassava is its low content of protein (2.5-3.5%) and essential fatty acids (< 1.0 %), in contrast with maize and sorghum. Due to these limitations, the price of cassava flour is generally around 70-75% in relation with the price of maize. The difference in price allows the poultry, swine or balanced feed producer to supplement the diet with sources of protein and fat such as soybean. A moderate amount of soybean (full-fat or extruded) can supplement all the nutritional deficiencies of cassava when used in animal feeding programs. The other product of cassava, the leaves, is characterized by their high protein content (18-22%) and fiber content (25-30%). Depending on the animal to be fed, cassava can be used as a partial substitute of cereals, contributing protein, fiber, minerals, vitamins and energy (**Table 3**).

Table 3. Maximum levels of inclusion of cassava roots and leaves in animal balanced feed for various animals.

	Level of inclusion (%)	
Animal	Cassava roots	Cassava leaves
Poultry	25-40	6-8
Pigs	40-80	8-10
Horses	30	
Fish	25	8
Cattle	100	100

Experiences with the use of Cassava Flour in Animal Feeding in Europe

The use of cassava flour in animal feeding started at a commercial level in the 1970s when Thailand launched an aggressive program to produce and export cassava chips to European markets. These programs were built with a very heavy component of subsidies to establish the infrastructure needed to take advantage of this new market. Roads and ports were built, and cassava farmers had access to technical assistance, credit and subsidies to produce and process the crop. The main consumer for these cassava chips and pellets exported from Thailand have been countries in the European Union, especially Holland. In 1970, about 1 million tonnes of cassava flour and pellets were exported from Thailand to the EU, and Holland alone was responsible for using 76% of this volume. By 1980, the volumes exported had grown almost six times and Holland was responsible for consuming 70% of the total volume. Finally, by the year 2000, the volumes of cassava exported had decreased to 4.2 million tonnes and Holland was consuming almost half of the total. This reduction in imports was due to agricultural policies aimed at reducing the financial resources (subsidies) spent on agriculture in the EU and the need to increase the prices for cereals produced in the EU (**Table 4**).

Table 4. Imports of cassava flour and pellets from Thailand into Europe.

	1970	1978	1999
		('000 tonnes)	
European Union	1,000	5,962	4,269
of which Holland	760	4,261	2,429

Source: *Van Poppel, 2001.*

The massive use of cassava flour and pellets by the animal feed and animal production industries in Holland is based on the fact that one kg of cassava flour yields 7% more energy than 1 kg of barley, but 10% less than 1 kg of maize. However, the international price of cassava is 8% cheaper than the price of maize. With this difference in prices, the computer-based models used for calculating the diets prefer to include cassava instead of maize. For the last 40 to 50 years, in Holland, maize has not been included in swine feeding programs because the extra nutritive values that maize could give is not compensated for by the higher price of this cereal. In poultry feeding, cassava flour has 4% less energy than wheat and almost 11% less than maize, but today, with the current prices of maize and wheat in the international markets, the balanced feed industries in Holland use between 10 and 15% of cassava in the formulations. Maize is not used because it is very expensive. Another aspect that explains this preference for cassava is that consumers prefer a chicken with less yellow skin. The option has been to develop feeding systems in which maize only enters at 5% and the ration is based mainly on the combination of wheat and soybean **(Table 5)**.

Table 5. Maximum levels of inclusion of cassava flour and pellets in animal feeding in Holland.

Type of animal	% of inclusion
Swine - raising	20
Swine - fattening	40
Swine - reproduction	40
Poultry - broilers	20-25
Poultry - eggs	30% pellets, 15% flour

Source: *Van Poppel, 2001.*

Experiences with the Use of Cassava Flour in Animal Feeding in Colombia.

In Colombia, the use of cassava in animal feeding has been practiced during the last 30 years. However, the volumes used do not match the tremendous market potential that the balanced feeds sector offers. Among the reasons for this is the unreliable supply of cassava root flour and chips which does not make it attractive for the animal and balanced feed producers to change constantly their formulations. This limitation is now being tackled through government-supported programs that consider cassava as a strategic crop. These strategies will promote considerable increases in the area planted and the volumes processed during the next five years. Another reason for the relatively low use of cassava products in animal feeding in Colombia and other countries of Latin America is the lack of knowledge, dissemination and diffusion, throughout the region, of successful experiences on the use of cassava in animal feeding. CLAYUCA is trying to contribute to solve this constraint through the implementation of experimental work that helps to validate the information available and disseminates the results widely among interested parties. The next section presents some of the preliminary results obtained by CLAYUCA.

Levels of Inclusion of Cassava Flour in Poultry Balanced Diets

The use of cassava, both roots and foliage, in poultry feeding programs is affected by external and internal factors. The most important external factors are: the age of the animal, the type of processing (milled, pelleted, crombelized, extruded, etc) of the final product, and the complementary ingredients that will be included in the diet. The internal factors are related principally to the quality, availability and price of the products. The processing system is one of the external factors that influences the level of cassava that can be used in the diet. Cassava flour, for example, is a rather dusty product that causes management problems when it is mixed with other products and given to the animals. To counteract this limitation, the maximum level of cassava for inclusion in poultry diets is around 25 to 30%. If higher levels are used, then oil or sugarcane molasses have to be used to reduce the dusty characteristic of the diet. If the diet is prepared in the form of pelleted, crombelized or extruded products, higher levels of cassava can be used.

In the case of cassava foliage flour, the most limiting external factor is the fibrous characteristic of the foliage, a constraint that does not allow the inclusion of levels higher than 6 to 8% in the final diet. Even with these low levels, the inclusion of cassava foliage in poultry diets gives an important contribution of protein and natural pigments for both broilers and layers.

Complementarity of Cassava and Soybeans in Poultry Feeding Programs

When cassava root flour is used to prepare a balanced feed, due to its lack of protein and some essential fatty acids, it needs to be complemented with other ingredients that provide the nutrients needed for the feed to be appropriately balanced. Integral soybean (full and fat) has a good synergy with cassava in the design of poultry feeding programs with high nutritional quality. A balanced mixture of cassava flour and integral soybeans can totally cover the requirements for energy, protein and essential fatty acids for broilers and layers.

As shown in **Table 6**, the low concentration of some essential nutrients present in cassava root flour can be compensated satisfactorily by including soybeans in the balanced feed. The specific nutritional requirements for both layers and broilers can be fully satisfied by different mixtures of cassava flour (from roots and leaves) and integral soybeans. The complementarity between the two crops simplifies the design of sound animal nutrition programs under commercial conditions. A mixture of 82 parts of cassava root flour and 18 parts of integral soybean, becomes a product with similar characteristics to those of cereals **(Table 7)**

Table 6. Main nutrients in cassava flour and integral soybeans.

Nutrient	Unit	Cassava root flour	Cassava foliage flour[1)]	Integral soybean
Metabolizable energy	Mcal/kg	3.0 to 3.2	1.38	3.6 to 3.8
Starch	%	68		8.0
Protein	%	2.8	20.7	38.0
Fiber	%	2.6	15.2	4.9
Ashes	%	3.2	8.5	5.2
Fat	%	1.2	5.3	19.0
Linoleic acid	%	0.4		8.9
Lecitin	%	0.1		2.0
Methionine	%	0.03	0.36	0.51
Cystine	%	0.02	0.60	0.60
Lysine	%	0.05	1.87	2.31
Threonine	%	0.05	1.35	1.43
Tryptophane	%	0.02	0.24	0.52

[1)] Includes leaves, petioles and young stem, harvested at 3 months after planting.
Sources: *Van Poppel, 2001; Buitrago and Luckett, 1999.*

Table 7. Nutritional composition of cassava flour (82%) mixture with integral soybeans (18%) as compared to that of maize.

Nutrients	Cassava flour (82%) + integral soybean (18%)	Commercial maize
Metabolizable energy, Mcal/kg	3.25	3.34
Protein, %	9	8.5
Lysine, %	0.46	0.26
Methionine, %	0.12	0.18
Methionine + cystine, %	0.24	0.35
Threonine, %	0.28	0.29
Thryptophane, %	0.10	0.07
Arginine, %	0.51	0.40
Fat, %	3.5	3.6
Linoleic acid, %	1.7	2.1
Fiber, %	3.9	2.8
Ash, %	3.6	2.1
Calcium, %	0.29	0.04
Available phosphorus, %	0.09	0.08

Source: *Buitrago and Luckett, 1999.*

Experiences obtained in Colombia using this type of feed (mixture of 82% cassava flour and 18% integral soybean) have shown the possibility of obtaining performances that are similar to those obtained with diets elaborated using traditional cereals (maize and sorghum). Some results obtained in poultry feeding programs based on mixtures of cassava flour and processed integral soybeans are discussed in the next section.

Broiler Feeding Programs Based on Cassava and Soybean Mixtures

Balanced feed for broilers is generally prepared in the form of pellets or crombelized diets so the dustiness of the cassava flour is not a limitation; and the recommendation for the level of inclusion of cassava roots that can be used could be as high as the total substitution of cereal grains in diets for starting and finishing broilers. This type of diet allows the inclusion of the maximum levels of cassava root flour (45-50%) and cassava foliage flour (5-6%). If there is ample availability of these ingredients (cassava root flour, cassava leaf flour, integral soybeans and soybean meal) at competitive prices, it is possible to formulate a perfectly balanced diet for broilers, in which these four ingredients represent up to 95% of the total feed, as illustrated in **Table 8**.

Results of Feeding Programs for Broilers with Maximum Levels of Inclusion of Cassava Flour

CLAYUCA has conducted recently some work with financial support from FENAVI, the Colombian Poultry Growers Federation, and the Colombian Ministry of Agriculture and Rural Development. The objective was to evaluate the technical and economic feasibility of using diets similar to those presented in **Table 8**. The diets were prepared with total replacement of maize using cassava flour from roots and foliage and integral soybeans. The check was a commercial feed based on maize and integral soybean. The preparation of the cassava root flour was done using two processing methods: solar drying on cement floors and artificial drying using a pilot plant available at CLAYUCA, that uses steam to heat the air. **Table 9** presents the detailed composition of the four diets used.

Table 8. Example of a complete ration for broilers based on cassava products and integral soybean.

Ingredients, %	Starter		Finish	
	Roots	Roots and foliage	Roots	Roots and foliage
Cassava root flour	45.7	40.4	49.8	46.0
Cassava foliage flour		6.0		6.0
Integral soybean (toasted)	30.0	30.0	41.6	45.1
Soybean meal	18.7	16.4	5.2	
Palm oil	2.9	4.5		0.3
Dl-methionine	0.29	0.29	0.23	0.23
Dicalcium phosphate	1.52	1.52	1.52	1.5
Calcium carbonate	0.38	0.38	0.38	0.32
Salt	0.3	0.3	0.3	0.3
Vitamins and minerals	0.1	0.1	0.1	0.1
Anticoccidial and additives	+	+	+	+
Nutritional composition				
Metabolizable energy, Mcal/kg	3.22	3.22	3.18	3.18
Protein, %	22.00	22.00	20.00	20.00
Methionine, %	0.59	0.59	0.49	0.49
Methionine + lysine, %	0.90	0.90	0.78	0.78
Lysine, %	1.26	1.26	1.12	1.12
Linoleic acid, %	3.41	3.56	3.60	3.85
Calcium, %	0.91	0.91	0.96	0.90
Availabe phosphorus, %	0.42	0.42	0.40	0.40

***Source**: Gil et al., 2001.*

1. Effects on weight gain and feed conversion

Table 10 shows the performance of the broilers during the first 42 days when the trial was finished. It can be noticed that every group that consumed cassava flour and integral soybeans had a weight gain and feed conversion similar or superior to the control group fed with the commercial diet based on maize and integral soybeans. The consumption of the balanced feed was not affected by the treatments that included high levels of cassava flour. The mortality rates were the same in all the treatments. The performance of the chickens was superior when the cassava root flour was prepared using the artificial drying system, suggesting a positive effect from this processing method. The high temperature and the better sanitation control that is obtained with the artificial system could explain this positive effect.

Table 9. Diets based on cassava root and leaf flour in comparison with a maize-based control diet for broilers - Starting Phase.

Ingredients, %	Control	Cassava root flour		Cassava root flour + foliage flour
		Solar drying	Artificial drying	
Maize	59.37			
Cassava root flour		45.75	45.75	40.45
Cassava foliage flour				6.00
Integral soybean	12.80	30.00	30.00	30.00
Palm oil	3.00	2.90	2.90	4.50
Soybean meal	21.00	18.70	18.70	16.40
Dl-methionine	0.16	0.29	0.29	0.29
L-Lysine	0.07			
Bone meal	1.70	1.90	1.90	1.90
Calcium carbonate	1.50			
Salt	0.30	0.30	0.30	0.30
Vitamins and minerals	0.10	0.10	0.10	0.10
Nutritional composition				
Metabolizable energy, Mcal/kg	3.20	3.20	3.20	3.20
Protein, %	22.00	22.00	22.00	22.00
Methionine, %	0.59	0.59	0.59	0.59
Methionine + Cystine, %	0.90	0.90	0.90	0.90
Lysine, %	1.26	1.26	1.26	1.26
Linoleic acid, %	2.62	3.42	3.42	3.56
Calcium, %	0.91	0.91	0.91	0.91
Available phosphorus, %	0.42	0.42	0.42	0.42

2. Effects on pigmentation

Important observations were made in relation with the degree of pigmentation of the skin, legs and internal fat of the birds. The groups with diets based on cassava root flour were characterized by a poor pigmentation throughout the experiment. However, the group with a diet based on cassava root and cassava foliage flours had a pigmentation similar to that of the control group fed with diets based on yellow maize. The visual appreciation on a scale from 1 (more pale) to 5 (more pigmented), gave these two groups a score of 4, whereas the groups fed with only cassava flour obtained a score of 2.

Results of Feeding Programs for Broilers with Medium and Low Levels of Inclusion of Cassava Flour

Although the results obtained from replacing totally the cereal grains by cassava flour in pelletized diets have demonstrated the viability of this practice in commercial feeding programs for broilers, it is possible that in many occasions it is more convenient to use a partial substitution of the cereal grains. This partial substitution could be even more important when the diets are prepared in the form of flour given the dusty characteristics of cassava flour.

Table 10. Performance of broilers up to 42 days fed with cassava root flour dried using three different methods.

Parameter	Control	Cassava root flour			Cassava root flour and foliage flour
		Solar	Equipment A	Equipment B	
Initial weight, g	39.80	39.50	39.40	39.50	39.70
Final weight, g	2.14	2.28	2.24	2.39	2.11
Consumption, kg	4.73	4.88	4.65	4.68	4.72
Efficiency of feed conversion	2.21	2.14	2.08	1.96	2.24

Tables 11 and **13** show the composition of diets with intermediate levels of cassava flour, so as to substitute 50% of the sorghum and maize, respectively, used in diets for the starting and finalization phases of broiler feeding. The results obtained are shown in **Table 12** and **14**. It can be observed that, in general, the broilers that consumed diets with 50% substitution of sorghum or maize performed equal or better than those broilers fed with the conventional diets based on sorghum or maize. In terms of weight increase, the feed conversion ratio and carcass yield did not present significant differences either. Adverse effects of the inclusion of cassava flour in terms of mortality or morbidity were not observed.

Table 11. Diets for broilers with intermediate levels of cassava root flour to replace 50% of sorghum.

Ingredients, %	Starter	Finish
Sorghum	33.65	33.61
Cassava root flour	20.00	25.00
Toasted integral soybean	32.00	34.00
Soybean meal	8.20	2.80
Fish meal (65%)	3.50	4.00
Palm oil		0.10
Dicalcium phosphate	0.90	0.70
Calcium carbonate	0.80	0.90
Dl-methionine	0.27	0.22
Salt	0.25	0.25
Choline chloride (50%)	0.12	0.10
Vitamins and minerals	0.10	0.10
Anticoccidial	0.10	0.10
Fungicide	0.10	0.10
	Nutritional composition	
Metabolizable energy, Mcal/kg	3.15	3.20
Protein, %	21.00	19.00
Methionine, %	0.58	0.51
Methionine + Cystine, %	0.88	0.77
Lysine, %	1.23	1.10
Thryptophane, %	0.28	0.25
Threonine, %	0.60	0.59
Linoleic acid, %	3.08	3.10
Calcium, %	0.90	0.91
Available phosphorus, %	0.43	0.40

***Source:** Buitrago and Luckett, 1999.*

Table 12. Performance of broilers fed with sorghum or with an intermediate level of cassava root flour in the diet.

Parameters	Check [1)]	Cassava root flour + integral soybean[2)]
Starting number	48.441	24.000
Finalizing number	46.199	22.392
Number of days	42	42
Mortality, %	4.6	6.7
Final weight, g	1,934	1,915
Feed consumption, g	3,559	3,152
Feed conversion ratio	1.84	1.69
European efficiency factor	239	259

[1)]100% sorghum as main feed ingredient
[2)]50% of sorghum replaced by cassava root flour and integral soybean
Source: *Buitrago and Luckett, 1999*

Table 13. Diets for broilers with intermediate levels of cassava root flour to replace 50% of maize.

Ingredients %	Starter	Finish
Maize	25.34	30.79
Cassava flour (82%) + soybean (18%)	30.50	30.50
Toasted integral soybean	25.90	28.30
Soybean meal	12.10	4.80
Chicken innards meal	3.00	3.00
Dicalcium phosphate	1.30	1.00
Calcium carbonate	1.00	0.90
Dl-methionine	0.23	0.10
Salt	0.35	0.30
Vitamins and minerals	0.12	0.10
Anticoccidial	0.05	0.10
Fungicide	0.10	0.10
Nutritional composition		
Metabolizable energy, Mcal/kg	3.10	3.20
Protein, %	22.00	17.00
Methionine, %	0.56	0.40
Methionine + Cystine, %	0.90	0.72
Lysine, %	1.24	1.10
Thryptophane, %	0.28	0.25
Threonine, %	0.80	0.75
Linoleic acid, %	3.25	3.48
Calcium, %	0.90	0.82
Available phosphorus, %	0.42	0.39

Table 14. Performance of broilers fed with maize or with an intermediate level of cassava root flour in the diet.

Parameters	Check[1)]	Cassava root flour + integral soybean[2)]
Starting number	7,680	7,673
Finalizing number	7,415	7,108
Number of days	42	42
Mortality, %	3.2	5.7
Final weight, g	1,976	1,942
Feed consumption, g	3,754	3,781
Feed conversion ratio	1.90	1.94
European efficiency factor	239	218

1) 100% maize as main feed ingredient
2) 50% of maize replaced by cassava root flour and integral soybean
Source: *Buitrago and Lucket, 1999.*

Feeding Programs for Layers Based on Cassava and Soybean Mixtures

Feeding programs for layers generally involve the use of diets in flour form, which becomes an important limitation for the inclusion of high levels of cassava root flour. To overcome this limitation, low and intermediate levels of cassava root flour are used. Unless pelletized or crombelized diets are used, it is difficult to incorporate cassava flour in the diets with levels higher than 25%. The dusty nature and the high starch content of the cassava root flour make it difficult to manage higher levels of cassava root flour in the balanced feed.

With respect to cassava foliage flour, it is recommended that the maximum level to be used in diets is around 5 to 6%, to minimize the effects of the low palatability of the feed. Likewise, the energy concentration of the diet makes it difficult to include higher levels. When levels of 5 to 6% of cassava foliage flour are used, a good pigmentation is obtained in the egg's yolk due to the presence of natural xanthophylls in the cassava foliage.

Results of Field Experiences

The following results are a summary of experiments conducted in several regions of Colombia, at commercial scale, and using different stages of production, diets, raw materials and nutritional parameters. In all cases, the diets were prepared in the form of flour. **Tables 15** and **17** illustrate the composition of the diets used. **Tables 16 and 18** present the results obtained in the different trials.

No important differences were observed in the production parameters evaluated: egg laying percentage and conversion efficiency. The results obtained were within normal ranges for each line and hen age. Additionally, other parameters such us morbidity and mortality were not significantly different in those lots in which the hens consumed diets with intermediate levels of cassava flour.

Table 15. Diets for layers without and with 10% inclusion of cassava root flour.

Ingredients %	Check	Cassava flour 10%
Maize	57.80	45.30
Cassava flour		10.00
Soybean meal	16.20	15.00
Toasted integral soybean	5.30	9.10
Fish meal (65% protein)	5.00	5.00
Wheat bran	3.50	3.50
Calcium carbonate	9.71	9.64
Calcium phosphate	0.95	0.91
Salt	0.30	0.30
Liquid methionine (88%)	0.18	0.20
Vitamins and minerals	0.10	0.10
Additives and pigments	0.50	0.50
	Nutritional composition	
Metabolizable energy, Mcal/kg	2.75	2.75
Protein, %	17.50	17.50
Lysine, %	0.91	0.91
Methionine, %	0.44	0.44
Methionine + Cystine, %	0.75	0.75
Linoleic acid, %	1.36	1.39
Calcium, %	3.90	3.90
Available phosphorus , %	0.45	0.45

Table 16. Performance of layers without and with 10% inclusion of cassava root flour in the diet. Weeks 48 to 55.

	Check	Cassava flour 10%
Consumption, g/hen/day	102.6	103.2
Egg laying, %	89.2	89.5
Feed conversion per dozen of eggs	1.4	1.4

Source: *Gutierrez and Martinez, 1998.*

Table 17. Diets for white and red layers without and with 10% or 20% inclusion of cassava root flour.

Ingredients, %	Check	Cassava root flour 10%	Cassava root flour 20%
Maize	41.10	34.10	23.00
Cassava flour		10.00	20.00
Soybean meal	8.10	10.40	11.80
Extruded soybeans	20.00	20.00	20.00
Rice polishings	10.00	10.00	10.00
Wheat bran	9.10	4.30	3.60
Calcium carbonate	9.60	9.50	9.40
Calcinated bone flour	1.30	1.40	1.40
Salt	0.35	0.35	0.35
Dl-methionine	0.18	0.19	0.21
Vitamins and minerals	0.20	0.20	0.20
Additives and pigments	0.10	0.10	0.10
	Nutritional composition		
Metabolizable energy, Mcal/kg	2.70	2.70	2.70
Protein, %	17.00	17.00	17.00
Lysine , %	0.85	0.85	0.85
Methionine, %	0.45	0.45	0.45
Methionine + Cystine, %	0.70	0.70	0.70
Linoleic acid, %	1.74	1.49	1.37
Calcium, %	3.90	3.90	3.90
Available phosphorus, %	0.42	0.42	0.42

Table 18. Performance of Red Layers (Lohmann Brown) without and with 10% or 20% inclusion of cassava root flour in the diet. Weeks 78 to 88.

	Check	Cassava root flour 10%	Cassava root flour 20%
Number of layers	3,840	10,956	5,160
Consumption, g/hen/day	115.10	115.80	114.80
Egg laying, %	69.30	65.70	65.10
Feed conversion per dozen eggs	2.00	2.12	2.11

***Source:** Buitrago and Lucket, 1999.*

CONCLUSIONS

In many tropical regions, cassava appears to be a profitable energetic alternative to partially or totally replace cereal grains used in poultry feeding programs. The calories obtained per unit of cultivated area is usually greater for cassava as compared to cereals.

The integration of cassava with poultry production programs demands special efficiency and industrialization schemes to guarantee the cassava volumes demanded by the poultry sector, at competitive prices and with the quality standards required.

The use of high-yielding varieties, the mechanization of planting and harvesting, the industrial process of transforming the roots into flour, are some *sine qua non* requirements for the establishment of an efficient, viable integration between the cassava and poultry sectors. There have been recent advances in all of these components that are contributing to reduce production costs and increase the competitiveness of the crop.

Due to the protein deficiency of the cassava root, the price of the cassava root flour needs to be 25 to 30% lower than the price of cereals (sorghum, maize), to be able to enter in the poultry feeding programs.

In broilers and layers feeding, cassava root flour and cassava foliage flour are excellent sources of energy, protein and natural pigments.

Cassava foliage flour must not be included in diets for broilers or layers at levels higher than 5-6% due to its high fiber content and low energy level.

Cassava root flour has important limitations in the protein and fatty acid content. This is a reason why the balance of the final diet requires an effective complementation of these two nutrients. In numerous experiments it has been demonstrated that integral soybean is an excellent supplement to compensate for the nutritional deficiencies of cassava root flour.

As long as the broiler diet is pelletized, cassava flour can be used to totally replace the cereal grains in the diet, without affecting the performance. For diets in the form of flour, it is not recommended to include more than 25% of cassava root flour due to its dusty nature, which causes difficulties in consumption.

In the case of diets presented in the form of flour, it is recommended to replace cereals by cassava root flour up to 50%, which is approximately equivalent to using 25% of cassava root flour in the diet.

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CLEAN CASSAVA CHIPS FOR ANIMAL FEEDING IN THAILAND

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ABSTRACT

Thailand has been the top cassava products exporter to the world market for decades. However, there was a decline in exports of cassava pellets to the EU market and this has affected the prices of both cassava fresh roots and dry products in the country. Therefore, greater domestic use of cassava for animal feeding in Thailand is being encouraged.

Cassava has been promoted for use in animal feeds in Thailand for more than a decade, but adoption has been very limited due to the unsuitable quality of cassava products (cassava chips and pellets) available, and the relatively high price of the products (after mixing with a protein source) when compared to conventional cereals, such as maize and broken rice. In 1997, when Thailand suffered an economic crisis as well as a severe slump in cassava prices due to the sharp decline of cassava pellets exports to the EU market, the Animal Nutrition Research and Development Center (ANRDC) of Kasetsart University and the Thai Tapioca Development Institute (TTDI) decided to promote more actively the use of cassava for domestic animal feed production in Thailand.

The activities included the transfer of technology to the farmers in the proper use of cassava for animal feeding via seminars, workshops, publications T.V media, etc. They also included technologies to improve the quality of cassava chips to be employed by the farmers. Prime quality (clean) cassava chips are now produced by some cassava processors and this has facilitated the successful use of cassava in animal diets. At present, the Department of Interior Trade (DIT) and the Department of Foreign Trade (DFT), Ministry of Commerce, together with ANRDC and TTDI, have promoted more production and more uses of prime quality cassava chips, both for animal feeding in the country and for export to the world market.

Proper feeding of prime quality cassava chips to animals, including pigs, poultry (chickens and ducks) and cattle, both in laboratory and in commercial animal farms, have shown a very satisfactory and a comparable performance as compared to those animals fed with maize diets. But cassava diets also have an advantage in terms of better digestibility, health improvement of the animals, which has led to a much reduced use of antibiotics in animal production, and a considerable reduction in the odor of manure. Cassava has been extensively used in pigs and cattle (beef and dairy) diets at substitution levels of 40-60%. A series of studies on the advantages of using cassava in animal diets have been conducted at ANRDC of Kasetsart University and the results are very promising.

INTRODUCTION

Cassava is an important economic root crop grown in Southeast Asia as well as in tropical Africa and Central America. The crop plays a very important role in the economy of Thailand since a great number of farmers, especially those in the northeastern part of the country, rely on cassava for much of their income.

The fresh roots, which contain approximately 60% moisture, are mainly utilized for the production of cassava starch or dried cassava chips and pellets for animal feeds.

1. Cassava Cultivation in Thailand

Cassava is one of the most important economic crops in Thailand. The country produces approximately 18-22 million tonnes of fresh roots annually, of which

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approximately 8 million tonnes are utilized for cassava starch production and the remaining 10-14 million tonnes are processed into 4.5-6.0 million tonnes of dried cassava chips and pellets for animal feed. The chips are mainly utilized domestically while the pellets are exported mainly to the European Union (EU) countries. But in 1993, the EU initiated a CAP reform policy, with the objective to reduce the price of cereals grown in the EU countries; this has resulted in a decrease in the price of cassava and has gradually reduced the amount of cassava pellets exported to the EU market. However, more cassava chips are utilized domestically for animal feed; therefore, the production volume is still maintained and the cassava price crisis has been relieved.

Cassava production is scattered throughout the country but the major production areas are in the northeastern and eastern parts of Thailand, while considerable volumes of cassava are also produced in the northern and western parts of the country. Planting of cassava generally starts in April and May, at the beginning of the rainy season, and harvesting is normally done in October to March of the following year during the dry season. It is the good weather in Thailand during the cassava harvesting season that ensures that Thai cassava products are of high quality, compared to the products of some other countries.

In addition, in Thailand cassava varieties have been developed that produce high yields and have high starch contents; these are now widely distributed to the growers. For example, Kasetsart 50 (KU 50), which was developed by the Department of Agronomy, Faculty of Agriculture, Kasetsart University; and Rayong 5, Rayong 60 and Rayong 90 which were developed by the Department of Agriculture, Ministry of Agriculture and Co-operatives, are new cassava varieties which produce high yields and have high starch contents; these are now commonly grown by farmers in the country.

2. Toxic Substances in Cassava and their Detoxification

Fresh cassava roots contains the cyanogenic-glycoside, linamarin, which is hydrolyzed into glucose and hydrocyanic acid (HCN) by the activity of linamarase enzyme when the root is damaged or cut into small pieces. The released HCN slowly evaporates into the atmosphere, so the level of HCN in the cassava products is reduced.

Dried cassava chips are produced by chopping the fresh roots into small pieces and then sun-drying for 3-4 days; this, greatly reduces the HCN content of the chips to levels that are non-toxic to animals. Khajarern *et al.* (1982) have demonstrated that sun-drying of cassava chips for 6 days reduced the HCN content of the chips from 111.83 to 22.97 ppm (**Table 1**). Storing of dried cassava chips also further reduces the HCN content of the cassava product. Storing of dried cassava chips for five days reduced the HCN content of the product from 87.14 to 36.25 ppm (**Table 2**). Steam assisted pelleting of cassava further reduced the HCN content to 11.82 ppm (Khajarern *et al.*, 1979).

It can be concluded that production of dried cassava chips involving 3-6 days of sun-drying and a few days of storage before shipment to the feed manufacturer or users lowers the HCN content in the product to non-toxic levels. Additional storage of the cassava product at the feed mill will further reduce the HCN content and provide an additional safety margin for the users. The use of cassava pellets eliminates any risk of HCN toxicity to the animals.

From our field experiences, the authors have promoted the use of cassava chips in pig and poultry feeds for the past decade. Good quality cassava chips produced in

Thailand, in which the moisture content is less than 14%, have on average an HCN content below 30 ppm, and have produced no HCN toxicity in animals.

HCN in cassava may be eliminated by cooking, steaming, drying, ensiling as well as by washing. Some of these processes are not practical for preparation of cassava products for animal feeds, but they may be employed in the preparation of cassava for human consumption.

Table 1. Effects of length of sun drying on the HCN content of cassava chips.

Days of sun drying	HCN content (ppm)
0	111.83
1	111.96
2	110.96
3	109.96
4	90.72
5	52.22
6	22.97

Source: *Khajarern et al., 1982.*

Table 2. Effects of length of storage on HCN content of cassava chips.

Days of sun drying	HCN content (ppm)
0	87.14
1	56.76
2	40.11
3	29.52
4	31.46
5	36.25

Source: *Khajarern et al., 1982.*

3. Production of Dried Cassava Chips and Pellets

Dried cassava chips and pellets are common cassava products used in animal feeds. A schematic diagram of their production process is shown in **Figure 1**. Freshly harvested roots are cleaned by washing or sifting, then chipped into small pieces and sun-dried on concrete floors for 3-6 days, depending on weather conditions and sunlight. The chips are regularly turned over by mechanical raking throughout the drying period. Dried chips normally contain 13-14% moisture and are kept in the warehouse for a few days before shipment to the users.

Cassava chips may be ground, steamed and pelletized into cassava pellets which are more compact, less dusty and very convenient for transportation and bulk shipment. However, some additives such as palm kernel cake or palm oil should be added in order to facilitate the pelletizing process. Some additives which have a high crude fiber content may affect the nutritional value of cassava pellets; therefore, more attention should be paid to quality control when using cassava pellets in animal diets.

Dried cassava chips are bulky and dusty, and are not appropriate for bulk shipment and transportation by ship. However, chips are easy to determine their quality and are very appropriate for domestic use in the feed industry.

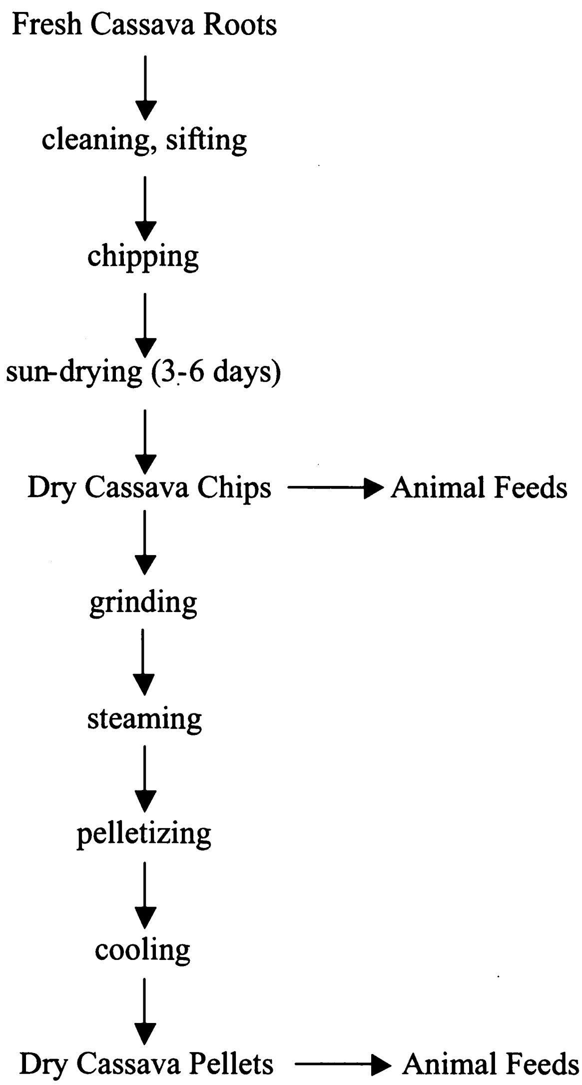

Figure 1. Schematic diagram of the cassava chips and pellets production process.

4. Nutritive Value of Dried Cassava Chips and Pellets

The chemical composition of cassava compared to maize, sorghum and broken rice is shown in **Table 3**. In general, cassava is an excellent energy feed ingredient but contains very little protein (approximately 2%) and has low levels of amino acids as compared to other feed ingredients. Cassava products are also low in fat and contain no pigments for poultry. The chemical composition of cassava chips and pellets produced in Thailand is shown in **Table 4**. In general, the crude fiber and ash contents of cassava pellets may be higher than cassava chips due to the addition of pelleting additives such as palm kernel cake or some vegetable oil for lubricants. The nutritive value of pelleted cassava varies according to the types and amount of pelleting additives included. Additives that increase the crude fiber and ash levels in the pelleted cassava will lower the nutritive value of the product.

Table 3. Comparison of chemical composition of cassava, broken rice, maize and sorghum.

	Cassava	Broken rice	Maize	Sorghum
Crude protein (%)	2.00	8.00	8.00	11.80
Lysine (%)	0.09	0.27	0.25	0.23
Methionine (%)	0.03	0.27	0.19	0.16
Methionine+Cystine (%)	0.06	0.32	0.39	0.27
Tryptophan (%)	0.02	0.10	0.09	0.10
Threonine (%)	0.07	0.36	0.32	0.33
Isoleucine (%)	0.07	0.45	0.34	0.44
Arginine (%)	0.12	0.36	0.40	0.39
Leucine (%)	0.12	0.71	1.17	1.38
Phen + Tyr (%)	0.12	1.15	0.81	0.96
Histidine (%)	0.03	0.18	0.25	0.22
Valine (%)	0.09	0.53	0.46	0.55
Glycine (%)	0.08	0.71	0.33	0.33
Metab. energy for pigs (Mcal/kg)	3.26	3.60	3.30	3.14
Metab. energy for poultry (Mcal/kg)	3.50	3.50	3.37	3.25
Fat (%)	0.75	0.90	4.00	3.00
Crude fiber (%)	4.00	1.00	2.50	3.00
Calcium (%)	0.12	0.03	0.01	0.04
Avialable phosphorus (%)	0.05	0.04	0.10	0.10

Table 4. Standard of cassava chips and pellets produced in Thailand.

	Cassava chips	Cassava pellets
Moisture (%)	13	13
Crude protein (%)	2	2
Crude fiber (%)	3.5-4.0	4.0-4.5
Ash /Sand	2	2
Nitrogen-free extract (%)	75-80	73-78

The crude fiber and ash contents of cassava chips depend very much on the quality of fresh roots and the processing techniques. Good quality fresh roots, which are clean and have minimal or no adulteration of stems or woody parts will produce good quality cassava chips with low crude fiber and ash contents. Washing or sifting of fresh roots to eliminate sand and soil before chipping significantly lowers the ash content. Production of large cassava chips not only minimizes the dustiness during processing but also prolongs the drying period and thus reduces the HCN content. Peeling of fresh roots before processing will also lower the crude fiber and ash contents of the chips. However, peeling is not recommended as it is very tedious and impractical as well as uneconomical for preparation of cassava for animal feed. The use of good quality cassava chips or pellets produced from unpeeled roots normally result in very satisfactory performances of the animals when compared to broken rice or maize.

The nutritive value of cassava products also depends on the contents of organic and inorganic parts of the cassava. Khajarern *et al.* (1979) have categorized the nutritive value of cassava products as chemical grade or quality score according to the following equation:

Chemical grade or quality score = OM – [ADF + (CF – 3)]

where OM = % organic matter
ADF = % acid detergent fiber
CF = % crude fiber

Cassava products may be classified into four grades: A,B,C and D when the quality score is >80, 75–80, 70-75 and <70, respectively. However they did not report any information on tested results of the effects of the quality score on the performance of the animals.

Phansurin *et al.* (2002) and Lokaewmanee *et al.* (2002) have shown that the metabolizable energy (ME) content of cassava chips are inversely related to the levels of crude fiber in the feed ingredients **(Table 5)**. Increasing the levels of crude fiber significantly ($P<0.05$) decreased the ME content of the cassava chips, both in pig and in chicken diets. It is advisable to use only high-quality cassava products in animal feeds; these not only have low fiber contents and thus allow a higher inclusion rate of the product in the animal diets, but they also have a higher nutritive value, which is worth the higher price.

Table 5. Metabolizable energy (ME) of cassava starch and chips with different levels of crude fiber in pig and chicken diets.

Types of cassava products	Crude fiber (%)	Pigs		Broilers	
		20 kg	60 kg	3 weeks	7 weeks
		ME (Kcal/kg)			
Cassava starch	0	3,741	3,756	3,819	3,848
Chips of peeled roots	2.3	3,540	3,574	3,712	3,749
Prime quality chips	3.9	3,356	3,385	3,587	3,615
Regular quality chips	5.2	3,189	3,291	3,283	3,335

***Source:** Punsurin et al., 2002; Lokaewmanee et al., 2002.*

Cassava starch is highly digestible due to the soft-starch as it consists of more than 80% amylopectin. Cassava has the highest digestibilities in dry matter, organic matter and energy in different parts of the digestive tract of growing pigs when compared to maize, sorghum and barley **(Table 6)** (Reas, 1996). The cassava diet showed a significant linear decline in dry matter, organic matter and energy from the stomach down to the caecum, resulting in an almost complete digestion before the large intestine. The maize diet had lower digestibilities for dry matter, organic matter and energy compared to cassava, but these differences were not statistically significant. Sorghum and barley were not significantly different from each other but were significantly lower than cassava and maize in the digestibilities of dry matter, organic matter and energy after the small intestine. It can be concluded that cassava is an excellent energy source and can replace the cereal grains in growing pig diets.

Table 6. Nutrient digestibility (%) of cassava, maize, sorghum and barley in the different parts of the digestive tract and anus (faeces) of growing pigs.

Diets	Stomach	Small intestine	Caecum	Large intestine	Faeces
Dry Matter					
cassava	30.6	59.0	87.5 [a]	89.1 [a]	90.3
maize	1.4	59.3	82.5 [a]	87.5 [ab]	88.2
sorghum	4.0	54.8	74.2 [b]	84.3 [bc]	87.6
barley	16.5	63.5	69.1 [b]	81.4 [c]	83.0
LSD	NS	NS	8.12	3.29	
Organic Matter					
cassava	30.2 [a]	61.6	88.8 [a]	90.9 [a]	92.7
maize	1.0 [b]	57.0	83.7 [a]	89.4 [ab]	90.1
sorghum	-7.8 [b]	56.3	76.2 [b]	86.8 [b]	89.6
barley	12.2 [ab]	64.3	72.7 [b]	83.4 [c]	84.0
LSD	19.8	NS	7.4	40.5	
Energy					
cassava	28.3 [a]	54.4	86.8 [a]	89.0 [a]	90.6
maize	2.0 [b]	50.4	81.9 [a]	87.6 [a]	88.3
sorghum	-7.6 [b]	49.6	72.5 [b]	83.5 [b]	86.8
barley	2.2 [b]	59.4	68.6 [b]	80.3 [c]	82.3
LSD	12.0	NS	8.9	2.8	

Source: *Reas, 1996.*

Cassava products may be contaminated with mold growth under standard production practices, but it appears that the molds produce very little or no aflatoxins or other mycotoxins. Scudamore *et al.* (1997) studied the occurrence of mycotoxins in 330 samples of raw ingredients used for animal feeding in the 186 feed mills in the United Kingdom in 1992. They reported that no cassava samples were found to be contaminated with aflatoxins or other mycotoxins, while samples of maize, rice bran, palm kernel meal, cottonseed meal, wheat and barley were found to be contaminated with aflatoxin B1, fumonisin B1 and B2, ochratoxin A or zearalenone. Protein enriched cassava (PEC), which is produced by two days of fermentation of cassava with *Aspergillus niger* followed by two days of fermentation with *Saccharomyces cereviseae* can totally replace maize in growing finishing pig diets (Laosriratanachai, 1986). Fermentation with these fungi produced heavy mold growth on the substrate but there were only trace amount of aflatoxins in the PEC product. Results of our own survey also indicate that pieces of heavily molded cassava chips collected from cassava chipping yards in Thailand contain only trace amounts of zearalenone and no aflatoxins (Sukanya Juttupornpong, personal communication). These findings are in agreement with the practical results of using cassava in animal diets in Thailand; there were no reported incidences of aflatoxins or other mycotoxin toxicities in cassava diets fed to pigs, cattle and poultry including ducks. Cassava may be classified as a clean or free-of-toxin feed ingredient for animals feeding.

5. Cost Comparison of Cassava Products to Maize and Other Cereals

Although cassava and maize are classified as energy feed ingredients, cassava contains less protein and fat than maize. In addition, cassava contains no pigment for yolk and skin coloring in poultry. It is necessary, therefore, to equalize the nutritive value of cassava products before any cost comparison can be made.

Cassava-maize equivalent mixture (CMEM) is a combination of cassava, soybean meal (SBM) and synthetic amino acids to increase the protein and amino acid content in cassava to be equivalent to those of maize.

CMEM-1 is a mixture of 0.87 kg of cassava + 0.13 kg of soybean meal (SBM) + 0.001 kg of Dl-methionine, which supplies crude protein, amino acids and metabolizable energy (ME) equivalent to maize.

CMEM-2 is a mixture of 0.845 kg of cassava + 0.13 kg of SBM + 0.025 kg of rice bran oil + 0.001 kg of Dl-methionine, which also supplies crude protein, amino acids, ME and fat equivalent to maize.

CMEM-3 is a mixture of 0.85 kg of cassava + 0.15 kg of extruded full-fat soybean + 0.001 kg of Dl-methionine which also supplies crude protein, amino acids, ME and fat equivalent to maize.

The chemical compositions and prices of CMEM-1, CMEM-2, CMEM-3 and maize are shown in **Table 7**.

CMEM-1 is appropriate for cost comparison of cassava to maize in swine diets where fat content is not considered as an important factor.

CMEM-2 and 3 are appropriate for cost comparison of cassava to maize in poultry diets where fat and linoleic acid contents are very important to the productivity of the animals.

The feasibility of including cassava in animal feeds, therefore, depends not only on the price of cassava itself, but also on the prices of soybean meal, extruded full-fat soybeans, rice bran oil and the Dl-methionine as well. All the CMEM formulations contain no pigment and the additional cost of natural or synthetic pigments need to be added when including cassava in poultry diets.

6. Advantages of Cassava in Animal Feed Rations

Studies on the utilization of cassava for animal feeds have been conducted for more than two decades. Oke (1978) have reported that cassava products are good energy feed ingredients for both mono-gastric and ruminant animals. The starch in cassava is highly digestible when compared to that of maize due to the high content of amylopectin. Cassava can be used as a sole source energy feed ingredient in pig, poultry and ruminant diets, but attention should be paid to HCN and protein as well as amino acid contents in cassava products. There have been a number of studies of the use of cassava in animal rations in Thailand and the results of the studies indicate a great potential for cassava to replace the conventional energy feed ingredients such as maize, broken rice and sorghum, which have commonly been used in animal diets in the region.

Table 7. Ingredients, price and nutritional composition of three cassava-maize equivalent mixtures (CMEM) as compared to those of maize.

	CMEM-1	CMEM-2	CMEM-3	Maize
Ingredients (%)				
Maize	-	-	-	1.00
Cassava	0.87	0.845	0.85	-
Soybean meal	0.13	0.13	-	-
Extruded full-fat soybeans	-	-	0.15	-
Rice bran oil	-	0.25	-	-
Dl-methionine	0.001	0.001	0.001	-
Price (baht/kg)	3.34	3.60	3.77	4.70
Nutritional composition				
Crude protein (%)	7.5	7.5	7.5	8.0
ME-swine (Mcal/kg)	3.25	3.39	3.30	3.30
ME-poultry (Mcal/kg)	3.35	3.48	3.47	3.37
Fat (%)	0.72	3.20	3.39	3.50
Fiber (%)	4.12	4.03	3.90	2.50
Lysine (%)	0.43	0.43	0.44	0.25
Methionine + Cystine (%)	0.31	0.31	0.31	0.39
Tryptophan (%)	0.09	0.09	0.10	0.09
Threonine (%)	0.28	0.28	0.32	0.32
Calcium (%)	0.14	0.13	0.14	0.01
Available phosphorus (%)	0.07	0.20	0.22	0.30

6.1 Pigs

Khajarern and Khajarern (1986) have reported that growing-finishing pigs (17-100 kg) fed a cassava diet had lower average daily gain and a higher feed conversion ratio than those fed with broken rice and sorghum diets, but the differences were not statistically significant (**Table 8**). Pigs on cassava diets tend to have lower feed intake due to the bulkiness of the diet, which may lead to a lower animal performance.

Chalorklang *et al.* (2000a) studied the effects of cassava meal substituted for broken rice in diets for weaned pigs (4-8 weeks). Weaned pigs on a 100% cassava diet (Diet 4) had a similar average daily weight gain and feed conversion ratio as those on the broken rice diet (Diet 1) (**Table 9**). Cassava starch has been shown to be very easily digestible by weaned pigs and produces minimum scouring and minimum unfavorable effects to the health of the animal.

Wu (1991) fed weaned pigs, aged 28 days (7.1 kg), a daily basal protein concentrated diet (41.0% protein) at 3% body weight together with ground cassava at 2% body weight and found that the diet resulted in an average gain of 451 g/day and a feed conversion ratio of 1.23.

Chalorklang *et al.* (2000b) also studied the effects of cassava substituted for maize in diets for growing-finishing pigs (30-100 kg). Pigs fed a 100% cassava diet (Diet 4) had slightly higher average daily gains but also slightly higher feed conversion ratios as compared to those on a diet of 100% maize (Diet 1). However, the differences were not statistically significant (**Table 10**). Pigs on cassava diets required less number of days to attain market weight while carcass characteristics of pigs on every experimental diet were not significantly different.

Table 8. Effect of the utilizatin of broken rice, sorghum and cassava diets for growing-finishing pig on their performance.

	Broken rice	Sorghum	Cassava
Initial weight (kg)	17.04	16.68	16.89
Final weight (kg)	104.08	103.43	102.09
Average daily gain (kg)	0.62	0.61	0.52
Average daily feed intake (kg)	1.84	1.93	1.72
Feed conversion ratio	3.00	3.19	3.30
Dressing percentage	72.31	73.22	72.31
Loin-eye area ($inch^2$)	4.55	4.55	4.62

***Source:** Khajarern and Khajarern. 1986.*

Table 9. Effect of the substitution of broken rice by cassava meal in diets for weaned pigs (4-8weeks) on their performance.

	Diet 1	**Diet 2**	**Diet 3**	**Diet 4**
Levels of substitution:	0	50%	75%	100%
Levels of cassava in diets:	0	24%	34%	43%
No. of animals	8	8	8	8
Initial weight (kg)	7.35	7.46	6.75	7.70
Final weight (kg)	18.53	20.24	17.64	18.39
Total weight gain (kg)	11.23	12.40	10.78	10.69
Average daily weight gain (kg)	0.400	0.440	0.389	0.383
Total feed intake (kg)	16.02	16.84	14.41	15.06
Feed conversion ratio	1.41	1.38	1.33	1.44

***Source:** Chalorklang et al., 2000a.*

Saesim *et* al. (1990) tested the effects of cassava diets and broken rice diets on the reproductive performances of breeder pigs. The trial was conducted at the farm for a period over one year. Sows on cassava diets had very similar reproductive performances to the sows on broken rice diets. It is clear that cassava can be an excellent source of energy feed ingredient in pig breeder diets **(Table 11)**.

6.2 Broilers

Khajarern and Khajarern (1986) have demonstrated that cassava meal could be used as a sole source of energy feed ingredient comparable to maize, broken rice and sorghum in broiler diets **(Table 12)**. Broilers on cassava diets tend to have smaller body weights and poorer feed conversion ratios than those on the other diets but the differences were not significant.

Sriwattanaworachai *et al.* (1989) compared the effects of maize, sorghum and cassava diets on the performances of 4-7 week old broilers. The animals on cassava diets had slightly poorer weight gains and feed conversion ratios than those on maize and sorghum diets **(Table 13)**, but the differences were not significant.

Table 10. Effect of the substitution of maize by cassava meal in diets for growing-finishing pigs (30-100 kg) on their performance.

	Diet 1	Diet 2	Diet 3	Diet 4
Levels of substitution:	0	50%	75%	100%
Levels of cassava in diets (grow/finish):	0	25/28%	40/44%	53/60%
No. of animals	16	16	16	16
Initial weight (kg)	30.63	30.79	30.07	29.22
Final weight (kg)	99.50	98.22	101.03	101.71
Total weight gain (kg)	68.87	67.44	70.97	71.99
Average daily weight gain (kg)	0.773	0.813	0.818	0.812
Feed conversion ratio	3.03	3.11	3.16	3.16
No. of days tested	92	83	87	86
Dressing percentage	77.23	75.42	76.14	76.51
Lean percentage	42.97	42.96	44.17	42.50
Back-fat thickness (inch)	1.08	1.17	1.17	1.20

***Source:** Chalorklang et al., 2000b.*

Table 11. Effect of the utilization of broken rice and cassava in diets for breeder pigs on their reproductive performance.

	Broken rice	Cassava
No. of litters	504	647
Farrowing percentage	93.16	88.19
Mummified+abnormal fetus (%)	1.91	1.64
Litter size at birth	9.25	10.02
Average birth weight (kg)	1.34	1.32
No. of lactating days	23.51	23.83
Litter size at weaning	8.09	8.23
Average weight at weaning (kg)	5.46	5.73

***Source:** Saesim et al., 1990d.*

Table 12. Effect of the utilization of maize, broken rice, sorghum and cassava in diets for broilers on their performance.

	Maize	Broken rice	Sorghum	Cassava
No. of animals	140	140	140	140
Mortality (%)	2.14	2.14	2.80	2.86
Body weight at 8 weeks (kg)	1.70	1.68	1.70	1.64
Feed conversion ratio	2.27	2.27	2.30	2.39

***Source :** Khajarern and Khajarern, 1986.*

Saentaweesuk *et al.* (2000a) studied the effects of substitution of maize by cassava in broiler diets and found that cassava can be substituted for 50% of the maize or at levels of 21%, 23% and 27% in broiler starter, grower and finisher rations, respectively, without any adverse effects on the performance of the animals. Higher levels of substitution led to a slightly but significantly ($P<0.05$) poorer weight gain and feed conversion ratio (**Table 14**). However, it is interesting to note that the trial was conducted in an open broiler housing of a small farmer during rather hot climate. Broilers on cassava diets (Diets 2, 3 and 4) were stronger, required much less medication and had lower mortality rates as compared to those on the maize diet (Diet 1). The meat of broilers on cassava diets (Diet 2, 3 and 4) had a better perception by consumers than those on the maize diets (Diet 1). The slightly slower growth of the animals and the minimal use of antibiotics may have improved the meat quality of broilers on the cassava diets.

Table 13. Effect of the utilization of maize , sorghum and cassava in diets for 4-7 week old broilers on their performance.

	Maize	Sorghum	Cassava
No. of animals	150	150	150
Initial weight (kg)	0.448	0.444	0.458
Final weight (kg)	1.92	1.93	1.85
Average weight gain (kg)	1.47	1.47	1.40
Feed consumed (kg)	3.41	3.51	3.38
Feed conversion ratio	2.32	2.36	2.42
Mortality (%)	0	2.0	0.67

Source : *Sriwattanawarachai et al., 1989.*

Table 14. Effect of the substitution of maize by cassava meal in diets for broilers (10–49 days) on their performance.

	Diet 1	**Diet 2**	**Diet 3**	**Diet 4**
Levels of substitution:	0	50%	75%	100%
Levels of cassava in diets[1)]	0	21/23/27%	31/35/42%	40/47/56%
No. of animals	400	400	400	400
Initial weight (g)	234.65	237.25	234.45	232.93
Final weight (g)	2,079.35[a]	2,003.26[a]	1,815.25[b]	1,846.00[b]
Mortality (%)	4.50	2.00	1.98	1.50
Total weight gain (kg)	1,844.70[a]	1,765.95[ab]	1,580.80[a]	1,613.06[bc]
Total feed consumed (kg)	3,745.22[a]	3,669.83[a]	3,449.45[b]	3,564.68[ab]
Feed conversion ratio	2.03[c]	2.08[bc]	2.19[ab]	2.21[a]

[1)] in starter/grower/finishing diets

Source: *Saentaweesuk et al., 2000a.*

Tathawan *et al.* (2002) found that broilers fed with cassava diets always had about half the mortality rate than those fed with maize diets (**Table 15**). Broilers on a cassava diet without antibiotics supplemention had significantly ($P<0.05$) lower mortality rate than those on a maize diet with antibiotics supplementation. It has been demonstrated that cassava diets have benefits on animal health and allow a minimal or no use of antibiotics in animal production. This advantage is also experienced by farmers and feed millers who have used cassava in animal diets in Thailand.

Table 15. Performances and mortality rate of broilers fed with maize or cassava diets, with or without supplementation with antibiotics.

Diets:	Maize	Maize	Cassava	Cassava
Antibiotics:	+	+	+	-
No. of chickens	198	198	198	198
Initial weight (kg/bird)	0.495	0.496	0.469	0.495
Final weight (kg/bird)	2.20	2.22	2.16	2.19
No. of days tested	28	28	28	28
Feed conversion ratio	1.86 [b]	1.92 [ab]	1.93 [ab]	2.00 [a]
Mortality (%)	8.79 [ab]	11.24 [a]	4.21 [b]	5.88[ab]

Source: *Tathawan et al., 2002.*

6.3 Layers

Khajarern and Khajarern (1986) have shown that cassava could be used as a sole source of energy feed ingredient in diets of pullets and layers when compared to maize, broken rice and sorghum (**Tables 16** and **17**). Pullets and layers on cassava diets had similar performances to those on maize, broken rice and sorghum diets. The animals on cassava diets had a low mortality rate and showed no signs of any toxicity of cassava in the diet.

Table 16. Effect of the utilization of maize, broken rice, sorghum and cassava in diets for pullets on their performance.

	Maize	Broken rice	Sorghum	Cassava
No. of animals	200	200	200	200
Mortality (%)	1.5	1.5	1.0	2.0
Body weight at 20 weeks (kg)	1.82	1.85	1.77	1.77
Feed conversion ratico	4.30	4.05	4.26	4.51

Source: *Khajarern and Khajarern, 1986.*

Table 17. Effect of the utilization of maize, broken rice , sorghum and cassava in diets for layers on their performance.

	Maize	Broken rice	Sorghum	Cassava
Laying percentage	66.22	72.90	62.06	69.56
Egg weight (g)	50.55	50.30	50.02	50.05
Yolk color score (NEAPA)	3.50	4.67	4.50	4.15
Feed consumed (kg)/dozen eggs	1.40	1.28	1.48	1.33
Mortality (%)	1/96	1/95	2/95	0/95

Source: *Khajarern and Khajarern, 1986.*

Saentaweesuk *et al.* (200b) studied the substitution of maize by cassava in diets for layers (22-37 weeks) **(Table 18)** and found that laying hens on 100% cassava diet (Diet 5) had similar production performances to those on 100% maize diets (Diets 1 and 2). Increasing the levels of cassava in the diets significantly ($P<0.5$) reduced the yolk color score. Diet 5, in which 100% of the maize was substituted by cassava, needed to be supplemented with 0.2% of marigold meal to provide adequate yolk pigmentation for local market acceptance. Cassava is an excellent energy feed ingredient for the production of pale yolk eggs for exportation.

Table 18. Substitution of maize cassava meal in diets for layers (22-37 weeks) on their performance.

	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5[1)]
Levels of substitution:	0	0	50%	75%	100%
Levels of cassava in diets :	0	0	25%	36%	48%
No. of animals	576	576	576	576	575
Feed intake/hen/day (g)	114.7	115	113.6	112.8	112.4
Laying percentage	60.16	61.24	58.40	59.72	59.92
Mortality (%)	0.42	0.26	0.42	0.14	0.22
Average egg weight (g)	57.43	57.70	57.81	57.78	58.22
Yolk color score (Roche)	9.27[a]	9.40[a]	8.75[b]	8.36[b]	8.38[b]

[1)] Supplemented with 0.2% of marigold meal
Source: *Saentaweesuk et al., 2000b.*

6.4 Dairy cattle

Kanchanapreuttipong *et al.* (2000) studied the effects of substitution of maize by cassava in dairy concentrate rations. A total substitution of maize by cassava in the ration produced very similar milk yield and milk composition as those cows on the maize diets **(Table 19)**. However, the percentage of feed cost/revenue was significantly reduced (P<0.5) when cows were fed the cassava diets. Cassava chips and pellets are ideal energy feed ingredients for beef and dairy cattle.

Table 19. Effect of substitution of maize by cassava chips in concentrate diets for dairy cattle on their performance.

Diets:	Maize	Maize + Cassava	Cassava
Levels of substitution :	100%	50%:50%	100%
Milk composition, % (kg/day)			
Butter fat	4.15 (0.80)	4.32 (0.85)	4.27 (0.83)
Milk protein	3.37 (0.65)	3.27 (0.64)	3.33 (0.65)
Lactose	4.97 (0.76)	4.93 (0.97)	4.96 (0.97)
Minerals	0.70 (0.13)	0.70 (0.14)	0.70 (0.14)
Solid non-fat	9.03 (1.74)	8.90 (1.75)	8.99 (1.75)
Total solids	13.19 (2.54)	13.23 (2.60)	13.26 (2.58)
Milk yield (kg/day)	19.23	19.64	19.44
Feed cost/revenue (%)	40.75[a]	34.33[ab]	28.17[b]

Source: *Kanchanapreuttipong et al., 2000.*

6.5 Aquaculture feed

Jintasataporn *et al.* (2000) evaluated the effects of substitution of maize by cassava in diets for hybrid catfish, and reported that the fish on 100% cassava (Diet 4) had similar production performances as those on 100% maize (Diet 1) **(Table 20)**.

Table 20. Effect of substitution of maize by cassava meal in diets for hybrid catfish on their performance.

	Diet 1	Diet 2	Diet 3	Diet 4
Levels of substitution:	0	50%	75%	100%
Levels of cassava in diets:	0	13%	20%	26%
Total weight gain (g/fish)	84.06	82.96	80.46	98.80
Average daily weight gain	0.70	0.69	0.67	0.82
Total feed consumed (g/fish)	144	115	147	176
Feed conversion ratio	1.72	1.36	1.83	1.79
Survival rate (%)	88.6	90.3	86.1	98.9

Source: *Jintasataporn et al., 2000.*

It can be concluded that cassava can be used as a sole source of energy feed ingredient in every kind of animal ration, including pigs, poultry, ruminants and aquaculture feeds. The inclusion rate of cassava in the animal rations are summarized in **Table 21**. However, care should be taken on the use of cassava for broiler rations, since fowls are sensitive to bulkiness and to the fiber contents of the feed; therefore, cassava is recommended to replace only 50% of maize (25-30% inclusion of cassava) in broiler diets.

Table 21. Recommended maximum inclusion levels of cassava meal in the feed rations of various animals.

Animal rations	Max. inclusion levels (%)
Pigs (weaners, grower, finisher, breeder)	40 - 60
Broilers	25 - 30
Layer hens	40 - 45
Ducks (meat and layers, breeders)	40 - 45
Beef and dairy cattle	35 - 40
Aquaculture	30 - 35

Note: Cassava has also been successfully used as a maize substitute in rabbit and horse feeds.

7. Practical Experiences in Using Cassava in Animal Feed Rations in Thailand

Cassava has been promoted as a replacement for maize in pig, poultry and ruminant diets in Thailand for more than 15 years. Initially only a limited number of farmers adopted and practiced the technology, but the results were very successful. Extensive use of cassava in animal rations has been practiced since 1997 when both the animal production and the feed industries were severely affected by the economic crisis. The devaluation of the Thai currency had resulted in an increase in feed costs and the cost of animal production while the local market prices of feed ingredients were reduced. In contrast, the exported price of cassava to the EU was also reduced due to the reduction of agricultural subsidies in the EU countries. The use of cassava in domestic animal diets was therefore the solution to various problems.

Cassava has been actively promoted for use in animal diets by the Animal Nutrition Research and Development Center (ANRDC), Kasetsart University, Kampaengsaen, Nakhon Pathom with a research grant from the Thai Tapioca Development Institute (TTDI). Seminars and workshops on the utilization of cassava in combination with soybean meal in animal rations have been conducted repeatedly in various parts of Thailand. Books and a video on the utilization of cassava and soybean meal in animal rations have been prepared and distributed to the farmers. Follow-up evaluations need to be conducted in order to correct the field problems and to ensure the success of the project. In addition, improvement of the quality of cassava chips produced in Thailand has been promoted in order to satisfy the requirement of the animal industry. Good quality cassava chips and pellets, which are key factors for the successful use of cassava in animal diets, are increasingly available in the country and are helping to increase the acceptance of cassava in the feed industry. To date cassava has been extensively accepted in animal feed rations in Thailand, including for growing-finishing, breeder and weaned pigs, layer hens and ducks, meat-type ducks, and dairy and beef cattle, with successful results and satisfaction to the farmers.

Cassava is an appropriate feed ingredient for pigs, ducks and cattle because these animals can tolerate high levels of dietary crude fiber and require no pigmentation in the diets (except for laying ducks). Acceptance of using cassava in animal feed rations is now widespread among farmers, ranging from small farmers (10-20 sows unit) to large commercial farmers (over 10,000 sows unit) with rather equally successful results. It is worthy to note that most of the farmers are satisfied with the following advantages of using cassava in their animal rations.

1. Satisfactory animal performances and carcass quality while the feed cost and animal production cost are reduced.
2. Reduction of medication and antibiotics used in animal production, and the improvement of animal health induced by cassava diets.
3. Reduction of the fetid smell of the manure and reduction of environmental pollution.

In many occasions when there were no differences in the prices between maize and cassava diets, a number of farmers still maintained the use of cassava in animal rations due to the advantages of animal health improvement and less smell and pollution as a result of the cassava diets. A number of pig and poultry (broiler) farms have used cassava as their main feed ingredient in the diets for production of antibiotics-free pork and poultry meat.

8. Advantages of Using Cassava in Animal Diets

The results of the past studies and the practical field trials have indicated that good-quality cassava has the following advantages in animal nutrition:

8.1 Comparable performance but higher quality of animal products than maize diet

Good-quality cassava with proper nutritional balance, obtained by good diet processing, has produced very comparable production performances of the animals as compared to those on cereal diets. But farmers always reported that cassava diets produced better quality animal products including meat, milk and eggs. Although no scientific explanation can be made, the favorable results may be due to less stress situation for animals on cassava diets.

8.2 Higher digestible starch

The starch in cassava is a very soft starch, which is more readily gelatinized and digested in the digestive tract of the animals as compared to cereal starches. Highly digestible starch create less stress to the animals and stimulate more growth of non-pathogenic microorganisms which will produce more acidic conditions and suppress the growth of pathogenic microorganisms in the digestive tract.

8.3 Minimum or no mycotoxins contamination

It has been shown that cassava products contain minimal or no mycotoxins, including aflatoxins, when compared to cereals, especially maize. Cassava has been successfully fed to breeder animals and ducks which are very sensitive to mycotoxin toxicities, expecially zearalenone and aflatoxins. Apparently, no aflotoxicosis or toxicity of other mycotoxins have been reported by the farmers who have employed cassava in animal diets for many years. Aflatoxin is a powerful stressor in animal diets, which not only reduces the performance of animals, especially their feed conversion ratio, but also impairs immunity production and causes more illness in the animals. Modern high-performance animals always are more sensitive to stress including aflatoxins in the diets. The animals, therefore, require feeds which are not only nutritionally balanced and highly digestible but also contain no or very low levels of toxic substances which cause stress to the animals. Cassava is an ideal feed ingredient meeting this requirement.

8.4 Animal health improvement and "green" food production

Animals on cassava diets always have better health and require less or no antibiotics during production, compared to animals on cereals, especially on maize diets. The highly digestible starch and minimal aflatoxin contamination could be responsible for this advantage. Cassava diets can therefore provide "green" meat or "green" food production which is an important consideration for animal production in this new millennium.

8.5 Minimum animal waste odor

Practical field trials have shown that manure or feces of animals on cassava diets produce less fetid smell or have less odor than those on cereal diets. Although the exact reasons are not known, the advantage helps to reduce the pollution problems of animal production units.

8.6 Non-GMO feed ingredient

Cassava varieties grown in Thailand have been produced through traditional breeding methodologies and are certified to be non-GMO. Cassava products can therefore be used in animal production for export, especially to EU countries.

8.7 Reduction of animal production costs

Cassava diets lower the cost of animal production, not only by the reduction of feed cost but also by the reduction or elimination of the use of antibiotics and medication in animal production. This advantage is an important factor for farmer acceptance, and for more utilization of cassava in animal diets in Thailand and in the rest of the world.

9. Key Factors For Successful Use of Cassava in Animal Feed Rations

Although cassava is an energy feed ingredient comparable to maize, cassava has many other characteristics that affect its utilization in animal diets. It is therefore necessary to have a thorough understanding of cassava in order to successfully use the ingredient in animal rations.

9.1 Production of good quality cassava chips and pellets

Only good quality cassava which has the following specification is recommended for inclusion in animal diets:

Moisture content	max.	14%
Crude protein content	min.	1.5-2.0%
Crude fiber content	max.	3.50-4.00%
Ash content	max.	2.00%

The above cassava products will contain 75-80% nitrogen-free extract and give very good results for animal feeding. Cassava chips that have minimal or no stem or woody parts will have crude fiber levels below this limit. High levels of sand or soil contamination will increase the ash content in the cassava products. The products should be dried for at least 3-6 days and should be stored for at least 5-6 days before being included in animal rations. Cassava products should be clean and have no visible mold growth. With enough experience, one can estimate the starch content by breaking a piece off dry cassava chip.

9.2 Feed formulation

Cassava diets should be balanced for protein and essential amino acids according to the requirement of each type of animals. Weight by weight substitution of cassava for maize in animal diets will lead to lower protein and amino acids contents of the diet and cause poor growth, poor feed conversion ratios, poor carcass quality and poor productivity of the animals. More soybean meal or extruded full-fat soybean need to be added when employing cassava diets. Cassava-soybean diets with a proper balance of amino acids have been used successfully by pig farmers in Thailand.

9.3. Grinding and reduction of dustiness

Cassava chips are very bulky and contain soft starch. Grinding of cassava chips is always very dusty and causes severe air pollution in the feed mill. Dust collection units of either the cyclone dust collector with filter bags or the automatic filter bag dust collector is required to prevent spreading the dust into the atmosphere. Ground cassava is still very dusty and always reduces the feed intake of animals raised on mashed cassava diets. Dusty feed will stimulate animals to drink more water which impairs feed intake and causes growth depression of the animals. Addition of 4-5% molasses in the diet is recommended in order to eliminate the dustiness of the feed. High levels of fat addition in the diets would decrease the levels of molasses required for dust control in mashed cassava diets. Pelleted feed or wet feed give no problems of dust and do not need molasses addition in the formula.

9.4 Body fat adjustment

Cassava diets may contain very low fat and may cause hard fat accumulation in the animal body. In countries where hard carcass fat is avoided, it is advisable that cassava diets contain at least 3% of soft–fat in order to correct the fat condition in the animal. High-fat feed ingredients such as rice bran, extruded full-fat soybean or rice bran oil are recommended to be included in the cassava diets.

9.5 Yolk and skin color of poultry

Cassava contains no pigment and the diet may cause pale egg yolk and pale skin of the poultry. Cassava diets may have to be supplemented with sources of pigment such as leucaena leaf meal, marigold meal or synthetic pigments in order to color the yolk and skin according to the requirements of the consumers. The required supplementation is approximately 30 mg of xanthophyl/kg of diet.

10. National Program on Cassava Chips and Pellets Quality Improvement and Quality Assurance in Thailand

Good quality cassava is an important factor for the successful use of cassava in animal diets. The government of Thailand is therefore launching a national program on the promotion of good quality cassava chips and pellets production in the country, both for domestic use and for export. Good quality cassava chips should conform to the following standard :

Moisture	max.	14%
Crude fiber	max.	3.5-4.0%
Sand/ash	max.	2.0%
Starch (NFE)	min.	75-80%

Cassava products containing minimal levels of crude fiber and sand/ash will be good substitutes for cereals in animal diets. Governmental offices and organizations related to cassava production, utilization and trading are involved in the program and carry out the following activities:

10.1 Department of Foreign Trade (DFT), Ministry of Commerce

DFT is providing a total of 120 million baht in soft loans to 300 commercial cassava chips/pellets processors for installation of sand sifters into the production process, which will reduce the content of sand in the cassava products to less than 2%. The processors also need to reduce the fiber content of the cassava products to less than 3.50-4.00%. DFT, together with ANRDC and TTDI, will test, monitor and certify processors who consistently produce good quality cassava chips according to the above standard. The project aims to produce a minimum of 3 million tonnes of good quality cassava chips annually.

10.2 Department of Cooperative Promotion (DCP), Ministry of Agriculture and Cooperatives

DCP is providing a total of 426 million baht in soft loans to 60 agricultural cooperatives who grow and process good quality cassava chips. The cooperatives may be directly involved in the production of good quality cassava chips, or in collection of good quality cassava chips produced by the members or villagers, and market these to the users. Cassava growers (farmers) are encouraged to partly process the fresh roots for good quality cassava chips which will produce an additional income to the families. Cassava chips produced by these farmers or villagers are always of high quality and are in great demand by the animal farms and feed mills. DCP and ANRDC will continuously and regularly test, monitor and certify the cooperatives who consistently produce good quality cassava chips according to the standard. The project will produce approximately 300,000-500,000 tonnes of good quality cassava chips annually for domestic consumption and for export.

10.3 Animal Nutrition Research and Development Center (ANRDC), Kasetsart University, and the Thai Tapioca Development Institute (TTDI)

ANRDC and TTDI have been pioneers in promoting the production of clean and good quality cassava chips for the animal feed industry in Thailand since 1998. A number of cassava processors, ranging from small villagers to large commercial processors, have joined the project and have improved the quality of cassava chips for the animal feed industry in the country. The project not only has demonstrated the benefit of high-quality cassava for animal feeding to the farmers, but has also provided assurances for the future production of good-quality cassava for the animal feed industry. ANRDC and TTDI have not only provided training and supervision in techniques and practices in the production of good quality cassava chips but have also tested and monitored the quality of the products produced, by direct sampling from the processors and by analyzing samples sent by the customers. Good processors, which consistently produce good quality products, are publicized directly to the farmers and to the feed industry.

ANRDC and TTDI will continue their activities in promoting the greater utilization of good quality cassava for animal feeds. Seminars and workshop on utilization of cassava in animal nutrition are conducted throughout the country. More research on the beneficial effects of cassava diets on the health of animals is being conducted. The results of recent advances in using cassava in animal diets and the names of certified cassava processors are publicized via www. tapiocafeed.com.

10.4 Office of Industrial Standard (OIS), Ministry of Industry, and Department of Livestock Development (DLD), Ministry of Agriculture and Co-operatives

OIS and DLD, which are authorized organizations to certify the standard of manufacturing practices and the standard quality of industrial products including animal feeds, have planned to improve cassava pellet production practices and to certify GMP and HACCP to processors who meet the standard. The certifications are essential for export of cassava products to the EU. Cassava pellet processors and exporters will be trained and monitored, and improvements will be made in the production process until the standards are met and certification can be provided. The activity is expected to be completed before December 31, 2001.

The government of Thailand expects that these national programs will result in an increase in the production of high quality cassava products, in increasing the use of cassava in animal feed in the country and in increasing the export of cassava products to the EU and other countries. The programs will also provide a sustainable marketing strategy and practice for the cassava industry in Thailand.

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POST-HARVEST MANAGEMENT OF CASSAVA FOR INDUSTRIAL UTILIZATION IN INDIA

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ABSTRACT

The importance of cassava has been realized as a high energy human food, animal feed and as an industrial raw material for sweeteners, ethanol and various other chemicals. Its industrial potential, however, has still not been tapped to any great extent. Broadening of the post-harvest utilization of cassava remains rather difficult due to several factors. The development of cost- and energy-effective processing equipment was considered essential for cassava, which, like other root and tuber crops, is invariably associated with labor intensive farming and a low-cost produce.

Simple and low-cost methods were developed for the storage of fresh cassava roots as well as packaging of important products of primary processing, such as cassava chips, flour and starch. Improved technology is also being developed for small- and medium-scale cassava starch extraction, a level of operation which is very common in India. In recent years the State Bank of India (SBI) and CTCRI have joined hands to significantly modernize and upgrade the entire cluster of cassava starch and sago industries in the Samalkot region of Andhra Pradesh state in India. This includes all aspects of the cassava starch/sago industry of the region, ensuring the availability of high quality raw materials, improved process efficiency, marketing and finance, which will benefit both the farming community as well as the industrialists.

Increased utilization of cassava roots as food by the urban and affluent section of society can be achieved by processing the roots into various convenience and fast food products, such as semolina, porridge, wafers, crisps, ready-to-cook and ready-to-eat extruded products, etc., to suit the taste and need of urban populations. Diversification into the manufacture of value-added products, such as adhesives, high-fructose syrup, maltose, maltodextrins and biodegradable plastics is currently envisaged as one of the most dependable methods to make cassava commercially lucrative.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a major source of carbohydrates in many developing countries. In India cassava is grown, by and large, for table purpose and is consumed as fresh human food after boiling, baking, steaming, roasting or frying. A relatively smaller fraction is used for animal feed, is processed into human food or is manufactured into various industrial products. It is a suitable crop for poor farmers since it can grow and yield under a wide range of soil, climate and environmental conditions in the tropics and subtropics. It ranks second among cultivated crops in terms of edible energy produced per unit area per unit time (138 MJ/ha/day), after sweet potato (194 MJ/ha/day).

Because of the high photosynthetic efficiency and the subsequent synthesis of carbohydrates, cassava is rated as one of the most efficient sources of energy, besides its importance in meeting rural food security. It can also be processed into various food products to suit the taste and need of the urban population. Traditionally cassava has supplemented the rice diet of the poor as well as during periods of scarcity, thus averting famines. Gradually it has become a subsidiary food as an outcome of the green revolution that changed the consumption pattern of the people in the country. However, in order to maintain the balance between the supply of food and the ever increasing population,

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secondary staple food crops like cassava have to be retained within the cropping system of marginal farmers for food security. Better post-harvest management practices involving storage, processing and marketing, as well as diversification for the production of value-added food and industrial products is one of the methods to make cassava more lucrative in recent times.

1. STORAGE

1.1 Simple Low-Cost Technology for Fresh Cassava Storage

A major constraint in the post-harvest marketing and utilization of cassava is the high perishability of the roots. Normally cassava roots cannot be stored without spoilage for more than 3-5 days. Physiological, biochemical as well as pathological factors operate to bring about the decay of the harvested roots. High-cost preservation techniques don't seem to be practical since the value of the cassava roots is low. Hence, attempts were made to develop a low-cost preservation technology for cassava in order to arrest the biochemical mechanisms (oxidation of polyphenols present in the roots) and also the entry of pathogens (fungi of *Rhizopus sp.*), which both lead to spoilage, and thereby, to prolong the shelf-life of the roots.

Fresh undamaged roots, along with a portion of the stem, are preferred for storage in moist sand and soil in pits under shade. Moist sand/soil is spread at the bottom of a pit, the size of which usually depends upon the quantity of the roots to be stored. The moisture in the sand/soil is adjusted within the range of 10-15%. Bunches of undamaged roots along with the attached stem are arranged layer by layer with moist sand/soil in between the layers. After arranging a maximum of three such layers the pits are covered with moist sand/soil. Observations made at weekly intervals up to two months have shown the recovery of undamaged stored roots to be in the range of 80-85%.

During such storage of cassava roots, there is a slow decrease in the starch content of the roots (only 15-20% reduction after two months of storage). Loss in weight of the roots due to dehydration could be prevented by providing a moist environment. The organoleptic tests conducted showed that cooking quality of the roots was not affected by the storage in moist sand and soil up to 1 1/2 - 2 months. This low-cost technique of fresh cassava storage developed at CTCRI has been transferred to extension workers and farmers for wide-spread adoption.

1.2 Packaging and Storage of Dried Cassava Products

Cassava chips are easily infested by a large number of pests. A survey conducted in cassava chips godowns in different parts of Kerala state has shown that *Araecerus faciculatus, Dinoderus bifoverolatus, Rhyzopertha dominica, Lasioderma serricorne, Sitophilus oryzae* and *Tribolium castaneum* are the important pests of plain dried chips and *R.dominica* and *S.oryzae* are the major pests of parboiled chips. The insects and the emerging grubs bore into the chips which are eventually converted into a powdery mass with a few broken pieces, and these are usually thrown out as waste. Parboiled chips could be stored for nine months with 3% loss in weight. In the case of plain dried chips the loss is quite high. Cassava flour and starch are prone to pick up moisture due to their powdery nature, which render open storage conditions unsuitable for dried cassava products.

Drying the cassava starch, chips or flour to low moisture content at the production level itself is an essential factor in minimizing attacks by fungi and insects. Subsequently, hygienic storage and effective packaging facilities have to be provided to offer continued protection against biochemical deterioration, microbial growth and insect infestation. Various modes of conventional packaging and storing of cassava products (starch, chips and flour) have been evaluated in a study to assess the shelf life of the commodity in storage. In this study, freshly processed cassava starch, chips as well as flour were packed and stored in the conventional packaging materials: 1. Plastic jar; 2. Polythene bag 300 LDPE; 3. Polythene bag 200 HDPE; 4. Paper bag; 5. Metal container; 6. Polythene-lined jute bag; and 7 Jute bag.

Storage of cassava starch

Samples of stored starch were periodically analyzed up to 240 days for moisture content, viscosity, total microbial count and viable bacterial and fungal populations. There was only a small increase in moisture content of starch when stored in HDPE bags, polythene-impregnated bags and metal container (0.52, 0.83 and 1.27%, respectively in 130 days). Deterioration of viscosity was fastest for the starch stored in jute bags (below 44 seconds Redwood in 60 days) and the least for the starch stored in metal containers (44 seconds Redwood at 180 days). However, metal containers could not be considered suitable for food grade starch due to a high fungal attack, whereas HDPE and poly-impregnated bags showed the lowest microbial load. Consequently, HDPE bags and polythene-impregnated bags were found to be the most suitable packaging system for storing cassava starch against microbes up to 180 days.

Storage of cassava chips

Samples of stored cassava chips were taken at intervals of 30 days and analyzed for moisture content and insect infestation. At the end of the storage period of 120 days, the amount of dust formed from chips due to infestation and the quantity of infested chips were determined in different packaging materials.

The increase in moisture content was minimum for cassava chips stored in metal container and polyethene-lined jute bag (0.46% and 0.76% in 120 days, respectively). In plastic jars the moisture content of the chips were within safe limits (13% ISI) up to 60 days only. Insect infestation at the end of 120 days of storage was minimal for cassava chips stored in metal containers, polythene-lined jute bag and plastic jar (7, 18 and 20 adult insects of *Araecerus fasciculatus* per kg, respectively). Percentage of infested chips in all other packaging materials ranged from 92.3 to 100% by weight, while the amount of dust formed ranged from 104.8 to 153.9 g/kg. Metal containers and polythene-lined jute bags were found to be the most effective packaging materials for safe storage of cassava chips against insects up to 90 days.

If cassava chips are stored for a longer period, intermediate sun drying is advisable as the chips with higher moisture content get spoiled earlier. Storing chips in metal bins and fumigating with aluminium phosphide tablets has also been found effective for bulk storage of dehydrated chips. Cassava chips dipped in sodium hypochlorite (0.5%) for 2-3 minutes and washed with fresh water and dried at 70°C have a longer shelf-life (90 days) as compared to untreated chips (25 days). The bacterial load was also found to be reduced in treated chips.

Storage of cassava flour

Samples of stored cassava flour were taken at intervals of 30 days and analyzed for moisture content as well as insect infestation. At the end of the storage period of 120 days loss of weight of the material stored was also determined with regard to different packaging systems.

The increase in moisture content of cassava flour stored in metal containers and polythene-lined jute bags was only 0.71 and 1.23%, respectively, after 120 days of storage. Cassava flour was found to be more hygroscopic in nature than cassava chips and starch. In case of cassava flour stored in polythene-lined jute bags, HDPE bags and fine woven jute bag, the insect population at 120 days of storage reached only 15, 45 and 65 per kg, respectively. *Tribolium castaneum* was the most common insect found in all containers. Loss in weight was maximum (4.83%) in case of cassava flour stored in jute bags though insect infestation was not so high. Thus, for short-term storage (up to 90 days) of cassava flour , only polythene-lined jute bags are ideal.

The investigations helped to determine effective packaging materials which can be easily adopted by the primary processors of cassava in order to minimize the qualitative and quantitative losses during storage of chips, flour and starch.

2. PRIMARY PROCESSING OF CASSAVA

The short shelf-life and bulkiness of cassava roots pose a great problem in transporting these roots from the farm to the market or factory sites. To overcome this difficulty in the marketing and utilization of cassava and to avoid heavy post-harvest losses, the roots need to be processed into some form of dried product with longer storage life. The simplest and the most common mode of processing cassava is the conversion of fresh roots into dry chips. The hydrogen cyanide content is also reduced during the slicing and drying operations. Cassava chips are used for edible purposes and for preparation of flour. Dried chips are also used in animal feed formulations. In industry, the chips are the raw material for manufacturing starch, dextrin, glucose and ethyl alcohol.

Conventional Methods of Cassava Chipping and Drying

Under the conventional practice, cassava roots are sliced with the help of hand-knives with or without peeling the outer skin and rind. Chips are then dried in the sun for 3 to 5 days depending upon the weather conditions. However, cassava chips are produced in various forms, sizes and shapes at different places. The method is tedious and time consuming and leads to uneven and delayed drying. The output by manual chipping was found to vary from 11 to 37 kg/hour, while the chip thickness varied from 2.7 to 12.5 mm.

The sliced roots are usually dried in the open air under sunlight by spreading them in a single layer on a cement floor, bamboo mat, rock surface or sometimes even on bare earth. Chips dry better on rocks and are white in color. Depending upon the weather conditions it takes 2 to 5 days to dry cassava chips. The chips should be turned periodically during the drying period until the moisture content reaches 13 to 15%. The chips are considered dry when they are easily broken but too hard to be crumbled by hand.

In order to remove the tedium of operation and to produce chips of uniform shape and thickness, the Central Tuber Crops Research Institute (CTCRI), in Trivandrum, has developed hand-operated and pedal-operated chipping machines as well as motorized chippers to increase operational convenience and output.

2.1 Hand-Operated Cassava Chipping Machine

The machine consists of two concentric *m.s.* drums, the annular space between which is divided into compartments for feeding the roots, supported on four m.s legs. A rotating disk at the bottom of the drum carries the knives assembly. A pair of *H.S.S.* bevel gears is provided to operate the hand-operated machine manually with a crank arm. Roots are fed into the compartments from the top and the chips are collected at the bottom.

Performance and economics

The average output of the hand-operated cassava chipping machine is up to 120 kg/hour for 6.9 mm thick chips, the increase in hourly output being 3 to 5 times more than the traditional method. Machine chipping is highly economical where labor charges are high or when family labor cannot be employed.

Higher output, low operational cost, moderate initial cost, easy to operate, requirement of no special skill to operate, accommodation of all sizes of cassava roots, production of uniform chips, adjustable chip thickness and convenience of feeding the roots into the machine are the specific advantages of this machine. However, mechanical chipping with this machine results in 2-5% breakage of chips.

Field evaluation

Six units of the hand-operated cassava chipping machine were evaluated for about one year by the contact farmers in Munchirai (Tamil Nadu), Melpuram, Vellanad and Manappuram villages (Kerala). The machine was well received with an average rate of adoption of 81.2%.

Transfer of technology

The machine was patented with the National Research and Development Corporation of India and the technology transferred to 11 manufacturing firms including the Kerala State Agro-Industries Corporation.

2.2 Pedal-Operated Chipping Machine

The pedal operated chipping machine is a modified version of the earlier prototype with additional provision of a pivoted pedal to transmit the power to the cutting disk through a suitable belt and pulley drive mechanism. The machine has the advantages of higher output and greater operational convenience. A trimming knife is also provided on the frame to remove the woody neck portion of the roots before feeding into the compartments. Four castor wheels are fixed on the legs of the machine to make it portable. The overall dimensions of the machine are 117 x 95 cm and the weight is 72 kg. Two persons are required for the most efficient operation of the machine, one to trim and feed the roots and another to pedal. The height of the operator's seat can be altered to the convenience of the operator. Thickness of the chips can be adjusted from 0.9 mm to 10 mm . Blades can be easily removed for sharpening or replacement.

Performance and economics

The output of the machine can be increased from 83 kg/hour to 768 kg/hour by increasing the chip thickness from 0.9 mm up to 6.9 mm. However, for further increase in chip thickness up to 10.0 mm, the average output gradually decreases to 529 kg/hour. In the case of chipping *Dioscorea rotundata* (white yam) roots, which resemble cassava roots in shape and size, the average output of the machine was found to be 471 kg/hour for chips of 4.73 mm average thickness. The economic analysis of the chipping machine has shown a profit of Rs.5,376 per year.

2.3 Motorized Cassava Chipper

The motorized chipper developed by CTRCI is powered by a 0.5 HP single-phase electric motor through a suitable belt drive. The feed hopper consists of two concentric rows of 25 cm high ms cylinders. The cylinders of the outer row are of 10 cm diameter, while the cylinders of the inner row meant for thinner roots are of 7 cm diameter. A ms circular disk of 87 cm diameter and 10 mm thickness carries two pairs of stainless steel blades.

A brick masonry foundation with a sloping chute serving as chips outlet is constructed with the motor and the chipper installed over it. Safety guards are provided for the V-belts and shafts. The square outlet made with flat ms. walls below the disk guide the chipped roots into the chute without spillage resulting from the centrifugal force of the rotating disk. The rotational speed of the cutting disk is optimized between 80-100 rpm so as to overcome the jolting of roots within the feed cylinders. The output of the machine, was found to be 286, 655 and 1091 kg/hour for chip thickness of 2.5, 5.3 and 9.9 mm, respectively. This technology has been transferred to one large-scale processor in Andhra Pradesh state.

2.4 Electrical Dryer for Cassava Chips.

Sun drying of chips takes 2 to 5 days. Unreliable climatic conditions, however, render continuous sun drying difficult, particularly in the state of Kerala where the monsoon is of long duration. Contamination by airborne dust, dirt and debris cannot be entirely avoided during sun drying especially on windy days. Artificial drying, has certain advantages. Besides saving time and floor space requirements, artificial drying allows for the continued drying at night time, especially during peak periods of harvest. For that reason, a through-circulation batch type dryer was been developed at CTCRI.

Design description

The system consists of a motorized centrifugal blower with ducts, an insulated heater box and the drying chamber. A thermostat has been provided to regulate the temperature of the drying air within 65-70°C range. The drying chamber has a perforated G1 sheet floor of one sq.m. area and four sliding walls of AC sheet to facilitate easy loading and unloading of cassava chips. Maximum holding capacity of the dryer is 500 kg cassava chips on a fresh weight basis. The overall cost (including blower) is about Rs. 30,000 per unit.

Performance

The dryer can be used to dry batches of 100 kg cassava chips in 8-10 hours and up to 500 kg in 20-24 hours from an initial moisture content of 65-73% to a final moisture content of 12-14%. Unpeeled chips take slightly longer time to dry than the peeled chips. Chips of regular shape and size dry relatively faster than irregularly shaped chips.

Taking the practical feasibility into account, a 300 kg batch size will be optimum for one batch per day operation with this dryer so that the required amount of cassava roots can be harvested, peeled (optional), chipped and also dried - all on the same day, if desired. The dryer can also be used for drying of chips produced from other roots and tuber crops. Discoloration and excessive drying are avoided due to relatively low temperature of the drying air. Mechanically dried chips have also been found to store better and remain free from insect infestation longer than sun-dried chips.

2.5 Non-Conventional Energy Aided Drying System for Cassava

Mechanical drying systems may produce a higher quality product but tend to have a high operational costs. Hence a renewable energy oriented dryer for cassava chips was developed at CTCRI which makes use of solar energy and/or combustion of agricultural waste for heating the air.

The dryer is batch type and has a maximum holding capacity of 2 m^3 or 1000 kg of fresh cassava chips/batch. The system consists of an agricultural waste fuel burner (internally insulated with ceramic fibre wool and white clay), a centrifugal ash separator, a motorized centrifugal blower coupled to a three-way distributor duct (connecting the blower with the solar collector and the waste burner) and a double-cylinder drying bin housed in a shed with corrugated GI sheet roofing painted black to serve as a solar collector. Glass panel covers, though a common feature in solar collectors for attaining higher temperature, were not adopted for economic considerations.

Test runs were conducted with 500 to 1000 kg cassava chips of about 5 mm chip thickness with the drying air temperature regulated around 85^0C before entry into the drying bin plenum. Fuel (partially dried coconut husks, cassava stems, etc.) feed rate in the waste burner was adjusted to 5-6 kg/hour to achieve the desired temperature limits. A drying time of 20 hours was required to bring down the moisture from 67-69% to 12-13%.

3. FOOD PRODUCTS FROM CASSAVA

3.1 Cassava Rava and Porridge

Rava or semolina is normally a wheat-based convenience food used for the preparation of various breakfast recipes like *uppuma* and *kesari halwa*. Attempts were made at CTCRI to develop a simple economic process for the production of cassava- based rava as a substitute for wheat rava. The method of preparation requires controlled gelatinization of starch. The process for producing cassava rava consists of the following steps:

1. Partial gelatinization of fresh chips of peeled cassava roots by steeping in boiling water for less than 10 minutes.
2. Drying of parboiled chips in the sun for about 36 hours or in a mechanical drier at 70°C for about 24 hours. The moisture content is brought down to around 15%.

3. Milling of the dried chips in a hammer mill, taking care that the powder is neither too fine nor too coarse. The fraction which is retained on 20 mesh may be repowdered and sieved. The fraction which passes through 20 mesh but does not pass through 80 mesh has a size range 0.5 to 3 mm and is most suitable for wheat semolina substitution. It can be used for preparation of products such as *uppuma* and *kesari*.

The fraction passing through 80 mesh is too fine and possesses a cohesive texture; it is used in the preparation of sweets, puddings etc., products which require fast miscibility of starch in milk or in water. The fine-grade pre-gelatinized cassava starch (porridge) can be utilized to make instant energy drink using hot milk or hot water. Two tea spoon full pregelatinized starch could be added to a cup of hot milk or water after adding sugar to taste and served to infants and invalids as an energy drink. Addition of cardamom powder to cassava porridge adds flavor to the product.

The process of cassava *rava* and porridge preparation has been transferred through training to village level workers for promoting rural employment and technology development.

3.2 Pappads, Wafers and Sago Wafers

Cassava *pappad* is an popular snack food item prepared from cassava flour. The preparation involves gelatinization of the flour with a minimum quantity of hot water, mixing in of salt and pepper, spreading out the paste on a mat, cloth or polythene sheet and drying in the sun. The *pappad* is consumed after deep-frying in oil. The final product undergoes 2-3 times expansion on frying. It is crisp and can be consumed as a side dish.

Wafers are made from cassava starch similar to sago wafer. In this case the starch cake containing about 35-40% moisture is used instead of sago. Wafers can be made in different shapes and sizes like round, square, flowery patterns etc. The product on frying undergoes 3-4 fold increase in size. It is also used as an adjunctant.

Sago wafer is an important product made at the cottage level scale in many parts of Tamil Nadu. The wafers are deep fried in oil and consumed as an adjunctant. Preparation involves packing the sago in the round aluminium trays. The trays are then introduced into steam boilers and allowed to be exposed to steam for 20 minutes. The gelatinization taking place makes the pearls stick to each other and give round shape. The trays are then sun dried and the resulting wafers are peeled out. Natural colors and salt are added to taste.

3.3 *Crisps*

Fried chips or crisps are made by deep fat frying very thin chips of cassava. The roots are washed thoroughly, the peel and rind removed and then sliced as thin as possible. Roots of correct maturity from varieties with relatively lower dry matter should be used for quality chips. The slices may be dipped into sodium chloride, or sodium bisulfite solution for 5-10 minutes, and then taken out, washed with water, and surface dried on a filter paper or cloth for improving the color. Compared to potato chips, cassava chips are slightly hardened, but the major advantage lies in the fact that the chips do not become soft like potato chips within a few minutes of exposure and they maintain their crispness.

4. USE OF CASSAVA FOR ANIMAL FEED

Being rich in carbohydrate, cassava alone or in combination with protein rich components can play an important role in the compound feed sector. Use of cassava chips in animal feed formulations as a substitute for more costly cereals will lower the cost of raw materials and allow the cereals to be used for human consumption.

4.1 Ensiling of Cassava Roots

Considering the short shelf-life of fresh cassava roots and the susceptibility of dried products to insect attack, ensiling emerges as one of the ideal techniques for preserving the nutritive value of cassava, prolonging the shelf life and increasing the palatability through lactic acid enrichment.

The cassava ensiling technology developed at CTCRI has been scaled up to plastic silos of 100 litres and 225 litres capacity. The process consists of four steps:

Step 1: Fresh cassava roots are washed free of dirt and chopped along with the rind into small chips. This is essential in order to achieve sufficient consolidation during ensiling.
Step 2: The chopped whole root cassava chips are then spread in the sun for 4 hours to enable partial loss of moisture and also to reduce the initial cyanogen load before entering the silo.
Step 3: Dehydrated rice straw is cut into small pieces and then thoroughly mixed with the exposed whole root chips in the ratio 10:90 (10 kg rice straw for 90 kg chopped cassava).
Step 4: The mix is packed tightly into plastic silos and the lid is closed airtight.

The ensiling process is completed in about a week and the stabilized silage is preserved in the silo till it is opened for utilization. There is no aerobic decay in the silage as long as the feed is utilized within a period of seven days. In the event of aerobic damage when utilization is delayed, the top layer (1-2 cm) may be discarded before feeding the animals.

Proximate analysis of the cassava-rice straw silage after 72 days of ensiling indicated that most of the nutrients were still conserved. There was very good lactic acid build up (pH 4.0-4.3) in the silage within the first 2-7 days of ensiling. Although this rapid decrease in pH helped to stabilize the silage, it was not favorable for the hydrolysis of the cyanogenic glucosides of cassava. However, exposing the chopped cassava roots to sunlight for 4 hours before mixing with rice straw helped to reduce the initial cyanogen load entering the silo. It was found that rice straw at a rate of 10% could serve as good absorbent of silage effluent.

4.2 Granulator for Animal Feed

The powdery nature of cassava flour often makes this product less palatable to the animals; it also increases handling losses. The process of particle size upgradation by pelletization and/or extrusion can help to contain this problem to a great extent. However. owing to the high energy consumption of these machines, small-scale processing becomes difficult due to low investment capacity of the majority of farmers.

A manually operated drum type centrifugal granulator (100 x 50cm) was fabricated using GI sheet (23SWG); the machine was evaluated at CTCRI for the production of two feed formulations, i.e. Feed 1: cassava-25%, groundnut cake-20%, coconut cake-25%, and bengal gram-30%; Feed 2: cassava-45%, rice bran-25%, and groundnut cake-30%. The flours of different ingredients are prepared and mixed thoroughly according to the above proportions and are introduced into the granulator. Water is sprayed uniformly to the feed flours using a sprayer. The drum is continuously rotated at 40-60 rpm for about 5-10 minutes. The granules formed need to be dried. Sieve analysis and measurement of various physical properties showed that the uniformity coefficients of feed granules were 3.25 and 2.23 for feeds 1 and 2, respectively, showing fairly uniform proportion of different sized feed granules. Sphericity - 90.34 and 81.15 %; porosity - 43.93 and 49.1 %; bulk density - 550 and 500 kg/m^3; true density - 980 and 990 kg/m^3 were obtained for feeds 1 and feed 2, respectively.

5. STARCH EXTRACTION FROM ROOT AND TUBER CROPS

5.1 Cottage-Scale Cassava Starch Extraction

The cassava roots are washed by hand and peeled with hand knives. These are then manually rasped to a pulp on a stationary grater, which is simply a tin or mild steel plate perforated by nails so as to leave projecting burrs on one side. The pulp is placed on a piece of fabric fastened on four poles and washed vigorously with water by hand. Finally, the fiber is squeezed out while the starch milk collects underneath in a bucket. When starch granules settle down, the supernatant water is decanted and the moist starch is crumbled and dried in a tray or on a bamboo mat. In some places the starch milk is squeezed through a closely woven thick fabric to trap the starch granules or hung overnight to remove gravitational water and then sun-dried. This simple process is used in many rural areas.

5.2 Small-Scale Cassava Starch Production

Most of the industrial starch production from cassava in India is small-scale. It is a thriving agro-industry with about 900 starch and sago factories in north-central Tamil Nadu and about 35 in East Godavari district of Andhra Pradesh. Before extracting starch, the roots are washed and peeled manually with the help of hand knives. In Tamil Nadu the outer skin as well as the rind are removed during peeling. The peeled roots are again washed and then rasped. The practice of peeling the roots is, however, giving way to processing of whole roots in Andhra Pradesh.

Rasping

Effective disintegration of roots is obtained by the rasper. It usually consists of a wooden drum wrapped around by a perforated metal sheet with protrusions facing outside. The drum rotates on a steel shaft, in a housing with a hopper at the top for feeding the peeled and washed roots. Against the sharp protrusions of the rasper surface, the cell walls are torn up and the root flesh is turned into a fine pulp releasing most of the starch granules. The pulped roots pass into the sump below. Water is added continuously to the rasper. The entire rasping process and the activating of shaking screens are usually carried out with the help of a single electric motor.

Screening

After rasping, pulp from the sump is pumped on to a series of flat, slightly inclined vibrating screens of diminishing mesh size. The screens used are usually 3-5 in number and of 80, 150 and 260 mesh, with the first retaining the coarsest fibre. A final washing may be carried out manually over a 300 mesh screen. A small spray of water is applied to assist the separation of starch granules from their fibrous matrix; this also keeps the screen meshes clean. The starch milk is channelled for gravitational sedimentation.

Residual fibrous pulp from the screening, called *thippi*, is considered as a by-product of the cassava starch industry. It is about 10% by weight of the cassava roots and on the basis of dry matter, consists of about 56.0% starch.

Dewatering in settling tanks

The oldest practice for settling starch from its suspension in water is to let the starch milk stand for a period of 8 hours in tanks with plugged effluent outlets at varying heights. The starch settles down in the bottom and the supernatant liquor is run off. During the process of dewatering a number of tanks are filled in succession. The dimension and number of tanks are determined by the level of production. The upper layer of the sedimented starch cake which has a yellowish green tint, contains many impurities and is scooped off and rejected. In small-scale industries starch is washed with fresh water and settled 3 to 4 times to obtain a reasonably clean, white product.

Drying

After the removal of free water from the starch by sedimentation, a cake is obtained containing 35 to 40% moisture. The starch cake is crumbled into small lumps and spread out in thin layers on large open concrete yards for sun drying for about 24 hours. During sun drying dirt contamination is a real problem resulting in occurrence of specks and lowered whiteness, though an important advantage is the bleaching action of the ultraviolet rays of the sun. The hard lumps of starch are pulverized before packing into bags.

5.3 Modern Large-Scale Industrial Starch Production

In large-scale factories, the roots are immediately peeled and washed by mechanical scrubbing or high pressure water spray from nozzles. The jahn-type rasper used in the modern process, consists of a rotating drum of about 40 to 50 cm length with longitudinally arranged saw tooth blades in grooves milled around the circumference. Blades have 8 to 10 saw teeth per cm and are spaced 6 to 10 mm apart projecting about 1 mm above the surface. The coarse pulp retained on first screen is usually crushed in a secondary rasper with finer blades having 10 to 12 teeth per cm and then returned for screening. While a rasping effect of about 85% is achieved at the first rasping, the overall rasping effect is raised to 90% after secondary rasping.

Modern starch factories use stationary sieve bends (DSM screens) working in 3 to 6 stages to separate fibers from starch milk as the slurried pulp is sprayed at a right angle onto it. A series of hydrocyclones and centrifugal separators are used for dewatering. The modern practice of pneumatic flash dryers dry the starch cake from 35-40% to 10-13% moisture content in a few seconds of residence time. The final product being in powder form, does not require pulverizing.

5.4 Sago Manufacturing

Originally sago was derived from the sago palm (*Metroxylon* sp.) found in Malaysia and Thailand. However, all the sago (*saboo dana*) marketed in India is manufactured using cassava starch. The initial steps of the process are similar to starch production i.e., peeling and washing; disintegration, and settling. The partially dried starch cake is globulated on power-driven gyratory shakers made of wooden trays with gunny cloth flooring. The oscillatory movement enables the starch granules to adhere together and form into spherical beads. The globules are graded by size. At least 95% of the globules should pass through IS-sieve 170 but retained on IS-sieve 85. The oversize granules are again powdered and granulated while the undersized granules are fed back to the globulator.

The next step is partial gelatinization of the globules by roasting on shallow metal pans which are smeared with small quantities of oil and heated by fire. The granules are stirred continuously throughout the operation for around 15 min. The granules are then dried in the sun, the dried mass is passed through a spike beater to separate the large clumps, and finally polished before packing in gunny bags. The yield of sago is around 25% of the weight of fresh roots. Sago contains about 12% moisture, 0.2% protein, 0.2% fat, 87% carbohydrates, and has a calorific value of 351 calories per 100 g. Sago is used mainly as infant and invalid food, and in preparation of puddings and sago wafer.

5.5 Extraction of Starch from Dried Cassava

Rapid deterioration of fresh roots makes it difficult to have a year-round supply. This has induced attempts for the preparation of starch from dried chips. Dried cassava chips are crushed to a long-fibered mass by rollers that rotate with equal peripheral speed so that little powder is produced. The mass is then soaked in water and the starch is extracted by washing and sieving. However, the whiteness and the viscosity characteristics of the starch so prepared is inferior to those of starch made from fresh roots. It is also obvious that the preliminary operations of dehydration and disintegration make the process highly energy consuming and expensive.

5.6 Cassava Peeling Knife

A cassava peeling knife of novel design has been developed and tested at CTCRI in Trivandrum, and was subsequently evaluated on-site at a starch and sago factory in Salem by the professional peeling workers with regard to: 1. The average output; 2. % removal of peel; 3. % removal of flesh; and 4. blade sharpness. Based on this initial field evaluation, modifications were made to increase the strength and durability, decrease the cost, and improve the economics of operation. Knives of the improved design have again been evaluated in the same starch and sago factory of Salem for one month.

Performance and economics

Results of the on-site evaluation of the improved prototype show that the average output of the peeling knife is 113.56 kg/hour, comparable to that of the traditional knife. The additional labor cost per tonne of roots peeled by the improved knife (at the rate of Rs.3/- per basket of 55-60 kg unpeeled roots is about Rs.12/- only. The loss of flesh loss with the improved knife is only 1.38% compared to the 5.70% by the traditional knife. The cost of the additional roots loss by the traditional knife, or in other words the saving of roots flesh by the improved knife, is nearly Rs. 106/- at the factory rate of Rs.145/- per bag (70 kg of roots). The traditional knife costs Rs.5/- each, and two to three knives are used by a laborer each week, with the minimum cost of operation being Rs.10/-. The cost of the improved knife is estimated at Rs.15/- and its blade can be replaced and/or sharpened at the same interval at a cost of Rs. 1.50 per week .

Extensive testing of the prototype and field evaluation of the improved peeling knife has confirmed its superior performance for peeling cassava roots. Preliminary trials also indicate its suitability for peeling near-conical and cylindrically shaped fruits and vegetables such as apple, pineapple, melon, cucumber etc.

5.7 Multi-Purpose Mobile Starch Separation Plant

The perishable nature of tropical root and tuber crops and the difficulties in long distance transport, storage and marketing, constitute a major problem for farmers whose bargaining power is low. In order to overcome this problem *in situ* production of starch and value addition is helpful. The process involved in producing starch from roots consists of disintegrating the root tissues, washing out the starch from the tissue, separating the starch and drying. The commercially available machinery for starch extraction are of high capacity and the cost is prohibitive for small farmers. Therefore, a simple, low-cost starch extraction unit was developed which can be transported to villages, have an appropriate capacity, with good efficiency for wet starch extraction from different roots and tubers, such as cassava, sweet potato, dioscorea and amorphophallus.

Construction features

The starch separation unit comprises of a hopper to feed the roots, a circular rotating crushing disk housed inside a crushing chamber, stainless steel tanks to collect the crushed starch pulp, a sieving tray, settling tank, and a framework to support these components.

The circular disk is 305 mm in diameter, made from 3 mm thick stainless steel sheet. The sheet is nail punched to have 15 protrusions per 100 mm. Crushing of the roots is achieved by a combination of shearing force between the roots and the crushing disk. Separation of starch is accomplished by the addition of water, while the pulp is carried down to the pulp collecting tank. A rotating shaft, 22 mm in diameter, passing through the crushing disc is supported by two ball bearings at it's two ends. At the bottom end of the shaft, the drive is transmitted through a V-belt pulley from a 0.75 kW, 1400 rpm, electric motor. The main frame is made of MS angle iron of 40x40x6 mm for mounting the hopper, tanks, electric motor and other accessories with wheels and a steering handle. The wheels and handle make the machine transportable to farm sites. The overall dimensions of the machine are 167 x 112 x 153 cm.

Freshly harvested roots of cassava and sweet potato, and tubers of dioscorea and amorphophallus were used for the evaluation of the machine. The performance of the machine is shown in **Table 1**.

Table 1. Comparative yield of starch from different root and tuber crops.

Crops	Starch extracted (%)		Starch recovery (%)
	Chemical	Machine	
Cassava	26.5	17.2	64.9
Sweet potato	19.6	12.0	61.2
Dioscorea alata	20.4	4.4	21.6
Amorphophallus	15.2	5.2	34.2

5.8 Prototype Primary Rasper

For the purpose of extraction of starch from cassava roots, rasping is considered as a better method of disintegration than grinding, milling or pulverizing and has been adopted by the small-scale starch and sago industries of Tamil Nadu and Andhra Pradesh in India. Traditional raspers are not quite effective. The efficiency of the rasper greatly influences the extractability of the starch. A prototype rasper was developed having an overall dimension of 76x39.5x109.2 cm and being operated from a 3-phase 2-HP motor through a belt-pulley drive. The main components of the machine are hopper, cylindrical crushing chamber, rotating drum with blades, outlet chute and pulp collecting box. The horizontal rotating drum inside the crushing chamber consists of 30 saw teeth blades with 25 teeths each. Performance evaluation of this rasper with regard to operational energy requirement, process water inflow and the output showed an increase in crushing capacity (from 240 to 400 kg/hour) and a reduction of running load (from 1,344 to 978 watts) while the inflow of process water was increased from 645 to 1240 litres per minute. The capacity of the rasper for two industrially popular varieties of cassava, e.g. H-165 and H-226, was found to be 360.17 and 384.94 kg/hour, respectively, with corresponding rasping effects of 75.99 and 78.81%.

6. OTHER INDUSTRIAL PRODUCTS FROM CASSAVA

6.1 Ethyl Alcohol

The ability of cassava to compete with sugar crops for alcohol production will largely depend on the total production cost. For ethanol production from sugarcane or cassava, approximately 35% of the final cost is comprised of production cost, and the remaining 65% is the cost of the raw materials.

Fresh cassava roots, or flour of dried cassava chips can be used for ethanol production. The first step is hydrolysis of gelatinized starch to glucose by a process called saccharification which is accomplished with the help of mild acids or amylase enzymes.

The saccharified starch is fed into fermentation vessels and is inocubated with yeast, *Saccharomyces cerevisiae*. The optimum concentration of sugars for ethanol fermentation is 12 to 18%, held at pH 4 to 4.5 and a temperature of 28 to 32°C. Alcohol is recovered from the fermented mash after 48 to 72 hours and is distilled to the desired purity. The CTCRI process for production of ethanol from cassava has been transferred to two licensees in Kerala and Tamil Nadu.

6.2 Sweeteners

Liquid glucose and dextrose

Starch is a polymer of glucose and can therefore be used as a raw material for production of glucose. The glucose syrup (43% db dextrose), obtained by acid hydrolysis or enzyme hydrolysis, may be further purified to obtain dextrose crystals. Glucose is used for various confectionery and pharmaceutical purposes.

High-fructose syrups

Fructose is 1.7 times sweeter than sucrose and 4 times sweeter than glucose. Glucose can be isomerized to fructose by alkali or by an enzyme. Fructose syrup has gained importance in view of the fluctuating prices of sugar and the harmful effects of some synthetic sweeteners.

Maltose

Maltose is a disaccharide that can be obtained by enzyme treatment of saccharified starch. The maltose syrups find use in brewing, baking, soft drinks, canning and confectionery industries.

Maltodextrins

Maltodextrins are partially hydrolysed starch with a dextrose equivalent (DE) of less than 20. Typically, malto-dextrins contain 0.3 to 1.6% glucose, 0.9 to 5.8% maltose and the rest are other saccharides. Manufactured by action of α-amylase on starch, they are approved as food ingredient and find extensive use in ice creams, hard candies and as fat and oil substitutes because of their low calorific value.

6.3 Pilot Plant for Commodity Chemicals

CTCRI has established a pilot plant to produce commodity chemicals such as ethanol, liquid glucose, dextrose, high, fructose syrup, maltose and maltodextrins using starch of various root and tuber crops.. The commodity chemical plant consists of an oil-fired steam boiler, an acid hydrolysis vat, filter press, neutralization tank, a fermenter and a steam distillation column.

6.4 Dextrin

The production of dextrin involves pre-drying of starch to less than 5% moisture content, acidification (pH of 4.5 to 5.5) by spraying a dilute solution of HCl and conversion by heating up to 95-120°C to produce white dextrin, 150-180°C for canary dextrins and 170-195°C for British gum. The adhesive industry is the major consumer of dextrins. Cassava starch is preferred for making dextrin.

6.5 Cold Water Miscible Starch

A technology for cold water soluble cassava starch has been developed at CTCRI. The process consists of treating cassava starch with some chemicals in a minimum quantity of water and thorough mixing. The intimate mixture is then oven dried and then transferred to a heater. The material is brought to a temperature of 140°C and is then continuously heated at 140-160°C with intensive mixing for 2-3 hours. The resulting product has a cream color and is totally soluble in water. Washing with alcohol or methyl alcohol can further purify it. A solution of the starch in cold water has higher viscosity as compared to a starch solution prepared by heating a starch suspension of similar concentration. For example, a starch suspension at 5% concentration has a viscosity of 500 Brabender units. The starch derivative can achieve the same viscosity at 6-7% concentration and that too without heating. The process is simple and economical, but requires care to get a quality product and good yield. The chemicals used are easily available and cheap. The cold water soluble starch is advantageous since no heating is required to dissolve it, and hence the product is exceptionally suited to applications where other components added to or with starch may be thermally unstable. The starch can have applications in the textile and paper industries. It can also find use in drilling mud formulations and in adhesives. Similar starch derivatives can be made from other starches. The technology has been transferred to M/s Vensa Biotech Ltd., Samalkot, Andhra Pradesh.

6.6 Liquid Adhesive

A laboratory process developed at CTCRI has been successfully adopted by one of the cottage industries for production of liquid adhesives from cassava starch. Applications of liquid adhesives include carton sealing, laminated board, corrugated board, foil-to-paper laminating, bottle and container labelling, bill posting, cigarette seaming, bag making, etc.

A pilot plant for manufacturing liquid adhesive from cassava starch was designed to replace more rudimentary equipment, and to demonstrate the techno-economic feasibility of the scaled-up process. It consists of a stainless steel digester of 100 liters capacity. Its immediate outer jacket contains used mobil oil as the heating medium while the outermost jacket serves the purpose of insulation. Starch, water, alkali and preservatives are cooked in the digester at 60-65^{0}C for about one hour with the help of 3 kW heaters and a thermostat. An agitator mechanism driven by a 1 HP motor at 90 rpm keeps the mass continuously stirred. Liquid adhesives have the advantage of being 'READY-FOR-USE' by the consumer, while cassava starch is the preferred raw material, resulting in better flow characteristics compared to cereal starches.

6.7 Bio-Degradable Plastics from Starch

About 32% of India's requirements of commodity plastics are met by imports. Agricultural and packaging sectors account for about 50% of the plastics consumed. The use of plastics has increased to such an extent that the disposal of used products has become increasingly difficult. The global shortage and mounting price of petroleum has also led to severe competition between fuel for energy and feedstock for petrochemicals. In the search of alternative feedstocks for polymers, starch, a natural polymer as well as a renewable raw material, has captured the interest of academic and industrial research workers across the globe pursuing environmentally degradable plastics for easier disposal.

Process

CTCRI's process for production of starch-based plastics involves blending corn (maize) or cassava starch with suitable synthetic polyolefins (e.g. LDPE, HDPE and LLDPE) as stabilizing agents and suitable amounts of appropriate coupling, gelatinizing and plasticizing agents. Compounding of the blend prior to extrusion film blowing is adopted to attain proper melt mixing. Successful extrusion film blowing and injection moulding was possible with formulations containing 10 to 40% starch. The CTCRI process has been patented in India and Europe. The technology for manufacturing of starch-based bio-degradable plastics has been licensed to four companies in the states of Delhi, Haryana, Himachal Pradesh and Karnataka.

Properties

The properties of these films with respect to strength, stability and physico-chemical properties were studied to ascertain their limitations and potentials for different end-uses. Films from starch-based plastics could be blown as thin (39-96 μm) as those from LDPE or LLDPE. Films containing starch above 20% exhibited relatively higher vapor transmission rates.

These starch-based plastic films have been found to possess adequate mechanical strength and flexibility to make them suitable for various potential agricultural applications. The tensile strength of these plastics films containing 10, 25 and 40% starch were found to be 12.56, 17.34 and 10.67 MPa, respectively. The elongation at break values for these films varied from 210.8% to 122% as the starch content varied from 10% to 40%. In comparison, the tensile strength and elongation values of the LDPE control films were 10.97 MPa and 384.1%. The storage stability of these films, with regard to changes in tensile strength and elongation, was almost equivalent to that of the ordinary polyethylene films, the granule form of the material being more stable than the film form.

The suitability of these films for the potential areas of application in the field of agriculture and single-use disposable packaging was assessed through outdoor weathering and soil burial which showed drastic reduction in mechanical strength and elongation values resulting in brittleness and disintegration. Deterioration of strength and of flexibility were progressively greater with the increase in starch content of the film and the duration of environmental exposure. Scisson of macromolecular chain was evident from morphological studies. Further rapid biodegradation (in 4 to 6 months) of these films could also be achieved by incorporating a suitable catalytic agent into the film composition. Films of the latter type would be much more suited for making nursery bags and single-use disposable packaging. Relatively easier dispersal and absorption of starch-based bio-degradable plastics into the soil after a specific time interval would make it an ecologically satisfactory mode of disposal of plastics waste.

CONCLUSIONS

Small-scale cultivation, a long duration to maturity, the highly perishable nature of the harvested produce, the inconsistent supply of marketable surplus, the irregular shape and bulky size of the roots are some of the factors which render the broadening of the post-harvest utilization of cassava rather difficult and discouraging. The importance of cassava has been realized as a high energy food, as animal feed component and as an industrial raw material for sweeteners, ethanol and other commodity chemicals. Its industrial potential, however, has not been fully tapped. Development of cost- and energy-efficient process equipment is an essential requisite for cassava, which, like other root crops, is invariably associated with labor intensive farming and low-cost produce. Improved technology needs to be developed for small- and medium-scale cassava starch extraction, a level of operation which is very common in India. Sales of snack products are growing rapidly throughout the world. The trend away from formal meals to snacking throughout the day has created a demand for new types of products. Increased utilization of cassava roots as food by the urban and affluent section of the society can be achieved by processing the roots into various convenience and fast food products.

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MODIFIED CASSAVA STARCH IN MALAYSIAN FOOD PRODUCTS

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ABSTRACT

Starch modification widens the possibility of having several different types of food products. Modified starches are more flexible than their native ones and are more appropriate for industrial usage. A few types of modified starches that are suitable for food thickener, batter mix and edible film are studied to increase the economic value of cassava and provide more choice to food manufacturers when selecting their food ingredients.

In the case of food thickener three different types of modified starches are prepared. Two of them are cross-linked hydroxypropylated while the other is cross-linked acetylated. The cross-linked acetylated starch produced has the clearest paste and lower gelatinization temperature than the cross-linked hydroxypropylated starches. The prepared modified starches are then incorporated into tomato sauces. All the three modified starches are found to be capable of producing tomato sauces but of different thickness or degree of viscosity.

For the batter mix the cassava starch is enzymatically prepared and used as an ingredient in a batter mix for deep-fried chicken pieces. The finished product is found to be comparable in terms of texture and sensory attributes with the deep-fried chicken pieces using a commercially available modified starch in the batter mix.

The modified starch for edible film is prepared by initially treating the native cassava starch with enzyme and then with acetic anhydride in alkaline medium. The product is subsequently purified before casting the aqueous solution onto a flat surface plate and drying. The high solubility property of the edible film enables it to be used for food sachets intended to be dissolved in water.

INTRODUCTION

In Malaysia, the total import value of starches (comprising mainly cassava, wheat, maize, potato and sago) in 2000 amounted to RM193,142,246. Cassava starch accounted for about 53% of this value, and its import volume has been growing at an annual growth rate of 16.26% between 1996 and 2000 (Tan *et al.*, 2002).

Since the late 1980s, imports of cassava starch have outstripped corresponding exports (**Figure 1**). Imports have exceeded exports by a maximum volume of more than 195,000 tonnes in 1999, before dropping to about 172,000 tonnes in 2000. Based on rising starch consumption trends in Malaysia, the growth prospects for cassava starch are highly positive.

The growing acceptance of cassava starch in food products due to its various beneficial properties has led to the expansion of related studies conducted in several countries. Cassava starch has a bland flavor that does not mask light flavors such as vanilla, peach and lemon. Its paste, film and gel are clearer than those of other starches; hence, it is suitable for use in certain products such as fruit filling. In addition, its gluten-free nature and easy digestibility have led to its widespread use in baby foods.

In line with the current trend of research, the Food Technology Centre of MARDI has developed a few types of modified cassava starches suitable for food use, including food thickener, batter mix and edible film. The existence of these modified starches is

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intended to increase the economic value of cassava and provide more choice to food manufacturers when selecting their food ingredients.

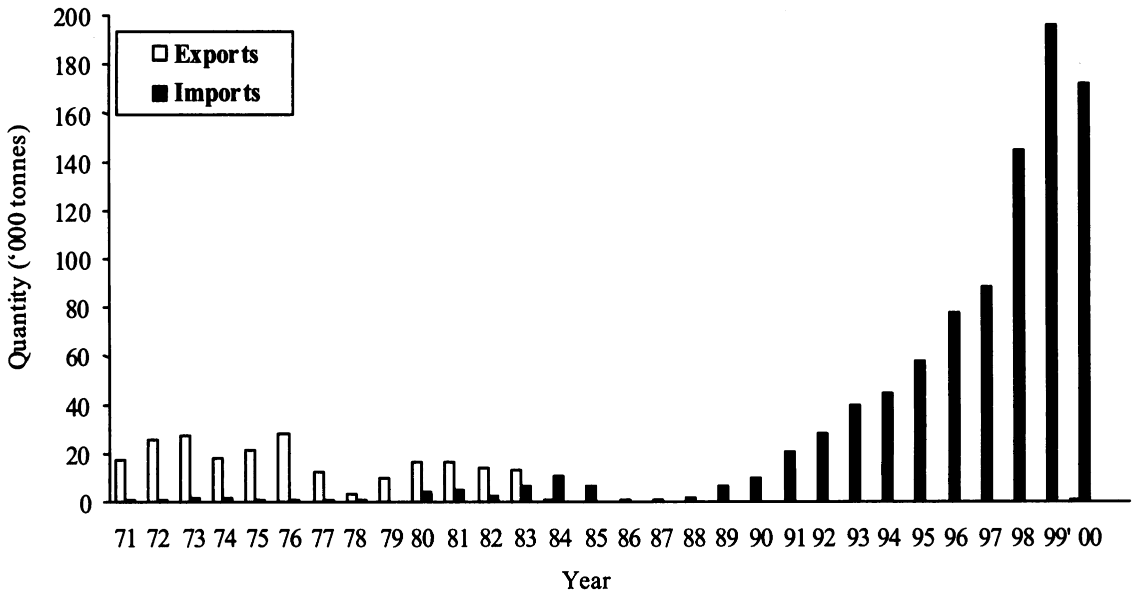

Figure 1. Cassava starch exports from and imports to Malaysia over the period of 1971-2000.
Source: *Department of Statistics, Malaysia.*

Food Thickener

Preparation of Modified Cassava Starches

Two types of cross-linked hydroxypropyl cassava starches (TA and TB) were prepared as shown in **Figure 2**. In the preparation of TB, the starch was reacted in a closed glass reaction vessel attached to a motorized vacuum pump. The vacuum pump was allowed to function at regular intervals. In addition, a cross-linked acetylated cassava starch (TC) was produced as shown in **Figure 3.**

Table 1 shows that the light transmittance values of the pastes, i.e. 6.5% for TA, 12.2% for TB and 23.7% for TC, were greater than that of the commercial starch (4.27 %) indicating greater clarity of the three modified starches. TC was found to be the clearest. This finding is in line with studies by Craig *et al.* (1989) who found that cross-linking would reduce the clarity of the starch paste, and by Wu and Seib (1990) who indicated that acetylation gave better clarity. Among the three modified cassava starches, TB had the lowest phosphorus content of 6.7 mg/100 g. Generally, phosphorus content affects the pasting characteristic of the starch. The pasting characteristic of TC was found to be similar to that of the commercial product (Com), while TA and TB had similar pasting curves **(Figure 4)**.

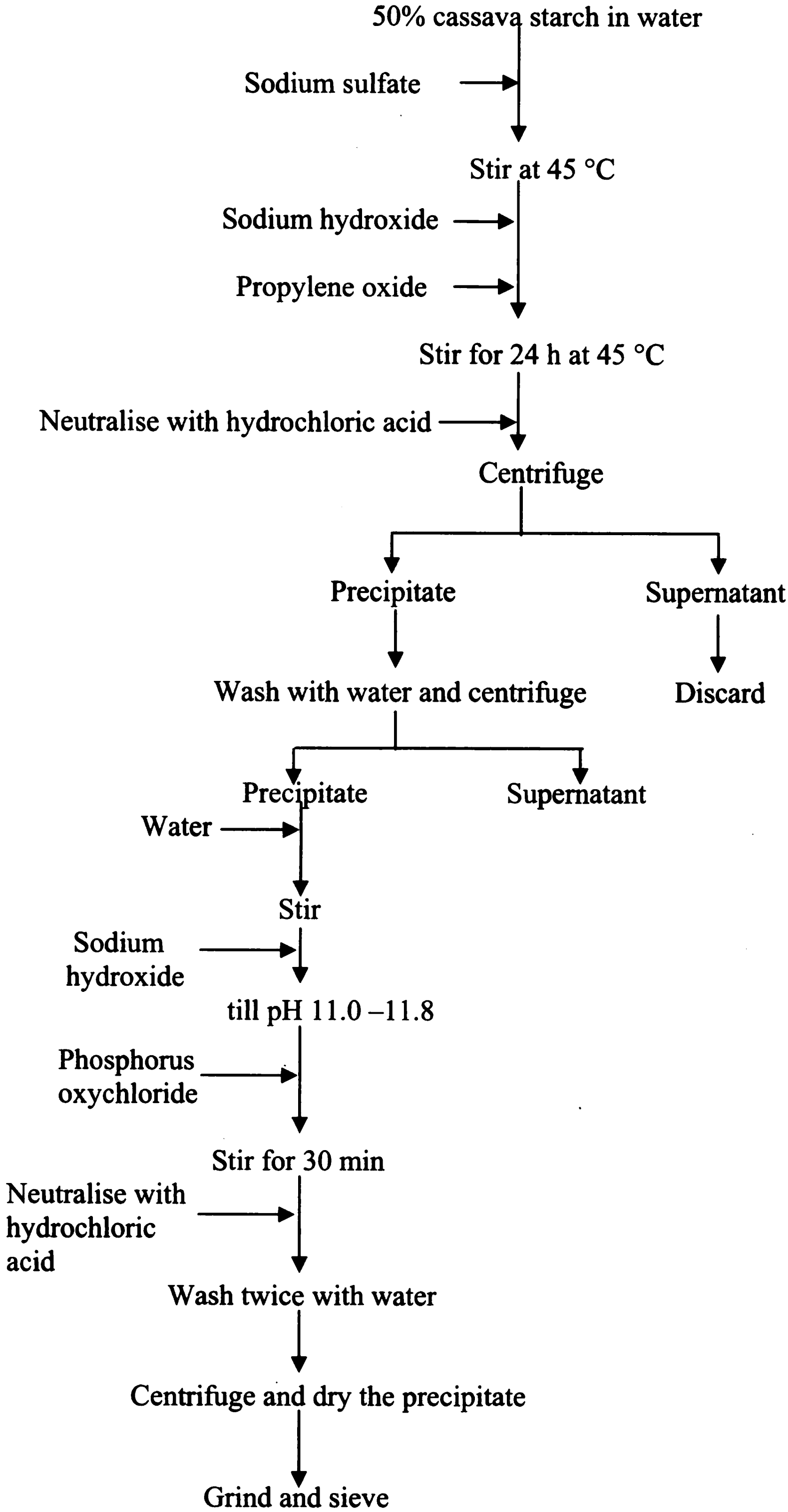

Figure 2: Preparation of cross-linked hydroxypropyl cassava starch.

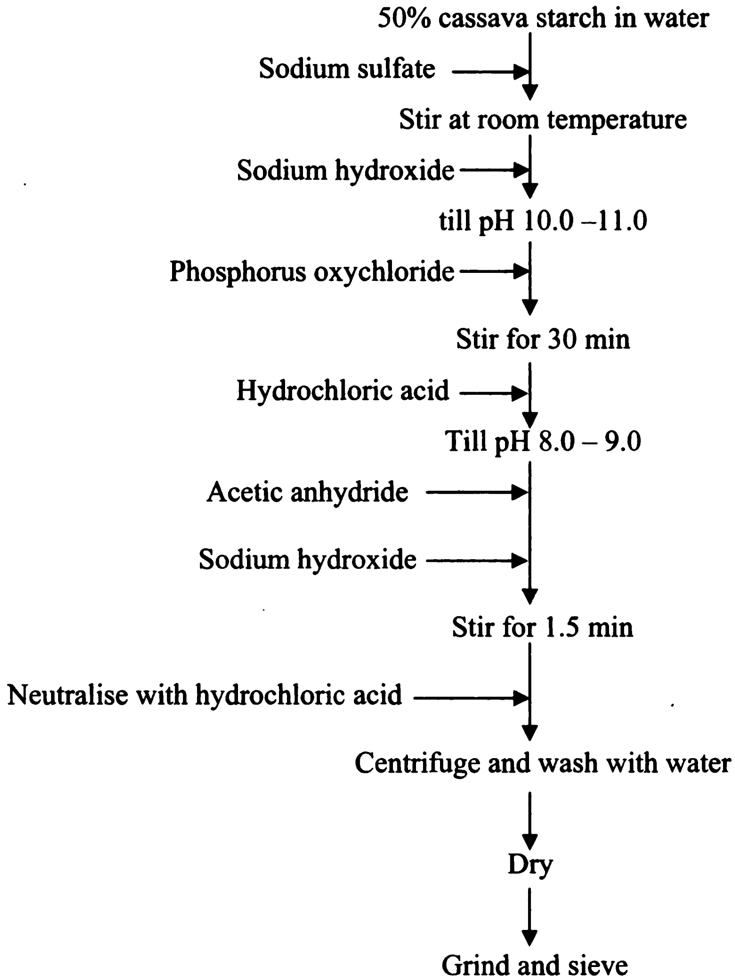

Figure 3: Preparation of cross-linked acetylated cassava starch.

Table 1. Paste clarity and phosphorus content in three modified cassava starches and a commercially available tapioca starch.

Properties	TA[1)]	TB[1)]	TC[1)]	Com.[2)]
Paste clarity (% T_{650nm})	6.55	12.16	23.69	4.27
Phosphorus (mg/100 g)	7.5	6.7	7.3	-[3)]

[1)] TA, TB and TC are modified cassava starches
[2)] Com. = commercially available starch for thickener in sauces
[3)] value not determined

Tomato Sauces Prepared with the Modified Cassava Starches

Figure 5 shows that the viscosity of tomato sauce (SC) containing TC was lowest while that of the commercial cassava starch (Com) was highest. The viscosity curves of tomato sauces SA (containing TA) and SB (containing TB) were also similar to those of commercialy well-known and widely consumed tomato sauces TS1, TS2 and TS3.

The color and pH of the tomato sauces did not show large variation (**Table 2**). The pH of the laboratory-prepared tomato sauces (3.43-3.45) was slightly lower than that of the commercial ones (3.61 –3.72). The total solid content of laboratory-prepared sauces was much higher than that of commercial ones. This could be due to the high amount of tomato paste used.

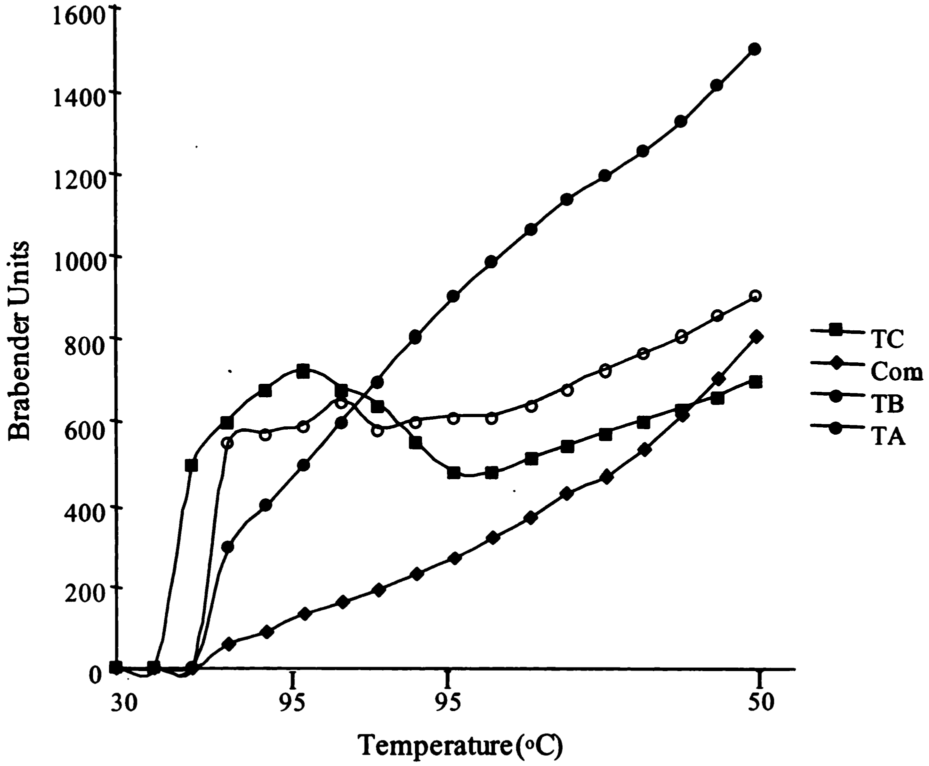

Figure 4. Pasting characteristics of three modified cassava starches and a commercially available starch (6 % d.b.) at pH 6.5.
TA, TB & TC – Modified cassava starches
Com. – Commercially available starch for thickener in sauces

2. Batter Mix

Intermediate- and high-amylose cassava starches were used to improve the texture of potato French fries. They were prepared by using an enzyme. A comparison was made between the French fries coated with the laboratory prepared intermediate-and high-amylose cassava starches and a commercially recommended starch. A Stevens QTS25 texture analyser was used to determine the texture profile of the French fries. The French fries coated with the laboratory prepared cassava starches were not significantly different ($p \leq 0.01$) from those coated with the commercially recommended starch in terms of hardness, cohesiveness, gumminess, chewiness, adhesiveness and springiness.

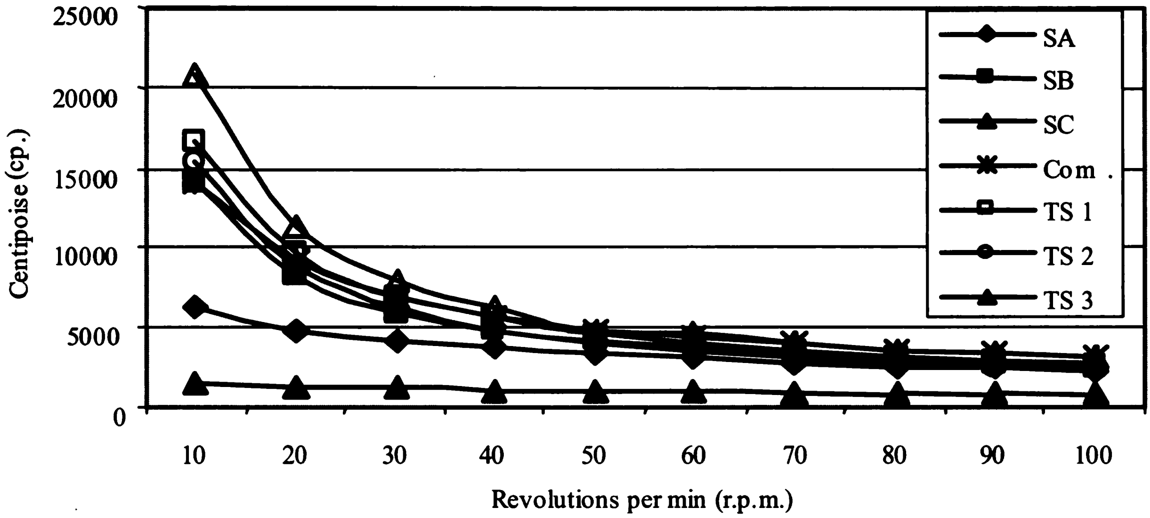

Figure 5. Viscosity of laboratory-prepared and commercial tomato sauces at room temperature.
***Note:** SA, SB and SC: Tomato sauces prepared in the laboratory*
TS1, TS2 and TS3: Commercially available tomato sauces

Table 2. Properties of tomato sauces containing the prepared modified cassava starches.

	Color				
Tomato sauces[1)]	*L*-value	*a*-value	*b*-value	pH	Total solids (%)
SA	30.85	15.11	16.05	3.43	82.68
SB	39.95	14.75	16.39	3.45	82.97
SC	28.85	15.73	16.46	3.44	82.90
Com.	28.86	15.87	15.60	3.43	82.71
TS1	24.63	16.49	10.99	3.61	37.09
TS2	25.09	17.27	11.41	3.65	35.43
TS3	25.23	13.93	10.78	3.72	37.09

[1)] SA, SB and SC are tomato sauces containing the prepared modified cassava starches, TA, TB and TC
Com. = tomato sauce containing commercially available starch for thickener in sauces
TS_1, TS_2 and TS_3 are commercially available tomato sauces

Coating Starches

The intermediate- and high-amylose cassava starches were prepared by using an enzyme, pullulanase, as described by Khatijah *et al.* (1998). A commercial starch recommended for coating French fries was obtained from the National Starch and Chemical Corporation.

French Fries

The potatoes were washed, deskinned and cut into strips (1x1 cm square by 7-8 cm in length). They were then steamed for 10 min, dipped into 0.5% sodium aluminium pyrophosphate and partially dried in an oven. The various coatings, consisting of wheat flour, salt, dextrin, starches and water, were applied onto the potato strips. The excess coatings were removed before the fries were parfried in palm olein at 160-170°C for 1-3 min. They were then frozen in a blast freezer before packing into plastic bags for storage in a freezer until further usage. The French fries were finished fried at 160-170°C prior to analysis or consumption.

The color of the French fries with coating consisting of a recommended commercial starch (III) was observed to be similar (light yellow) to those with coating consisting of high-amylose starch (II), while those with a coating consisting of intermediate-amylose cassava starch (I) were darker (brownish yellow) in color. The French fries from treatment I were slightly clumpy after frying compared to those from treatment II and III.

Several parameters were obtained from the force versus deformation curves of the texture profile analysis (TPA) **(Table 3)**. The French fries coated with three different coatings were not significantly different ($p \leq 0.01$) in terms of hardness, cohesiveness, gumminess, chewiness, adhesiveness and springiness. They could be considered of similar crispiness as demonstrated by their hardness values.

Table 3. Texture values[1)] of starch-coated French fries.

Samples[2)]	Adhesiveness[3)] (gs)	Chewiness[4)] (kgmm)	Cohesiveness[5)]	Gumminess[6)] (kg)	Hardness[7)] (kg)	Springiness[8)] (mm)
I	2.59 ± 1.92^a	2.00 ± 0.45^a	0.33 ± 0.04^a	0.41 ± 0.10^a	1.25 ± 0.28^a	4.94 ± 0.41^a
II	4.24 ± 1.92^a	2.23 ± 0.88^a	0.35 ± 0.06^a	0.43 ± 0.16^a	1.26 ± 0.45^a	5.21 ± 0.65^a
III	4.34 ± 2.77^a	1.40 ± 0.39^a	0.28 ± 0.07^a	0.28 ± 0.11^a	1.15 ± 0.81^a	5.27 ± 0.75^a

[1)] The values were expressed as mean ± standard deviation
Means with similar superscript within each column are not significantly different at $P \leq 0.01$
[2)] I: Coating consisting of intermediate-amylose tapioca starch
II: Coating consisting of high-amylose tapioca starch
III: Coating consisting of a recommended commercial starch
[3)] Adhesiveness or stickiness : The work required to pull the blade upward
[4)] Chewiness : Gumminous x springiness
[5)] Cohesiveness : The ratio of work done during the second compression divided by the work done during the first compression
[6)] Gumminess: Hardness x cohesiveness
[7)] Hardness: The force necessary to deform the French fry
[8)] Springiness: The height that the French fry springs back after the first compression to the maximum deformation performed

3. Edible Film

Edible films were developed from aqueous solutions of cassava starch. They were prepared by initially converting the native starches into high-amylose starches by using the enzyme pullulanase, and treating the high-amylose starches with acetic anhydride in alkaline medium. The product was then purified before casting the aqueous solution onto a flat surface plate and drying. The films obtained were transparent and clear but a bit fragile. They were highly soluble in cold water and almost completely soluble in hot water **(Table 4)**. The films could be used as food sachets for beverages and dry mixed powder that are intended to be added to hot or cold water prior to use in instant or convenient foods

Table 4: Solubility of edible films in cold and hot water.

	Solubility (%)[1]	
Edible films	Cold water	Hot water
Cassava	99.1	99.8

[1] The values are expressed as mean of duplicate samples.

CONCLUSIONS

Modified cassava starch has the potential of being used in various food products. The products developed in this study are intended to be an eye opener to entrepreneurs and hence lead to further development of the cassava industry.

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RECENT DEVELOPMENTS IN CASSAVA STARCH AND DERIVED PRODUCTS USED IN FOOD PROCESSING IN INDONESIA

N. Richana[1], J. Wargiono[2] and Nasir Saleh[3]

ABSTRACT

Annual cassava starch production in Indonesia during the past ten years was about 0.35 million tonnes. Cassava starch is presently utilized mainly for food processing, such as in the canning industry as well as for production of glucose, fructose, sorbitol, monosodium glutamate (MSG), ethanol, noodles, cakes and many traditional foods. Demand for canned food is presently 40% higher than supply. It means that the canned food industries should increase production to meet the demand. Therefore, production of starch, which is the raw material of these industries, has to be increased as well. Developing a small-scale starch industry, which could increase farmers' income, will be discussed. Enzymatic and hydrolization methods are used by the food processing industry. Most of the factories are located in Java island. The capacity of small-scale and large-scale factories are approximately 200 and 1000 tonnes/month, respectively. The prospect of developing a food processing industry using cassava starch as well as other starch-derived products, and its ability to increase farmers' income, will be discussed.

INTRODUCTION

Annual cassava starch production in Indonesia during the past ten years was about 0.35 million tonnes. Cassava starch is presently utilized mainly for food processing, such as in the canning industry as well as for production of glucose, fructose, sorbitol, monosodium glutamate (MSG), ethanol, noodles, cakes and many traditional processed foods. Demand for cassava starch for food and non-food industries were 0.342 and 0.725 million tonnes, respectively (CIC, 1998). Therefore, starch production should be increased to meet the demand.

Presently, demand for canned food is 40% higher than supply. The country is presently importing 5,989 tonnes of cassava starch, 66,733 glucose, 310 of fructose, 2,458 of other inverted sugars and 11.72 tonnes of other convectionary sugars (CBS, 2002). This indicates that both food and non-food industries should increase production to meet the demand. Production of starch, which is the raw material in these industries has to be increased as well.

Medium-size cassava starch factories, with a capacity to process more than 200 tonnes of fresh cassava roots/day, have been developed at various production centers, but were not able to stabilize or increase the fresh root price paid to farmers. Factors that keep the price of the fresh roots low are: 1. roots are bulky and highly perishable; 2. poor road infrastructure and long distance to the factory; and 3. weak marketing system. Development of a village-scale production capacity of both cassava starch and derived products will be a way to reduce transportation costs, while the perishability can be minimized by transporting roots to starch factories in the village soon after harvest. Small-scale starch factories will minimize the transportation cost of bulky roots and stimulate farmers to arrange planting and harvesting time according to the factory's demand. If these small-scale starch factories

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are able to reduce production costs, their products will become more competitive in emerging markets. Derived products of cassava starch in these emerging markets include glucose, glucose syrup, fructose, fructose syrup, sorbitol and MSG.

Other derived products made from cassava starch with good prospects in emerging markets are gum xanthan, bio-degradable plastics and bio-surfactants. Establishment of these industries will depend on the price of cassava starch and on the starch characteristics. Current research on cassava starch-derived products will be discussed in this paper.

DEVELOPMENT OF SMALL-SCALE CASSAVA STARCH FACTORIES

Table 1 shows that most small-scale cassava starch factories are located on Java island, especially in West Java province. Most cassava production on Java island is for direct human consumption as fresh roots (after boiling or roasting) or as dried roots pounded or milled into a flour (Wargiono *et al.*, 2002). Small-scale cassava starch factories in Java use traditional processing methods. This starch is of medium to low quality and is characterized by a high fiber content. This starch is subsequently collected by medium-scale starch factories to be reprocessed into a product of high quality and high fiber. This starch is used as raw material for food industries of high-fiber content products. Small-scale cassava starch factories outside of Java do not use this traditional processing method, and the starch produced is of low quality and has low fiber content. Medium-scale cassava starch factories at production centers are able to process fresh roots at full capacity, while large-scale cassava starch factories in Java find it difficult to produce starch at full capacity. Medium-to large-scale cassava starch factories located outside of Java pay farmers only a low and highly unstable price for cassava roots indicating that there is little cooperation between factories and farmers. This condition in turn affects the level of cassava production, as cassava production is not supported by government policies. Establishment of small-scale cassava starch factories at the village level will allow for a higher price of roots at the farmers' level due to:

- These cassava starch factories are located close to the farmers' fields, so transportation costs are relatively low and the roots can arrive at the factories soon after harvest.
- The members of the farmers group can better plan the time of cassava planting and harvest according to the demand for roots at the factory.

Table 1. Number and scale of cassava starch factories in Indonesia by region in 1998.

	Number of factories		
Region	Small	Medium	Large
Java	211	80	0
Sumatra	13	19	70
Kalimantan	0	4	4
Sulawesi	0	0	11
Maluku and Irian Jaya	0	2	1

Source: *PT. CIC, 1998.*

Once organized, the farmers' group can adopt appropriate varieties and improved agronomic practices that will increase cassava yields and production.

As more than 50% of cassava starch is currently produced on Sumatra island, especially in Lampung province, the government of Lampung province is supporting a program for the development of small-scale starch factories (ITTARA). A case study was conducted in these sub-districts where ITTARA has been implemented. It indicates that small factories can not easily produce high-quality starch. It means that the price of starch will still be low and these small-scale cassava starch factories will not be able to compete with the big starch factories. The main reason for the low quality of starch is the sun-drying process used by small-scale starch factories. Factors affecting low price are starch quality and marketing system. The low quality of starch and poor linkages with the marketing system are the reasons why small-scale starch producers have no bargaining power and have a low profit margin. Improving the drying process and organizing the marketing system by ITTARA member associations or corporations (KOPATARA) might be a way to increase starch quality and thus the bargaining power of small-scale starch factories. The advantage of developing KOPATARA is to establish a floor price for fresh cassava roots among the members of ITTARA for the small-scale production of either wet or dry starch (**Table 2**).

Table 2. Processing costs and the break-even point for production of wet and dry cassava starch in small-scale factories in Lampung province of Indonesia in 2001.

	(Rp/kg)					
Price of peeled fresh root	160	170	180	190	200	210
Processing cost of wet cassava starch	10.23	10.23	10.23	10.23	10.23	10.23
Total production cost of wet cassava starch	170.23	180.23	190.23	200.23	210.23	220.23
Processing efficiency of wet starch (%)	35	35	35	35	35	35
Break-even point (BEP) for wet starch	486.37	514.94	543.51	572.08	600.66	629.23
Cassava starch drying cost	30	30	30	30	30	30
Total processing cost of dry starch	200.23	210.23	220.23	230.23	240.23	250.23
Processing efficiency of dry starch (%)	20	20	20	20	20	20
Break-even point (BEP) for dry starch	1001.12	1051.12	1101.12	1151.12	1201.12	1251.12

Processing efficiency percentage = kg of product per 1 kg of raw material x100%
Source: *Feasibility study of small-scale cassava starch factory development program (ITTARA).*

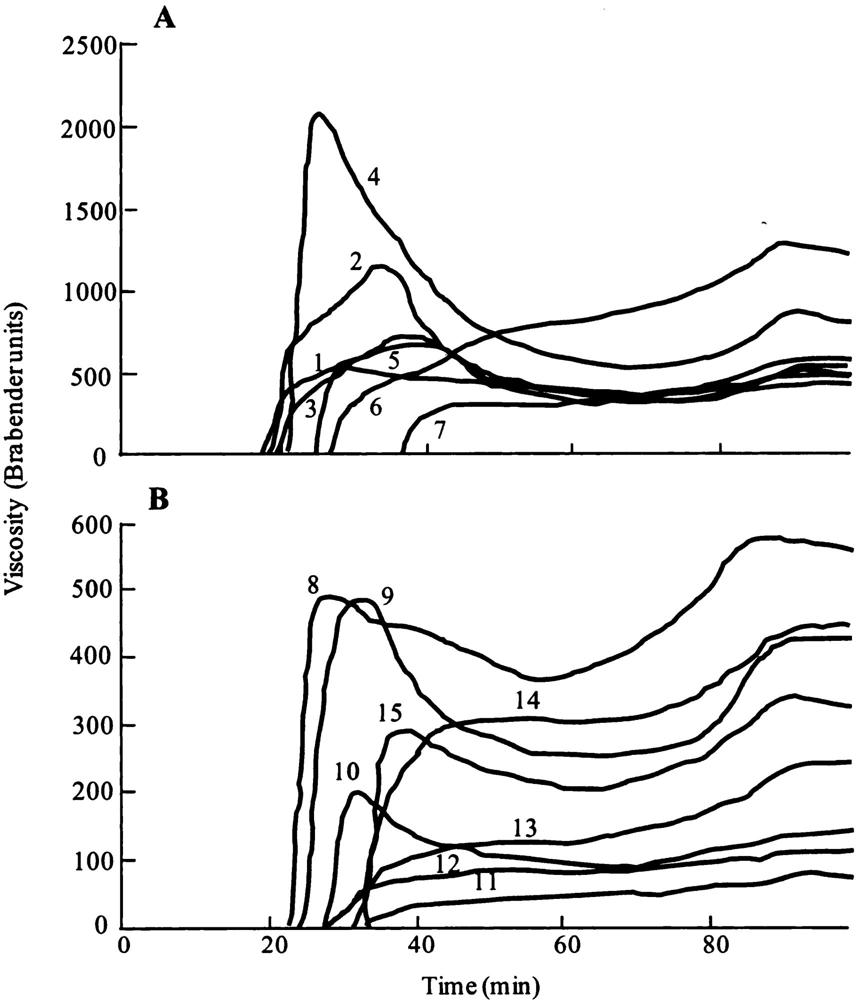
Reasons for the low price of fresh roots at the farmers' level when large-scale cassava starch factories process the roots are:

- High transportation cost due to long distance from the farmers cassava field to the starch factories, and the bulkiness of roots.
- Bad road infrastructure, allowing trucks to transport fresh roots only during the dry season. As such, most farmers harvest cassava at the same time during the dry season.
- Fresh roots are highly perishable, so the price of fresh roots decreases when it takes more than three days for the roots to reach the starch factories.
- The bargaining power of the farmer is low due to the lack of alternative markets to sell the roots.

The high production cost and the problems of poor infrastructure and root perishability can be reduced by the development of small-scale cassava starch factories at production centers run by farmers' groups. The ability to produce low-cost starch will in turn support the development of industries producing starch-derived products.

CASSAVA STARCH AND DERIVED PRODUCTS USED IN FOOD PROCESSING

Cassava starch can be used as raw material for many kinds of industries, both food and non-food, due to its intrinsic characteristics (**Figure 1**). Among the various starches cassava starch is generally the cheapest. It means that developing a cassava starch industry may be a way to establish several starch-derived industries as well. These industries may include noodles, cakes, fermentation products, glucose, fructose, and sorbitol. Demand for cassava starch for these industries is presented in **Table 3.**



1. Yam; 2. Oca; 3. Ulluco; 4. Potato; 5. Sweet potato; 6. Queensland arrowroot; 7. Arracacha; 8. Arowroot; 9. Cassava; 10. Swamp palm; 11. Giant taro; 12. Yam bean; 13. Cocoyam; 14. Plantain; 15. Taro

Figure 1. Visco-amylograms of non-cereal starches.
***Source:** Dufour et al., 2000.*

Table 3. Annual starch demand for various starch-based industries in Indonesia.

Industries	Demand: Amount ('000 t)	%
Food industries		
Syrup sugars[1)]	151	14
Instant noodles	45	4
Cakes	70	6
Biscuits	28	3
Others	48	5
Total	**342**	**32**
Non-food industries		
Paper	63	6
Textile	6	1
Sorbitol	43	4
Others	612	57
Total	**724**	**68**

[1)]glucose, fructose

Source: *PT CIC. 1998*

1. Instant noodle industry

Consumption of instant noodles in Indonesia increases 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, and followed by another 25 smaller instant noodle companies (Capricorns, 1998). 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 for the noodle industries they should cooperate with ITTARA by provinding external credit for the purchase of fertilizers and for land preparation costs.

2. 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 30-80% for biscuits. The wheat flour demand 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 increases at an annual rate of 14.9% (Capricorns, 1998). 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.

3. Fermentation industries

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

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

Glucose syrup can be produced by hydrolizing starch with either acid or α-amylase enzyme. Cutting the starch chain using acid will produce a mixture of dextrin, maltose and glucose (**Figure 2**).

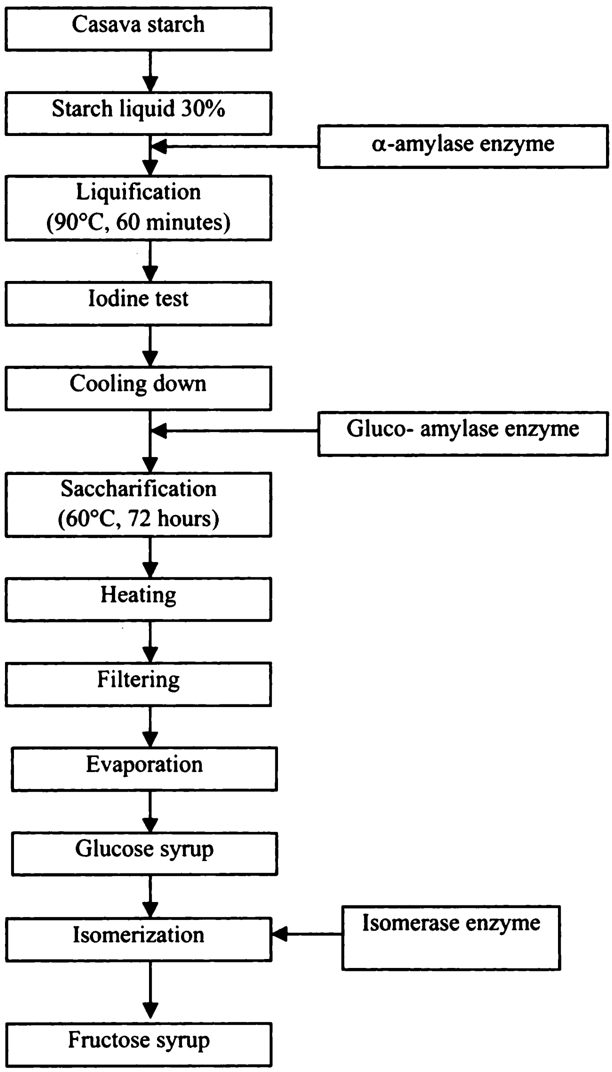


Figure 2. Flow chart for producing glucose and fructose syrups from cassava starch.

Imported gluco-amylase and α-amylase for producing glucose and fructose syrups could well be substituted by other enzymes produced domestically (Richana *et al.*, 1999; Lestari *et al.*, 2000). **Table 4** shows that the amylose content of cassava starch is lower than that of arrowroot, but the productivity of cassava roots is much higher than that of arrowroot. For that reason, cassava starch will probably be the main raw material for the domestic glucose and fructose syrup industries.

Table 4. Amylose content of different types of starches and their effect on the yields of glucose and inverted sugars in the saccharification process.

Starches	Amylose content (%)	Glucose syrup yield (%)		Invested sugar yield (%)	
		A[1)]	B[1)]	A[1)]	B[1)]
Arrowroot	34.80[c]	83.5[ab]	73.08[bc]	86.51[b]	89.45[b]
Cassava	29.86[b]	80.0[ab]	87.98[a]	87.02[a]	87.54[a]
Sago	23.94[a]	62.5[c]	64.09[c]	87.66[a]	87.57[a]

[1)]A = Enzymatic hydrolization method; B = Acid hydrolization method
Source: *Richana et al., 2000.*

The great amount of imported glucose, fructose and sorbitol indicates that production of these products produced by large-scale factories with a capacity of about 1000 tonnes/month is still lower than the demand The establishment of small-scale factories following the ITTARA model, using cassava-starch to increase domestic production of glucose and fructose syrup should be supported. Small-scale glucose syrup factories set up in Central Java seem to be economically sound. The capacity of this factory is 200 tonnes/month; the use of acid in the hydrolization process is most suitable for this small scale. The products of this factory become the raw material of large-scale factories, which further process glucose into fructose syrup and sorbitol. This could be a model for the establishing of small-scale glucose and fructose syrup industries.

RECENT RESEARCH DEVELOPMENTS

The best prospects for developing bioprocesses based on cassava starch are bio-degradable products such as gum xanthan and biosurfactants.

- **Gum xanthan**

Gum xanthan is a hetero-poly-saccharide produced extra-cellularly by *Xanthomonas campestris* bacteria. Gum xanthan is utilized by many factories due to its chemical characteristics and unique rheology. Gum xanthan is used as coagulator, suspender, stabilizer, and emulsifyer for industries of food, textile, ceramic, paper, print ink, medicines fungicides and pesticides (Petit, 1979; Ochao *et al.*, 1992). Demand for gum xanthan is higher than production. About 342 tonnes of this product are imported to meet domestic demand (CBS, 2000).

Cassava starch used as the media for producing *Xanthomonas campestris* bacteria produced 26.5% gum xanthan, while glucose used as the media produced 31.5% (Wiryosasmita, 1993). This result shows the potential for establishing gum xanthan production factories, since production of cassava starch and glucose can be increased according to demand. Since the demand by many factories in the country is relatively high, developing gum xanthan production facilities is urgently needed in the near future.

- **Biosurfactants**

Surfactants or surface-active agents are used for industries of detergents, cosmetics, food additives, insecticides and herbicides (Banat, 1993). As demand for biosurfactants by industries is increasing, therefore, biosurfactants should be produced domestically. Research result shows that cassava starch is a potential culture media for producing biosurfactants (**Table 5**). As the dependance of many factories on biosurfactants increases, the demand for cassava starch used as the raw material also increases. There is therefore a good posibility to establish biosurfactant factories in the country.

Table 5. Effect of various glucose substrates as carbon source on the yield of lipopeptide biosurfactants by *Bacillus* sp. BMN 14.

Glucose substrates	Biomass (g/l)	Biosurfactant extract (g/l)	Surface elasticity (mN/m)
Glucose (Sigma)	2.02	0.85	33.5
Cassava starch 1	1.94	0.78	33.6
Cassava starch 2	1.87	0.68	35.0
Arrowroot root starch 1	1.78	0.73	36.0
Arrowroot root starch 2	1.81	0.58	38.0
Sago starch 1	1.96	0.81	34.6
Sago starch 2	2.08	0.62	38.0

***Source:** Richana et al., 2000*

- **Poly-β-hydroxy butirate**

Poly-β-hydroxy butirate (PHB) is characterized by its structural elasticity; it is easy to be formed and can be formed either as fibers or can be processed into plastic film (Caldwell, 1994). The production process of PHB is based on various micro-organism species. The capability of each micro-organism to produce a high yield of this product is affected by the kind of culture media, such as *Alcaligenus entrophus* on fructose, *Pseudomonas* sp on methanol, *Bacillus* sp, and *Rhizobium* on glucose (Atkinson and Mavituna, 1991; Holmes, 1988).

CONCLUSIONS

As the development of cassava by the year 2020 will be better integrated into emerging markets, through the efficient and enviromentally sound production of a diversified mix of high-quality and competitive products for food, feed and industry, and the model for agricultural development will involve the active participation of farmers, this will lead to a more demand-driven and industrialized agriculture. Therefore, developing industries of cassava starch-derived products is a way to obtain high added-value of cassava.

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TAPIOCA PRODUCTS AND TRADE IN THAILAND[1]

Mongkol Tungphaisal[2]

The Thai Tapioca Trade Association (TTTA)

The Thai Tapioca Trade Association (TTTA) has been active in promoting the production and the trading of tapioca products in Thailand for the past 40 years. Our efforts have resulted in tapioca trade growing rapidly from a negligible quantity at its inception to a significant export item which contributes a great deal to the Thai economy. Although there are currently more than one trade associations involved in the tapioca trade, TTTA has been duly recognized by the government as well as other domestic and foreign organizations as the leading organization in the tapioca trade.

TTTA was founded on June 28, 1963 by a group of Thai tapioca traders. It was then known as "The Tapioca Association of Thailand." In 1966, Commercial Association Act B.E. 2509. was enacted . The Act prohibits the use of such words as 'of Thailand' in any trade association's name. Since then, TTTA has been renamed "The Thai Tapioca Trade Association"

Today, TTTA has a membership of about 110. Although the majority of the members are exporters of tapioca chips, pellets and starch, the membership comprises chip producers, pelletizers, starch mills, traders and consumers of tapioca products. There are also a number of foreign members who are welcome to join as our associate members.

Table 1. World cassava production in 2000.

	Cassava production ('000 t)	(%)
World	175,670	100
- Africa	94,087	54
- Latin America and Caribbean	31,849	18
- Asia	**49,448**	**28**
-Thailand	18,752	11.0
- Indonesia	16,089	9.0
- India	6,250	3.6
- China	3,601	2.0
- Vietnam	2,038	1.2
- Philippines	1,771	1.0
- Malaysia	380	0.2

[1] In many countries, including Thailand, the word "tapioca" is used for any product made from "cassava", which is the plant or crop.

[2] The Thai Tapioca Trade Association (TTTA), Bangkok, Thailand.

Table 2. Area yield and production of cassava in Asia, 2001.

Country	Area (ha)	Production (t)	Yield (t/ha)
Asia	**3,420,936**	**43,476,000**	**14.5**
Brunei	168	2,000	11.9
Cambodia	20,833	200,000	9.6
China	234,438	3,751,000	16.0
India	291,667	7,000,000	24.0
Indonesia	1,219,063	15,804,000	12.8
Laos	5,182	71,000	13.7
Malaysia	36,893	380,000	10.3
Myanmar	12,632	144,000	11.4
Philippines	211,765	1,800,000	8.5
Sri Lanka	28,523	251,000	8.8
Thailand	1,105,272	18,237,000	16.5
Vietnam	254,500	1,036,000	8.0

Table 3. Characteristics of cassava production and utilization in five Asian countries in 2000.

	China	India	Indonesia	Thailand	Vietnam
Cassava production ('000 t)	3,601	6,250	16,089	18,752	2,036
Cassava harv. Area ('000 ha)	225	260	1,257	1,150	254
Cassava yield (t/ha)	16.0	24.0	12.8	16.3	8.0
Utilization - primary	Starch -domestic	Human consumption	Human consumption	An. feed (50%) exp (85)/dom (15)	On-farm pig feeding
-secondary	On-farm pig feeding	Starch -domestic	Starch -dom/export	Starch (50%) -exp (65)/dom (35)	Starch -export/dom
Time of planting	March	Apr/Sept	Oct/Nov	Apr-May	Feb-May
Land preparation	Manual/oxen	Manual/oxen	Oxen/manual	Tractor	Oxen/manual
Fertilization - organic - chemical	rel. high low	rel. high rel. high	some low-high	some low-medium	rel. high low-medium

Table 4. World trade of cassava products (chips, pellets and starch in million tonnes).

	1994-1995 Avg.	1996-1997 Avg.	1998-1999 Avg.
World exports	**6.30**	**6.39**	**5.47**
Thailand	5.00	5.16	4.62
Indonesia	0.60	0.43	0.23
China and Taiwan	0.40	0.39	0.20
Others	0.25	0.42	0.43
World imports	**6.30**	**6.39**	**5.47**
European Union	4.20	3.72	3.58
China and Taiwan	0.65	0.61	0.62
Japan	0.35	0.38	0.32
S. Korea	0.35	0.46	0.35
Others	0.70	1.23	0.61

Table 5. Cassava crop surveys in Thailand from 2000/01 to 2002/03.

	2000/01	2001/02	2002/03
Harvested area (ha)	1,101,168	988,220	1,079,117
Production (t)	18,265,400	16,868,309	18,426,211
Yield (t/ha)	16.59	17.07	17.08

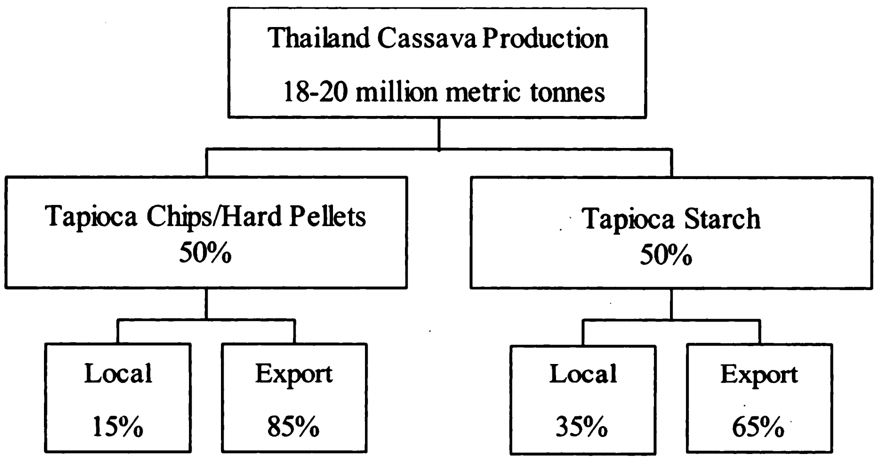

Figure 1. Approximate distribution of cassava products in the domestic market and for export.

Table 6. Conversion of cassava fresh roots into dry chips, pellets and starch.

Fresh roots —— 45.5% ——→ Chips ——98%——→ Pellets
1,000 kg ——————→ 455 kg ——————→ 446 kg

Fresh roots ———25%———→ Starch
1,000 kg ———————→ 250 kg

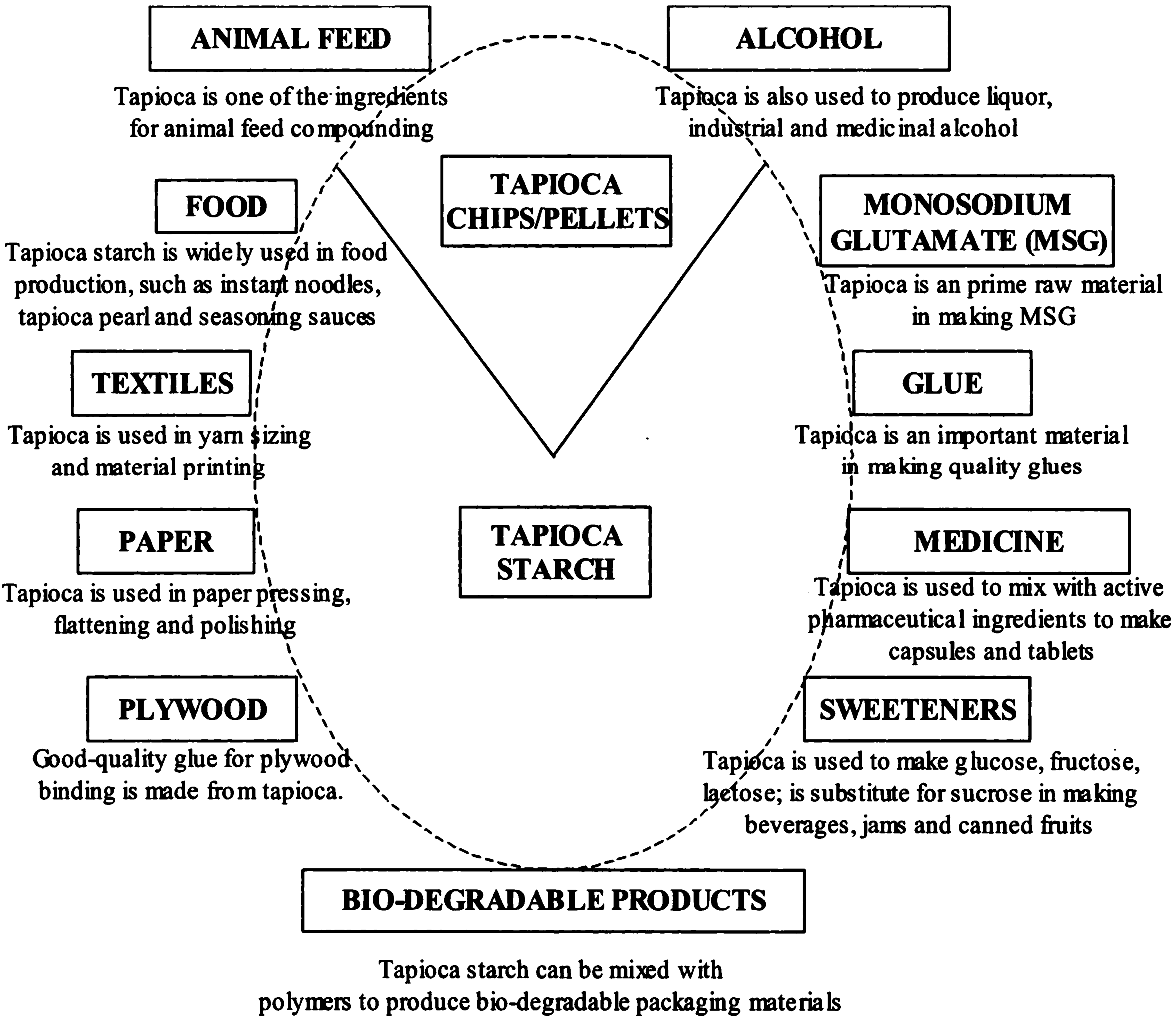

Figure 2. Industrial applications of cassava products.

Table 7. Thai cassava chips and hard pellets specifications for export to the EU.

Starch	65% min
Moisture	14% max
Sand/silica	3% max
Fiber	5% max

Table 8. Thai cassava starch specifications.

1. Whiteness	
2. Starch	85% min.
3. Moisture	13% max.
4. Ash	0.2% max.
5. Pulp	0.2% max.
6. pH	5-7
7. Viscosity	550 Brabender Units min.

Table 9. Comparison of prices of various cassava products and corn and soybean used in animal feed in Bangkok in 2002.

Cassava prices								Corn/soybean prices			
Roots at drying yard		Chips at warehouse		Pellets at factory		Starch at factory		Corn at factory		Soybean meal at factory	
Baht/t	US$/t	Baht/t	US$/t	Baht/t	US$/t	Baht/t	US$/t	Baht/t	US$/t	Baht/t	US$/t
1,400	32.18	2,800	64.37	2,960	68.05	7,700	177.01	4,830	111.03	8,743	201.00

[1)] exchange rate: 1US$ = 43.50 baht in March 2002.

Table 10. Quantity (metric tonnes) of cassava pellets exported from Thailand to various countries from 1989 to 2002.

Country	1989	1992	1999	2001	2002
Belgium	114,343	177,693	73,148	21,601	28,279
China	66,795	15,254	-	65,020	10,500
Italy	214,460	-	26,616	-	-
Germany	590,471	111,069	-	7,350	-
Japan	308,135	168,858	16,603	16,889	17,239
Netherlands	4,624,243	4,420,430	3,409,728	1,838,825	1,021,283
Portugal	238,278	226,482	57,125	223,465	153,535
Spain	416,244	396,841	535,329	480,616	223,410
S. Korea	754,186	942,677	-	169,595	42,340
Taiwan	181,500	135,528	-	15,880	-
U.S.S.R.	825,640	48	-	-	-
Others	700,843	1,129,500	-	5,500	-
Total quantity	9,032,915	7,724,387	4,118,549	2,844,741	1,496,586

***Source:** TTTA Annual Reports 1989 to 2002.*

Table 11. Quantity (metric tonnes) of cassava chips exported from Thailand to various countries from 1989 to 2002.

Country	1989	1992	1999	2001	2002
China	81,523	136,905	155,261	1,638,726	1,560,200
Germany	-	4,700	-	-	-
Hong Kong	-	-	-	10,500	-
Indonesia	-	79,580	-	-	-
Italy	-	-	32,277	-	-
M	1,200	-	-	-	-
Malaysia	8,608	9,200	-	-	-
Netherlands	4,730	18,370	24,720	-	16
Portugal	2,752	-	9,800	-	-
S. Africa	-	-	-	-	10
S. Korea	23,280	47,908	-	12	126
Turkey	-	2,000	-	-	-
Total quantity	122,093	298,663	222,058	1,649,238	1,560,352

***Source:** TTTA Annual Reports 1989 to 2002.*

Table 12. Quantity (metric tonnes) of cassava starch exported from Thailand to various countries from 1989 to 2002.

Country	1989	1992	1999	2001	2002
China	2,078	-	63,634	83,590	108,026
Hong Kong	-	23,410	52,560	58,865	67,517
Indonesia	994	40,882	47,147	91,726	82,969
Japan	186,168	246,192	255,938	333,991	320,154
Malaysia	2,635	35,641	91,065	115,683	107,812
Netherlands	9,952	12,271	15,149	30,927	27,472
Philippines	-	-	21,326	42,114	50,968
Singapore	15,978	33,708	51,402	58,005	57,987
Taiwan	177,425	258,180	305,970	306,370	313,477
U.S.A.	22,056	5,324	46,254	42,145	40,670
Others	99,994	44,787	77,676	121,131	76,681
Total quantity	517,179	755,685	1,028,021	1,284,547	1,307,635

***Source:** TTTA Annual Reports 1989 to 2002.*

Table 13. Number of cassava pellitizing companies certified or in the process of being certified in Thailand.

Certified	41	companies
In process	6	companies

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APPENDIX

Results of Soil Analyses in Asia 2001-2006

Reinhardt H. Howeler[1)]

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 1N NH_4-acetate; S in Ca-phosphate;
B in hot water; and Cu, Mn, Fe and Zn in 0.05 N HCI + 0.025 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.

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Table 2. Soil samples taken in Cambodia in 2004 to 2006.

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Kandal	-1	Kandal Stung district; Rolons commune, Kandal village; new site CelAgrid	Mar 04			
	-2	Saang, Sampan Commune; red and green local cassava varieties	July 04			
Kampong Cham	-1	Tbong Kmom district, Vihea Loung commune; cassava field, brown clay	Mar 04			
	-2	Tbong Kmom, Lreang village; vigorous cassava KM 94, red clay	Mar 04			
	-3	Tbong Kmom, cassava variety trial at planting	Jul 04			
	-4	Tbong Kmom, Thor Pich commune, Chub Rubber Co. variety trial; poor cassava	Mar 05	11°56'16"	105°41'28"	38
	-5	Tbong Kmom, Vihae Loung commune, Sre Leu village; variety trial, dark red clay	May 05			
	-6	Ponia Krek, Ampox village; NPK trial grey sandy soil	May 05	11°53'47"	105°49'51"	31
Kampong Speu	-1	CJ. Cambodia starch factory plantation; plot B8 -grey sandy loam	Mar 04			
	-2	CJ. Cambodia starch factory plantation; plot B12 -grey sandy loam	Mar 04			
	-3	CJ. Cambodia starch factory plantation; plot B28 (low) -grey sandy loam	Mar 04			
	-4	CJ. Cambodia starch factory plantation; plot F3 (high) -grey sandy loam	Mar 04			
	-5	CJ. Cambodia starch factory plantation; plot J1 -grey sandy loam	Mar 04			
	-6	CJ. Cambodia starch factory plantation; plot J2 -grey sandy loam	Mar 04			
	-7	CJ. Cambodia starch factory plantation; plot D45-new fertilizer trial	July 04			
	-8	CJ. Cambodia starch factory plantation; plot C1, very poor cassava, K def	July 04			
	-9	Trapeang Saray village; Mr. Lim Sokhom, sandy yellow soil in FPR variety trial	Oct 05	11°12'50"	104°12'49"	89
	-10	Cham Car Leu village; Mrs. Sam Khon, yellow sandy clay loam in NPK trial	Oct 05	11°14'37"	104°10'57"	119
	-11	Cham Car Leu village; Mrs. Mom Darom, yellow sandy loam in FPR variety trial	Oct 05	11°14'31"	104°10'53"	126
Battambang	-1	Pailin CARDI station, variety trial	Mar 05			
	-2	Pailin city, Sala Krap, O Roel village; Mr. Chomroeun, dark red clay in cassava field	Oct 05			
	-3	Ratanak Mondoul district, Thmor Prous village; variety trial at planting, brown clay	May 05	12°52'17"	102°58'24"	62
	-4	Ratanak Mondoul district, Ondeuk Hep village; NPK trial at planting, black clay	May 05	12°51'09"	102°57'37"	
	-5	Ratanak Mondoul district, Thmor Prous village, check plots of NPK trial at harvest	Mar 06	12°52'14"	102°58'24"	50
	-6	Banon district, Peak Kdei village; Mr. Chray Son; soil in lower part of large cassava field	Oct 05	13°07'19"	102°54'54"	29
	-7	Banon district, Peak Kdei village; Mr. Chray Son; upper part cassava field	Oct 05			
	-8	Banon district, Peak Kdei village; Mr. Chray Son; 2d cassava field, sandy clay loam	Oct 05	13°07'51"	102°51'59"	30

Table 3. Chemical and physical characteristics of cassava soils in Cambodia, 2001 to 2006.

		Chemical characteristics																Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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]
Kandal	-1	5.1	1.41	4.0	1.70	1.93	0.85	0.16		37			0.29	1.52	67.6	2.18	189.6	14.9	40.8	44.3	si.c
	-2	5.9	1.43	35.0	0	7.56	2.57	0.16	0.10	0	1.0	0.17	0.39	3.13	80.0	2.82	93.5	11.7	54.4	33.9	si.c.l.
Kampong Cham	-1	5.0	2.79	19.3	1.02	1.00	0.52	0.12		38			0.43	2.99	161.0	0.87	23.9	25.6	19.6	54.8	clay
	-2	4.8	4.43	6.8	0.61	2.54	1.46	0.11		13			0.73	2.72	131.8	0.73	17.9	12.8	25.0	62.2	clay
	-3	5.1	2.48	18.0	1.41	0.98	0.46	0.17		47		0.04	0.52	3.09	114.4	1.04	22.4	17.3	20.4	62.3	clay
	-4	5.03	3.39	6.51	0.51	1.55	0.79	0.15		17			1.14	4.49	484.5	1.69	12.4	18.1	26.4	55.5	clay
	-5	4.95	2.89	3.70	0.31	2.76	1.04	0.12		7			0.72	5.93	130.8	1.19	10.8	18.1	25.7	56.2	clay
	-6	4.36	1.44	12.06	1.04	0.34	0.24	0.05		62			0.28	0.45	15.9	0.14	17.8	68.4	16.5	15.1	s.l.
Kampong Speu	-1	5.2	1.14	7.9	0.08	1.09	0.31	0.09		5			0.41	0.63	11.6	0.37	57.9	69.5	15.8	14.7	s.l.
	-2	5.5	0.76	6.2	0.07	0.67	0.21	0.08		7			0.67	0.45	8.6	0.34	64.8	73.4	13.2	13.4	s.l.
	-3	5.3	1.03	10.0	0.10	1.30	0.35	0.08		5			0.38	0.44	23.3	0.47	70.0	49.5	35.8	14.7	loam
	-4	5.7	1.38	6.9	0	1.90	0.40	0.06	0.02	0	0.8		0.81	0.66	34.4	0.30	20.6	62.0	23.3	14.7	s.l.
	-5	5.8	1.72	4.5	0	1.12	0.60	0.10	0.02	0	1.1		0.53	0.43	14.6	0.24	30.1	67.8	18.8	13.4	s.l.
	-6	5.5	1.57	48.4	0.26	0.75	0.38	0.10		17			0.33	2.47	14.2	0.55	76.9	57.6	23.9	18.5	s.l.
	-7	5.8	0.66	2.5	0	0.58	0.15	0.04	0.02	0	2.5	0.02	0.39	0.29	5.2	0.41	50.3	70.2	16.3	13.5	s.l.
	-8	6.0	0.40	1.6	0	0.14	0.01	0.02	0.01	0	5.6	0	0.39	0.22	0.6	0.29	20.2	72.2	15.5	12.3	s.l.
	-9	6.61	1.21	11.19	0	1.30	0.43	0.06	0.01	0	0.6		0.53	0.67	35.2	0.20	35.9	63.1	17.1	19.8	s.l.
	-10	7.06	1.23	2.40	0	2.59	0.73	0.10	0.02	0	0.6		0.52	0.97	41.4	0.40	15.3	58.0	15.8	26.2	s.c.l.
	-11	5.86	1.68	2.79	0	1.57	0.45	0.08	0.01	0	0.5		0.67	1.07	41.3	0.22	27.4	60.5	14.6	24.9	s.c.l.
Battambang	-1	6.20	3.51	9.05	0	6.25	2.83	0.36	0.02	0	0.2		1.03	1.55	70.6	0.40	25.4	39.0	35.1	25.9	loam
	-2	7.09	5.28	30.94	0	18.72	6.93	0.75	0.03	0	0.1		1.12	2.35	75.9	0.19	1.4	24.2	36.1	39.7	c.l.
	-3	7.68	3.89	4.49	0	62.00	2.44	0.85	0.03	0	<0.1		1.02	0.16	0.1	0.00	0	9.4	25.3	65.3	clay
	-4	6.46	4.13	1.42	0	46.40	8.05	0.44	0.05	0	<0.1		0.28	0.51	9.4	0.17	0.7	9.0	19.8	71.2	clay
	-5	6.03	2.82	2.16	0	54.56	6.09	0.82	0.06	0	0.1		0.66	0.39	30.9	0.17	2.9	15.2	23.2	61.6	clay
	-6	7.25	3.76	4.08	0	42.16	8.33	0.23	0.12	0	0.2		0.53	0.55	12.2	0.19	1.1	12.3	25.5	62.2	clay
	-7	7.82	6.90	7.57	0	55.49	2.98	0.64	0.04	0	0.1		0.81	0.00	0.3	0.00	0	19.0	35.2	45.8	clay
	-8	5.51	2.07	15.98	0	4.34	3.07	0.12	0.06	0	0.8		0.30	0.99	45.6	1.03	19.6	30.0	35.1	34.9	c.l.

[1] s.c.l. = sandy clay loam.
si.c = silty clay
s.l. = sandy loam
si.c.l. = silty clay loam
c.l. = clay loam

Table 6. Soil samples taken in East Timor from 2000 to 2006.

Sample no.		Sample location and description	Date	Coordinates S	Coordinates E	Elevation (masl)
Dili	-1	Near Hera campus; Mr. Antonio da Costa, local cassava germplasm collection, fertile soil	Aug 05			
Baucau	-1	Fatomaca; Don Bosco Technical School; field of dark brown limestone derived soil	Nov 00			
	-2	Fatomaca; Baucau experimental site; red clay soil	Jan 02			
	-3	Fatomaca; Don Bosco Technical School, new cassava trial	Jan 03			
	-4	Fatomaca; Technical School; cassava variety trial at harvest	Aug 05	08°33'43"	126° 23'37"	568
Aileu	-1	Near Maubisse; 80% slope, purple brown clay soil after burning	Nov 00			
	-2	South of Maubisse; at 1,300 masl, yellow clay with lime stones	Nov 00			
	-3	South of Maubisse; same site, lower field, brown-red clay soil	Nov 00			
	-4	Maubisse, Coffee Cooperative; Bobonaro clay	Oct 01			
	-5	Aileu experimental site; dark purple soil	Jan 02			
	-6	Aileu experimental site; in cassava trial	Mar 02			
	-7	Aileu experimental site; in cassava trial	Jun 03			
	-8	Aileu experimental site; in cassava trial variety trial	Oct 04			
	-9	South of Aileu town, Suco Malere; rocky clay loam of Mr. Francisco's FPR trial	Aug 05	08° 44'15"	125° 33'59"	925
	-10	Sloi Craic village; very hard yellow clay in Nunu father's FPR trial	Aug 05	08° 41'54"	125° 32'37"	1098
	-11	Sloi Craic village; hard yellow clay, very poor cassava in Johaes FPR trial	Aug 05	08° 42'03"	125° 31'56"	1117
Manufahi	-1	Betano MAFF station; grey clay with rocks	Oct 01	09° 09'53"	125° 43'12"	3
	-2	Betano MAFF station; in cassava trial, yellow cassava	Mar 02			
	-3	Betano MAFF station; east side cassava trial, many rocks, poor growth	Jun 03			
	-4	Betano MAFF station; west side cassava trial, good cassava growth	Jun 03			
	-5	Betano MAFF station; in new cassava variety trial	Aug 05			
	-6	Near Betano, Pemuda Tani village; grey loam, FPR variety trial	Aug 05	09° 10'00"	125° 41'00"	13
	-7	Near Betano; Lalika village; grey loam, 2d FPR variety trial	Aug 05			
Cova Lima	-1	Beco village, about 10 km east of Suai; black clay	Feb 06			
	-2	Beco village, about 15 km east of Suai; in future cassava planting area	Feb 06			
	-3	Zunalai subdistrict, 1,400 ha of future cassava planting area, grey clay	Feb 06			
	-4	Zunalai subdistrict, Webaba SPI transmigration area of future starch factory	Feb 06			
Bobonaro	-1	Maliana MAFF station; dark yellow clay in cassava variety trial	Aug 05	08° 55'54"	125° 10'21"	142
	-2	First FPR trial near Maliana town, Mrs. Lucrecia; red clay loam	Feb 06			
	-3	Second FPR trial near Maliana town, Mr. Domingos; stony dark clay loam	Feb 06			
	-4	Third FPR trial near Maliana town, Mr. Anzelmos; stony red clay; very tall cassava	Feb 06			
	-5	SOL rice experiment outside of Maliana town	Feb 06			
Liquica	-1	Lois Transmigration Office; field behind office, silty loam	Oct 01			
	-2	Lois Transmigration Office; rice fields; grey loam	Oct 01			
	-3	Lois experimental site; in sweet potato trial	Aug 04			

Table 7. Chemical and physical characteristics of cassava soils in East Timor, 2000-2006.

		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)]
Dili	-1	7.07	2.01	128.3	0	4.02	1.65	1.00	0.18	0	2.63		1.07	3.75	34.3	0.40	10.4	46.6	27.2	26.2	s.c.l.
Baucau	-1	5.6	3.30	6.2	0	15.41	0.98	0.28	-	0	-	-	0.48	0.32	209.7	0.24	0.6	20.0	25.0	55.0	clay
	-2	5.7	3.69	7.9	0	11.78	0.87	0.19	0.06	0	0.5	0.35	0.90	0.45	208.0	0.22	0.8	15.6	18.3	65.1	clay
	-3	5.6	3.71	17.0	0	9.67	1.19	0.20	0.04	0	0.4	0.31	1.31	0.41	411.2	0.39	1.5	13.0	27.8	59.2	clay
	-4	5.60	4.04	11.28	0	8.76	0.99	0.11	0.04	0	0.4		0.44	0.44	145.3	0.40	0.9	8.1	32.3	59.6	clay
Aileu	-1	6.5	6.00	28.5	0	15.39	3.20	0.84	-	0	-	-	2.00	2.75	140.2	1.01	4.4	64.2	16.7	19.1	s.l.
	-2	6.6	3.10	2.4	0	16.17	5.40	0.51	-	0	-	-	0.56	1.78	95.0	1.31	8.8	21.0	36.4	42.6	clay
	-3	6.6	3.30	2.3	0	16.18	5.51	0.47	-	0	-	-	0.56	1.87	126.7	1.57	15.2	26.3	33.7	40.0	c.l.
	-4	7.2	3.10	8.6	0	26.80	6.11	0.54	-	0	-	-	0.60	0.89	142.8	0.07	15.1	19.8	29.9	50.3	clay
	-5	4.9	4.96	5.3	0.94	3.20	1.35	0.49	0.03	16	0.6	-	0.90	1.37	28.8	0.32	49.9	38.4	27.8	33.9	c.l.
	-6	5.0	5.63	2.6	1.77	2.51	1.09	0.47	-	30	-	0.44	0.89	1.28	22.1	0.32	47.6	24.0	31.8	44.2	clay
	-7	5.0	4.77	3.7	1.93	1.76	0.82	0.28	-	40	-	0.46	0.86	0.89	17.0	0.39	54.3	27.3	31.0	41.7	clay
	-8	4.7	2.46	3.4	3.04	1.21	0.59	0.39	-	58	-	-	0.51	1.15	27.9	0.57	56.2	8.9	32.0	59.1	clay
	-9	6.17	1.99	11.39	0	2.09	1.47	0.24	0.03	0	0.8		0.72	7.27	55.8	1.10	44.5	37.0	31.0	32.0	c.l.
	-10	4.91	4.17	3.29	2.39	0.92	0.45	0.27	-	59	-		0.57	0.81	12.8	0.68	186.1	13.3	26.3	60.4	clay
	-11	4.36	7.53	3.88	3.17	0.58	0.43	0.43	-	69	-		0.42	0.73	12.8	0.92	74.4	28.3	14.9	56.8	clay
Bobonaro	-1	6.02	1.98	4.35	0	7.57	1.13	0.28	0.03	0	0.33		0.28	1.37	131.2	0.54	9.7	29.8	37.8	32.4	clay
	-2	6.47	2.03	2.48	0	7.67	2.40	0.57	0.04	0	0.4		0.53	6.36	202.7	1.78	15.1	20.8	37.6	41.6	clay
	-3	5.75	3.33	1.02	0	7.76	1.23	0.17	0.03	0	0.6		0.21	2.62	183.0	1.21	19.3	26.2	42.5	31.3	c.l.
	-4	5.78	3.32	20.34	0	8.74	3.39	1.50	0.03	0	0.2		0.72	1.75	134.0	0.62	9.4	21.1	22.5	56.4	clay
	-5	7.35	3.60	85.09	0	22.13	6.25	0.59	0.23	0	0.8		1.65	3.53	182.3	0.99	3.8	20.3	35.8	43.9	clay

Table 7. Chemical and physical characteristics of cassava soils in East Timor, 2000-2006. (continued)

		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)]
Manufahi	-1	7.0	3.04	111.1	0	30.46	1.57	3.49	-	0	-	-	1.03	0.03	1.0	0.06	0.3	30.5	24.6	44.9	clay
	-2	7.5	3.04	93.9	0	31.67	1.42	3.92	0.41	0	1.1	1.37	1.54	0.00	0.3	0.06	0.0	20.3	28.8	50.9	clay
	-3	6.9	3.30	129.5	0	34.73	1.12	3.44	0.14	0	0.3	0.28	1.40	0.0	0.2	0.06	0.0	28.8	25.5	45.7	clay
	-4	7.0	3.00	129.8	0	34.93	1.17	3.88	0.13	0	0.3	0.31	1.31	0.0	0.1	0.04	0.0	25.4	24.0	50.6	clay
	-5	7.74	2.64	50.84	0	29.72	1.14	2.99	0.18	0	0.5		1.09	0.0	3.3	0.02	0.0	14.3	36.4	49.3	clay
	-6	7.87	2.76	15.95	0	20.24	1.33	0.63	0.08	0	0.4		0.74	0.0	11.6	0.05	0.0	24.3	38.0	37.7	c.l.
	-7	7.89	3.67	5.47	0	23.07	2.89	0.65	0.21	0	0.8		1.32	0.0	7.1	0.05	0.0	3.9	48.8	47.3	loam
Cova Lima	-1	7.67	4.57	4.93	0	22.48	3.01	0.79	0.44	0	1.6		1.55	0.01	8.0	0.05	0.1	9.4	42.5	48.1	si.c
	-2	7.73	4.08	0.44	0	29.36	3.19	1.36	0.06	0	0.2		1.63	0.01	2.1	0.05	0.1	2.0	35.8	62.2	clay
	-3	7.20	4.56	62.14	0	18.09	2.35	0.91	0.11	0	0.5		1.91	1.90	100.4	0.38	1.9	22.5	35.4	42.1	clay
	-4	7.60	1.97	6.17	0	24.04	3.99	0.62	1.08	0	3.6		0.96	0.01	9.8	0.06	0.1	0.8	50.8	48.4	si.c
Liquica	-1	7.1	3.40	138.3	0	6.98	1.88	0.42	0.40	0	4.1	-	0.88	2.45	72.2	0.44	35.0	43.4	33.7	22.9	loam
	-2	7.2	2.40	62.5	0	7.55	1.52	0.17	0.40	0	4.1	-	0.61	2.73	190.3	3.74	192.9	8.1	76.6	15.3	si.l.
	-3	6.3	2.30	188.5	0	11.47	2.52	0.53	1.16	0	7.4	0.79	1.03	2.99	88.8	1.43	11.6	9.8	52.4	37.7	si.c.l.

[1)] s.c.l. = sandy clay loam c.l. = clay loam si.l. = silt loam s.l. = sandy loam si.c.l. = silty clay loam si.c. = silty clay

Table 8. Soil samples taken in India from 2001 to 2002.

Sample no.		Sample location and description	Date
Kerala	-1	Trivandrum district, Mandapam village; brown soil with lowland cassava	Jul 01
	-2	Trivandrum district, Chenkal village; gravilly soil, upland cassava, rather poor	Jul 01
	-3	Trivandrum district, Chenkal village; lowland cassava, very vigorous	Jul 01
	-4	Pathanamthitta district, Thatta village near Adur, lowland cassava	Jul 01
	-5	Trivandrum district, Chenkal village; upland area with cassava, red clay loam with laterite	Jul 02
Tamil Nadu	-1	Salem district, Daranaickanpatti village; grey sandy loam, irrigated cassava	Jul 01
	-2	Salem district, Valaisaiyur village; red Alfisol, upland cassava H226	Jul 01
	-3	Salem district, Masakkalipatty village; MKD-1 in irrigated black Vertisol	Jul 02
	-4	Salem district, Veddukkadu village; irrigated H-165, grey sandy clay	Jul 02
	-5	Kolli Hills; field being harvested, dark-red Alfisol, many stones	Jul 02
	-6	Kolli Hills; cassava field without stones, elephant grass hedgerows, red Alfisol	Jul 02
	-7	Salem district, Poovalitlui village; C1 of cassava true seed, Zn def. symptoms	Jul 02
	-8	Salem district, near Varalakshmi sago factory; triploid trial, dark grey sandy loam	Jul 02
A. Pradesh	-1	Near Samalkot, Kattamuru village; poor cassava stand, sandy loam	Jul 02
	-2	Rampachodavarum, Tativada village; recent cassava planting, reddish sandy loam	Jul 02
	-3	Burugapudi, Gangababi village; C+cucumber, very sandy soil, K+P deficient	Jul 02

Table 9. Chemical and physical characteristics of cassava soils in India, 2001-2002.

Sample no.		Chemical characteristics															Physical characteristics			
			%	ppm	me/100 g					%	%	ppm					%			
		pH	OM	P	Al	Ca	Mg	K	Na	Al	Na	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Kerala	-1	5.2	2.48	27.5	1.25	1.03	0.38	0.13		45		1.24	1.67	29.8	3.82	48.2	40.4	15.7	43.9	clay
	-2	5.3	1.18	19,2	0.16	1.48	0.59	0.08		7		1.21	0.58	50.3	0.62	6.6	72.6	13.0	14.4	s.l.
	-3	4.7	1.88	51.7	0.62	1.16	0.27	0.38		25		1.43	1.44	60.2	2.18	40.4	56.2	10.5	33.3	s.c.l.
	-4	5.7	1.07	188.5	0	2.94	0.07	0.08		0		0.62	0.48	1.0	0.61	58.6	76.4	10.5	13.1	s.l.
	-5	6.0	1.67	63.5	0	2.04	0.92	0.15	0.04	0	1.3	0.79	2.00	73.2	0.75	10.1	54.8	6.4	38.8	s.c.
Tamil Nadu	-1	6.7	2.60	329.2	0	18.24	5.84	0.22		0		1.04	14.4	37.8	0.32	1.6	53.9	17.2	28.9	s.c.l.
	-2	6.8	1.37	51.7	0	6.74	3.10	0.25		0		0.75	3.5	47.0	1.84	87.6	64.6	13.2	22.2	s.c.l.
	-3	6.8	1.04	619.6	0	7.81	5.56	1.24	0.30	0	2.0	1.18	3.67	54.4	1.46	27.5	64.7	6.4	28.9	s.c.l.
	-4	7.3	1.42	143.7	0	13.10	7.03	0.32	0.36	0	1.7	1.35	0.03	7.1	0.05	0.0	63.4	8.9	27.7	s.c.l.
	-5	5.9	2.40	11.9	0	2.57	0.77	0.45	0.02	0	0.5	0.98	3.09	136.5	2.18	11.8	62.4	11.4	26.2	s.c.l.
	-6	5.4	3.08	11.0	0.28	3.73	1.34	0.29		5		1.30	0.56	185.1	1.68	11.4	37.9	14.0	48.1	clay
	-7	7.0	1.03	187.4	0	5.19	3.03	0.39	0.29	0	3.2	1.44	2.79	38.6	0.44	6.7	70.1	10.1	19.8	s.l.
	-8	6.8	1.72	212.2	0	13.53	7.63	0.53	1.06	0	4.6	0.95	0.04	18.7	0.05	0.1	59.5	12.8	27.7	s.c.l.
Andhra Pradesh	-1	6.7	0.53	30.2	0	0.92	0.37	0.16	0.04	0	2.7	0.74	3.20	32.4	0.76	9.8	79.7	4.4	15.9	s.l.
	-2	6.7	0.87	59.9	0	1.69	0.56	0.40	0.03	0	1.1	0.88	2.06	52.5	0.41	21.3	70.2	12.6	17.2	s.l.
	-3	6.9	0.82	39.4	0	14.04	0.49	0.12	0.05	0	0.3	0.97	2.38	36.2	0.42	10.5	77.9	5.0	17.1	s.l.

[1)] s.c.l. = sandy clay loam
s.l. = sandy loam
s.c. = sandy clay

Table 10. Soil samples taken in Indonesia from 2001 to 2006.

Sample no.		Sample location and description	Date	Coordinates S	Coordinates E	Elevation (masl)
West Java	-1	Sukabumi, Cikambar, Cimangu village; brown clay soil in cassava field	Aug 05	06°58'15"	106° 45'47"	335
	-2	Sukabumi, Cimanggu village; FPR fertilizer trial Mr. Juju, Plot A, red clay	Feb 06			
	-3	Sukabumi, Cimanggu village; FPR variety trial Mr. Jaja, red-brown clay	Feb 06			
	-4	Sukabumi, Cimanggu village; FPR variety trial Mr. Nyanyang	Feb 06	06°58'29"	106°45'43"	341
	-5	Sukabumi, Cimanggu village; FPR fertilizer trial Mrs. Ijah, Plot C	Feb 06			
Central Java	-1	Pati, Ngemplak Kidul; red clay in Markonah field	Aug 05	06° 36'47"	111° 02'48"	42
	-2	Pati, Tegalarum village; yellow-red clay in 8-month old Markonah field	Aug 05	06° 36'46"	110° 59'30"	207
	-3	Pati, Tayu subdistrict, Sonean village; black-brown clay in 8-month old Kasetsart field	Aug 05	06° 36'36"	111° 02'11"	38
	-4	Pati, Tlogowungu subdistrict, Tamansari village; variety x fert., trial, red clay	Feb 06	06° 43'33"	110° 59'47"	78
	-5	Pati, Cluwak subdistrict, Gerit village; variety x fertilizer trial, red clay	Feb 06	06° 31'23"	110° 58'29"	109
	-6	Pati, Tayu subdistrict, Senangrejo village; Mr. Arif field of Markonah	Feb 06	06° 33'24"	111° 01'45"	105
	-7	Pati, Tayu subdistrict, Sonean village; Mr. Rudi Siswanto field of Markonah, very vigorous growth	Feb 06	06°36'31"	111° 02'08"	52
Yogyakarta	-1	Playen; micronutrient applic. trial, IV-1, severe Zn def	Mar 02			
	-2	Playen; micronutrient applic. trial, IV-5, very good growth	Mar 02			
	-3	Playen; micronutrient applic. trial, I-9, very poor growth	Mar 02			
	-4	Playen; micronutrient applic. trial, III-5, very good growth, in eroded sedinents	Mar 02			
	-5	Playen; micronutrient applic. trial, III-9, poor growth	Mar 02			
	-6	Playen; micronutrient applic. trial, I-10, very good growth	Mar 02			
	-7	Playen; variety trial in black soil; rather good cassava	Apr 04			
	-8	Gunung Kidul, Tanjungsari, Hargosari; cassava multiplication Mr. Wardiyo, red clay	Mar 05	08° 03'22"	110° 36'39"	329
	-9	Guanug Kidul, Tanjungsari, Hargosari village; 2d fert. trial, dark brown clay	Feb 06	08° 03'45"	110° 37'22"	273
East Java	-1	Probolinggo; Muneng station, Rep III of cassava collection	Jan 03			
	-2	Malang; Jatikerto station, in fertilizer trial, C+M, T_1; black clay	Feb 05			
	-3	Malang, Kromengan, Ngadirejo village; variety trial Mr. Sopri, dark clay loam	Feb 06	08° 08'08"	112° 30'54"	325
	-4	Malang, Kromengan, Ngadirejo village; variety trial Mr. Juni	Feb 06			
	-5	Malang, Pagak, Sempol village; variety trial Mr. Misidjan, C+P, dark clay	Feb 06	08° 17'10"	112° 29'25"	408
	-6	Malang, Pagak, Sempol village; variety trial Mr. Misidjan, K def. in contour ridge	Feb 06			
	-7	Malang, Pagak, Sempol village; 2d variety trial, good maize, weak cassava	Feb 06			

Table 10. Soil samples taken in Indonesia from 2001 to 2006. (continued)

Sample no.		Sample location and description	Date	Coordinates S	Coordinates E	Elevation (masl)
Lampung	-1	Tamanbogo; long-term NPK trial (11th year); monoculture –T_1	Oct 01			
	-2	Tamanbogo; long-term NPK trial (11th year); monoculture –T_2	Oct 01			
	-3	Tamanbogo; long-term NPK trial (11th year); monoculture –T_3	Oct 01			
	-4	Tamanbogo; long-term NPK trial (11th year); monoculture –T_4	Oct 01			
	-5	Tamanbogo; long-term NPK trial (11th year); monoculture –T_5	Oct 01			
	-6	Tamanbogo; long-term NPK trial (11th year); monoculture –T_6	Oct 01			
	-7	Tamanbogo; long-term NPK trial (11th year); monoculture –T_7	Oct 01			
	-8	Tamanbogo; long-term NPK trial (11th year); monoculture –T_8	Oct 01			
	-9	Tamanbogo; long-term NPK trial (11th year); monoculture –T_9	Oct 01			
	-10	Tamanbogo; long-term NPK trial (11th year); monoculture –T_{10}	Oct 01			
	-11	Tamanbogo; long-term NPK trial (11th year); monoculture –T_{11}	Oct 01			
	-12	Tamanbogo; long-term NPK trial (11th year); monoculture –T_{12}	Oct 01			
	-13	Tamanbogo; long-term NPK trial (11th year); intercropped –T_1	Oct 01			
	-14	Tamanbogo; long-term NPK trial (11th year); intercropped –T_2	Oct 01			
	-15	Tamanbogo; long-term NPK trial (11th year); intercropped –T_3	Oct 01			
	-16	Tamanbogo; long-term NPK trial (11th year); intercropped –T_4	Oct 01			
	-17	Tamanbogo; long-term NPK trial (11th year); intercropped –T_5	Oct 01			
	-18	Tamanbogo; long-term NPK trial (11th year); intercropped –T_6	Oct 01			
	-19	Tamanbogo; long-term NPK trial (11th year); intercropped –T_7	Oct 01			
	-20	Tamanbogo; long-term NPK trial (11th year); intercropped –T_8	Oct 01			
	-21	Tamanbogo; long-term NPK trial (11th year); intercropped –T_9	Oct 01			
	-22	Tamanbogo; long-term NPK trial (11th year); intercropped –T_{10}	Oct 01			
	-23	Tamanbogo; long-term NPK trial (11th year); intercropped –T_{11}	Oct 01			
	-24	Tamanbogo; long-term NPK trial (11th year); intercropped –T_{12}	Oct 01			
	-25	Tamanbogo; long-term NPK trial (14th year)- T_1	Nov 04			
	-26	Tamanbogo; long-term NPK trial (14th year)- T_2	Nov 04			
	-27	Tamanbogo; long-term NPK trial (14th year)- T_3	Nov 04			
	-28	Tamanbogo; long-term NPK trial (14th year)- T_4	Nov 04			
	-29	Tamanbogo; long-term NPK trial (14th year)- T_5	Nov 04			
	-30	Tamanbogo; long-term NPK trial (14th year)- T_6	Nov 04			
	-31	Tamanbogo; long-term NPK trial (14th year)- T_7	Nov 04			
	-32	Tamanbogo; long-term NPK trial (14th year)- T_8	Nov 04			
	-33	Tamanbogo; long-term NPK trial (14th year)- T_9	Nov 04			

Table 10. Soil samples taken in Indonesia from 2001 to 2006. (continued)

Sample no.		Sample location and description	Date	Coordinates S	Coordinates E	Elevation (masl)
Lampung	-34	Tamanbogo; long-term NPK trial (14th year)- T_{10}	Nov 04			
	-35	Tamanbogo; long-term NPK trial (14th year)- T_{11}	Nov 04			
	-36	Tamanbogo; long-term NPK trial (14th year)- T_{12}	Nov 04			
	-37	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_1	Oct 05			
	-38	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_2	Oct 05			
	-39	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_3	Oct 05			
	-40	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_4	Oct 05			
	-41	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_5	Oct 05			
	-42	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_6	Oct 05			
	-43	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_7	Oct 05			
	-44	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_8	Oct 05			
	-45	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_9	Oct 05			
	-46	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_{10}	Oct 05			
	-47	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_{11}	Oct 05			
	-48	East Lampung, Tamanbogo; NPK trial (15th year); monoculture-T_{12}	Oct 05			
	-49	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_1	Oct 05			
	-50	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_2	Oct 05			
	-51	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_3	Oct 05			
	-52	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_4	Oct 05			
	-53	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_5	Oct 05			
	-54	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_6	Oct 05			
	-55	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_7	Oct 05			
	-56	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_8	Oct 05			
	-57	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_9	Oct 05			
	-58	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_{10}	Oct 05			
	-59	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_{11}	Oct 05			
	-60	East Lampung, Tamanbogo; NPK trial (15^{th} year); intercropped-T_{12}	Oct 05			
	-61	East Lampung, Tamanbogo; NPK trial; (15th year) III-T_5 (with lime)	Feb 06			
	-62	East Lampung, Tamanbogo; NPK trial; (15th year) II-T_5 (without lime)	Feb 06			
	-63	Tamabogo; Mr. Mulyono's rice field, to be followed by cassava	Feb 05	05° 01'04"	105° 30'14"	35
	-64	East Lampung, Sukadana, Sukadana Uir village; FPR fertilizer trial Mr. Marno	Feb 06	05° 02'08"	105° 31'08"	39
	-65	East Lampung, Sukadana, Sukadana Uir village; FPR fertilizer trial Mr. Jiono	Feb 06	05° 01'17"	105° 30'50"	50
	-66	East Lampung, Sukadana, Sukadana Uir village; FPR variety trial Mr. Bolo	Feb 06	05° 02'03"	105° 31'10"	46

Table 11. Chemical and physical characteristics of cassava soils in Indonesia, 2001-2006.

		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)]
W. Java	-1	4.85	5.09	46.62	1.04	4.29	0.74	0.33	-	16			0.53	3.83	225.6	1.91	5.4	35.4	19.8	44.8	clay
	-2	4.84	4.46	18.03	0.83	3.49	0.83	0.68		14			0.55	3.98	193.1	1.92	8.1	24.1	22.1	53.8	clay
	-3	4.47	3.94	28.07	1.14	1.92	0.57	0.27		29			0.48	3.00	201.7	2.15	8.9	24.0	22.2	53.8	clay
	-4	4.45	4.72	4.99	2.91	1.34	0.67	0.20		57			0.61	2.54	204.2	2.01	7.7	23.8	23.6	52.6	clay
	-5	4.88	3.82	12.33	1.52	3.99	1.24	0.29		22			0.54	4.01	190.7	1.73	5.9	27.6	23.5	48.9	clay
C. Java	-1	5.57	3.77	72.07	0	5.48	2.23	1.30	0.21	0	2.3		0.60	7.24	209.4	2.24	11.7	12.6	26.2	61.2	clay
	-2	4.91	1.59	20.64	1.46	2.42	0.60	0.25	-	31			0.28	1.75	87.6	1.95	19.0	21.2	28.4	50.4	clay
	-3	4.78	3.27	6.41	1.51	6.78	1.20	0.79	-	15			0.40	4.23	182.9	7.90	97.2	18.3	31.1	50.6	clay
	-4	4.90	1.51	5.87	1.14	5.05	1.35	0.23		15			0.42	1.82	161.3	2.76	24.4	9.4	19.5	71.0	clay
	-5	4.77	2.32	2.62	3.48	1.56	0.59	0.12		61			0.36	4.16	198.2	3.89	20.7	4.4	19.5	76.1	clay
	-6	5.13	2.71	33.23	0.31	4.66	1.55	0.43		4			0.52	16.43	180.8	3.33	16.6	8.5	26.0	65.5	clay
	-7	4.67	5.35	6.15	1.87	5.62	1.14	0.34		21			0.48	3.92	154.7	9.33	167.8	13.0	30.1	56.9	clay
Yogyakarta	-1	7.0	0.75	3.6	0	58.31	2.72	0.19	0.06	0	0.1	0.35	0.30	0.00	0.2	0.02	0.0	25.9	23.4	50.7	clay
	-2	7.2	0.83	4.7	0	62.35	2.90	0.15	0.08	0	0.1	0.35	0.40	0.00	0.7	0.01	0.0	21.1	16.7	62.2	clay
	-3	7.4	1.32	7.0	0	60.40	1.70	0.15	0.07	0	0.1	0.35	0.41	0.00	0.2	0.01	0.0	25.2	27.3	47.5	clay
	-4	7.5	1.42	17.5	0	69.02	1.75	0.21	0.06	0	0.1	0.38	0.47	0.00	0.3	0.01	0.0	19.4	19.2	61.4	clay
	-5	7.5	1.13	5.1	0	60.13	1.93	0.17	0.06	0	0.1	0.35	0.37	0.00	0.2	0.01	0.0	25.7	10.8	63.5	clay
	-6	7.6	1.34	3.1	0	63.04	2.35	0.28	0.06	0	0.1	0.35	0.39	0.00	0.4	0.01	0.0	19.7	10.9	69.4	clay
	-7	7.3	2.00	4.1	0	62.75	2.79	0.31	0.13	0	0.2		0.38	0.13	7.2	0.10	0.2	3.6	14.6	81.8	clay
	-8	5.68	2.17	2.68	0	10.87	1.12	0.27	0.11	0			0.42	1.55	98.2	2.87	7.2	6.0	18.0	75.9	clay
	-9	5.92	2.03	21.99	0	14.78	0.85	0.38	0.07	0	0.4		0.46	3.77	132.8	2.38	2.4	6.8	28.0	65.2	clay
E. Java	-1	6.3	1.96	87.2	0	10.94	5.05	0.71	0.17	0	1.0		1.40	3.47	155.5	2.21	6.6	21.6	46.9	31.5	c.l.
	-2	6.49	1.51	11.61	0	8.51	3.55	1.56	0.10	0	0.7		0.22	3.04	83.9	4.79	21.5	28.5	33.9	37.6	c.l.
	-3	6.17	1.89	19.53	0	8.39	3.02	1.42	0.09	0	0.7		0.46	4.37	76.4	5.10	26.9	28.9	32.9	38.2	c.l.
	-4	5.29	1.07	3.31	0.62	4.24	1.75	0.46	0	9	0		0.35	2.51	51.6	4.49	96.0	33.5	31.3	35.2	c.l.
	-5	5.52	2.29	0.77	0	8.46	1.51	0.20	0.18	0	1.7		0.29	3.35	84.9	3.21	18.7	19.2	33.2	47.6	clay
	-6	5.60	1.74	0.94	0	10.85	1.05	0.07	0.15	0	1.2		0.38	2.51	94.9	3.17	19.6	21.7	27.9	50.4	clay
	-7	5.52	2.05	1.45	0	9.39	1.47	0.55	0.12	0	1.0		0.32	2.57	121.8	3.01	14.4	14.5	29.5	56.0	clay

Table 11. Chemical and physical characteristics of cassava soils in Indonesia, 2001-2006. (continued)

		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)]
Lampung	-1	4.5	2.01	2.8	2.18	0.38	0.22	0.06		77											
	-2	4.6	2.31	22.0	2.29	0.52	0.13	0.08		76											
	-3	4.6	2.06	13.3	2.44	0.40	0.13	0.08		80											
	-4	4.5	1.82	18.6	2.18	0.41	0.14	0.09		77											
	-5	4.2	2.06	7.2	2.60	0.24	0.08	0.06		87											
	-6	4.2	2.21	2.4	2.65	0.14	0.08	0.12		89											
	-7	4.5	2.15	8.4	2.39	0.29	0.09	0.10		83											
	-8	4.6	2.51	31.1	2.08	0.75	0.17	0.10		67											
	-9	4.3	2.24	9.4	2.70	0.21	0.08	0.07		88											
	-10	4.5	2.33	7.8	2.60	0.30	0.11	0.09		84											
	-11	4.5	2.21	10.1	2.29	0.32	0.13	0.10		81											
	-12	4.3	2.35	23.3	2.70	0.38	0.10	0.10		82			0.40	0.23	7.2	0.29	26.6	43.1	12.3	44.6	clay
	-13	4.6	1.96	2.4	2.18	0.39	0.21	0.06		77											
	-14	4.6	2.44	12.0	2.18	0.47	0.13	0.13		75											
	-15	4.6	2.24	24.2	2.39	0.44	0.11	0.09		79											
	-16	4.4	2.40	29.1	2.39	0.46	0.10	0.09		79											
	-17	4.2	2.24	6.7	2.60	0.27	0.09	0.09		85											
	-18	4.3	2.10	2.3	2.70	0.13	0.10	0.13		92											
	-19	4.5	2.30	13.5	2.60	0.31	0.14	0.09		90											
	-20	4.5	2.43	81.8	2.03	0.79	0.16	0.11		66											
	-21	4.2	2.37	12.3	2.34	0.40	0.15	0.07		79											
	-22	4.4	2.42	6.8	2.50	0.38	0.11	0.09		81											
	-23	4.3	2.14	14.3	2.60	0.31	0.08	0.10		84											
	-24	4.4	2.20	19.9	2.50	0.44	0.12	0.12		79			0.38	0.27	9.1	0.30	26.0	37.6	13.6	48.7	clay
Lampung	-25	4.67	2.02	2.41	2.39	0.31	0.17	0.05		82			0.17	0.25	7.4	0.36	24.8	38.8	16.6	44.6	clay
	-26	4.73	2.34	11.58	2.19	0.49	0.15	0.07		76											
	-27	4.66	2.48	7.39	2.55	0.37	0.11	0.07		82											
	-28	4.71	2.54	8.40	2.29	0.36	0.12	0.07		81											
	-29	4.74	2.14	8.55	2.29	0.35	0.09	0.05		82											
	-30	4.63	2.07	3.01	2.60	0.15	0.08	0.07		90											

c.l. = clay loam

Table 11. Chemical and physical characteristics of cassava soils in Indonesia, 2001-2006. (continued)

		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)]
Lampung	-31	4.70	2.28	6.64	2.39	0.27	0.10	0.07		84											
	-32	4.68	2.45	19.14	2.60	0.45	0.09	0.04		82											
	-33	4.67	2.39	10.16	2.39	0.27	0.10	0.05		85											
	-34	4.56	2.45	20.02	2.60	0.41	0.11	0.05		82											
	-35	4.77	2.42	6.06	2.34	0.38	0.10	0.07		81											
	-36	4.82	2.45	16.03	2.50	0.45	0.10	0.07		80			0.67	0.33	6.7	0.30	24.1	39.8	16.7	43.5	clay
	-37	4.17	1.98	14.96	3.22	0.40	0.15	0.05		84											
	-38	4.21	2.08	7.71	2.39	0.79	0.18	0.13		68											
	-39	4.12	2.00	7.58	2.96	0.41	0.10	0.05		84											
	-40	3.98	2.04	5.52	3.02	0.28	0.09	0.07		87											
	-41	4.06	1.91	3.03	3.07	0.20	0.05	0.04		91											
	-42	3.86	1.95	12.88	2.76	0.19	0.09	0.09		88											
	-43	3.89	1.98	12.79	3.07	0.28	0.08	0.08		87											
	-44	4.04	2.08	20.74	2.60	0.52	0.13	0.06		79											
	-45	3.86	2.32	13.70	2.86	0.20	0.07	0.04		90											
	-46	3.91	2.24	6.43	2.81	0.26	0.07	0.05		88											
	-47	4.04	2.14	3.53	2.50	0.45	0.12	0.09		79											
	-48	4.00	2.20	8.30	2.86	0.35	0.08	0.07		85			0.28	0.30	12.7	0.57	29.1	34.0	15.7	50.3	clay
	-49	4.17	2.11	1.25	2.86	0.49	0.22	0.05		79											
	-50	4.35	2.32	10.99	2.70	0.80	0.14	0.07		73											
	-51	4.02	1.93	7.08	2.81	0.51	0.13	0.06		80											
	-52	3.95	1.58	7.38	2.91	0.35	0.09	0.07		85											
	-53	4.10	1.66	4.48	2.70	0.41	0.11	0.04		83											
	-54	4.00	1.56	1.89	2.60	0.26	0.09	0.07		86											
	-55	4.01	1.89	2.15	2.70	0.37	0.12	0.05		83											
	-56	4.26	2.12	6.05	2.44	0.64	0.14	0.04		75											
	-57	4.07	2.18	2.52	2.91	0.40	0.11	0.04		84											
	-58	4.28	2.14	3.89	2.91	0.34	0.06	0.03		87											
	-59	4.14	2.34	5.62	2.81	0.58	0.14	0.08		78											
	-60	4.09	2.30	3.91	3.33	0.40	0.08	0.05		86			0.28	0.37	11.2	0.61	30.4	32.6	14.5	52.9	clay

c.l. = clay loam

Table 11. Chemical and physical characteristics of cassava soils in Indonesia, 2001-2006. (continued)

		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)]
Lampung	-61	4.46	2.35	6.79	2.50	0.69	0.04	0.05		76			0.39	0.67	35.2	0.37	31.5	36.2	18.4	45.5	clay
	-62	4.34	1.88	2.16	2.29	0.17	0.06	0.07		88			0.38	0.31	4.1	0.30	34.0	47.2	15.0	37.8	s.c.
	-63	4.29	2.03	3.78	2.97	0.08	0.02	0.03		96			0.21	0.29	6.0	0.41	29.1	38.9	17.3	43.8	clay
	-64	4.43	2.60	7.67	2.76	0.59	0.16	0.04		78			0.38	0.48	16.2	0.32	40.2	41.4	14.6	44.0	clay
	-65	4.27	2.38	3.10	3.07	0.30	0.13	0.05		86			0.36	0.42	10.4	0.24	46.6	41.5	18.3	40.2	clay
	-66	4.59	2.26	10.27	1.66	1.15	0.27	0.07		53			0.36	0.42	10.4	0.24	46.6	41.5	18.3	40.2	clay

c.l. = clay loam

Table 12. Soil samples taken in Laos from 2001 to 2006.

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Vientiane	-1	Namsuang Livestock Research Center; cassava variety trial	May 01			
	-2	Napok Agriculture Research Center, cassava variety trial, white sandy loam	May 04	18°08'44"	102°44'05"	168
Luang Prabang	-1	Houay Khot, NAFRI station; cassava variety trial	May 01			
	-2	Ngeum district, Kew Ta Loun village; cassava in slash-and-burn	May 01			
	-3	Killtalunnyi village; variety trial at 1,300 m; P deficiency symptoms	Aug 03			
	-4	Long-Or village; variety trial, dark red clay, rather good cassava growth	Aug 03			
	-5	Luang Prabang, Pik Noi village; variety trial, red clay on 30% slope; good cassava growth	Aug 03			
	-6	Luang Prabang, Pik Noi village; Mrs. Pornthip; red brown clay; Mg deficiency symptoms	Sept 04	20°05'65"	102°15'20"	320
	-7	Luang Prabang, Pik Noi village; Mr. Kam Pham FPR variety trial	Sept 05			
	-8	Luang Prabang, Kout Ngen village; Mr. Xieng Keo FPR variety trial	Sept 05			
	-9	Pak Ou, Haat Yai village; Mr. Bun Chan FPR variety trial	Sept 05	20°04'87"	102°15"05"	333
	-10	Pak Ou, Somsannouk village; Mr. Sinthorn FPR variety trial	Sept 05			
	-11	Xieng Nguen district, Houay Yen village; clay soil in slash-burn	Nov 03			
	-12	Xieng Nguen district Pak Wed village; variety trial on steep slope	May 05	19°46'49"	102°10'39"	331
	-13	Xieng Nguen dustrict, Sylarlaek village; Mr. Khame Lee FPR variety trial	Sept 05			
Oudomxay	-1	Xay, cassava multiplication field of PAFO	May 05	20°41'57"	101°59'29"	640
	-2	Houn district, Phou Lath village; field in siam weed to be used for cassava trial	May 04	20°17'07"	101°20'32"	627
	-3	Houn district, Kone Theoy village; clay loam, very poor cassava	Sept 04	20°16'26"	101°24'04"	1,042
	-4	Pak Baeng district, Kone Lang village; black clay, very good cassava	Sept 04	20°04'19"	101°10'33"	770
	-5	Pak Baeng district, Kone Lang village; Mr. Soun, steep slope above fish pond	May 05	20°04'14"	101°10'30"	781
	-6	Pak Baeng district, Kone Lang village; Mr. Chit FPR variety trial	Sept 05	20°04'15"	101°10'30"	816
	-7	Pak Baeng district, Kone Lang village; Mr. Thongwue; dark clay with small rocks	Sept 05			
	-8	Pak Baeng district, road to Kone Lang village; soil clods eaten by pregnant women	May 05			
	-9	Pak Baeng district, Mok Loi village; rather good cassava on steep slope	Sept 04	20°05'07"	101°11'13"	788
Xieng Khouang	-1	Paek district; dark sticky clay in farmer's field with new cassava varieties	May 04			
	-2	Paek district, Cattle Bank Station; field near road (grass trial)	May 04	19°20'35"	103°09'10"	1,102
	-3	Paek district, Cattle Bank Station; large fenced area for cassava trial	May 04			
	-4	Paek district, Cattle Bank Station; 4 $N_0P_0K_0$ plots; 0.5 t/ha lime applied in NPK trial	Sept 05			
	-5	Phou Khout district, Phuong Man village; 3-month cassava in back yard	May 04	19°38'54"	103°08'11"	1,116
	-6	Phu Khout district, Phuong Man village; plowed field for cassava trial	May 04			

Table 12. Soil samples taken in Laos from 2001 to 2006. (continued)

Sample no.		Sample location and description	Date	Coordinates N	Coordinates E	Elevation (masl)
Xieng Khouang	-7	Phu Khout district, Naa Xaithong, Song Hak village; cassava variety trial, Fo	Sept 04	19o37'32"	103o05'50"	1,057
	-8	Phou Khout district, Man village; cassava variety trial, Fo	Sept 04	19o30'32"	103o08'08"	1,119
	-9	Phou Khout district, Pung village; cassava variety trial, Fo; sandy clay loam	Jun 04	19o40'08"	103o08'43"	1,127
	-10	Phou Khout district, Vieng village; cassava variety trial, Fo	Apr 06	19o38'31"	103o09'39"	1,126
	-11	Phou Khout district, Koeng village; cassava variety trial, Fo	Apr 06			
	-12	Phou Khout district, Sombone village; cassava variety trial, Fo	Apr 06	19o38'35"	103o06'48"	1,111
	-13	Phou Khout district, Song Hak village; cassava variety trial, Fo	Apr 06			
	-14	Phou Khout, Pong Man village; Mrs. Sommee; dark yellow clay loam in FPR variety trial	Sept 05			
	-15	Phou Khout, Pong Man village; Mrs. Outh Tha; sandy clay loam in FPR variety trial	Sept 05	19o40'24"	103o09'19"	1,114
	-16	Phou Khout, Pong Man village; Mrs. Vanhsee; coarse sandy loam, 0.5 t/ha lime applied in FPR trial	Sept 05	19o40'31"	103o09'29"	1,118
	-17	Phaxay district, Xoya village; cassava variety trial, Fo; poor cassava	Sept 04			
	-18	Phaxay district, Xoya village; Mrs. Phomma; 0.5 t/ha lime applied in FPR variety trial	Sept 05	19o17'56"	103o05'55"	1,118
	-19	Phaxay district, Xoya village; Mrs Khamphan; 0.5 t/ha lime applied in FPR variety trial	Sept 05	19o17'54"	103o05'45"	1,130
	-20	Phaxay district, Xieng Nuea village; Mr. Son, cassava variety trial; Fo, dark soil, quite good cassava	Jun 04	19°17'44"	103°04'35"	1,134
	-21	Phaxay district, Xieng Nuea village; Mrs. Singtong, dark yellow clay loam in FPR variety trial	Sept 05	19°17'44"	103°04'57"	1,121
	-22	Phaxay district, Xieng Nuea village; Mr. Son, in new cassava field, vigorous growth	Sept 05			
Bolikhamxay	-1	Pakxa district, Si-sa-aat village; yellow clay loam in young cassava plantation in school	Jan 06			
	-2	Pakxa district, Pakhadin village; KU-50 at 4 MAP, very hard white clay	Jan 06			
Khamnuan	-1	Siang Song village; very hard yellow clay loam in slash-burn cassava field	Jan 06			
	-2	Mahaxay district; outside DAFO office; very hard clay loam	Jan 06			
	-3	Mahaxay district; near DAFO office in food crop garden area at bottom of cliff.	Jan 06			
Savannakhet	-1	Kisone district, Dong Kan Luang village; sandy loam near cassava garden	Jan 06			

Table 13. Chemical and physical characteristics of cassava soils in Laos, 2001-2006.

			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]
Vientiane	-1	5.2	1.45	13.3	0.52	0.78	0.32	0.36		26			0.51	0.68	16.3	0.29	67.2	66.2	20.6	13.2	s.l.
	-2	5.4	1.77	15.8	0.11	2.36	0.42	0.34		3			0.30	0.64	19.9	0.84	112.5	31.1	48.6	20.3	loam
Luang Prabang	-1	5.4	3.50	12.4	0.10	6.94	2.78	0.89		1			0.76	3.16	110.1	0.79	16.2	19.7	29.9	50.4	clay
	-2	5.4	6.50	7.0	0.73	3.33	3.38	1.05		9			1.20	3.84	160.0	0.53	25.6	19.2	30.0	50.7	clay
	-3	4.8	6.08	2.7	3.35	0.90	0.91	0.15		63			0.44	1.12	88.7	0.99	79.0	10.4	24.4	65.2	clay
	-4	6.0	3.12	7.1	0	6.88	1.97	0.35		0			0.76	4.03	144.4	1.18	10.6	24.2	26.6	49.2	clay
	-5	6.0	3.99	13.6	0	6.69	4.20	0.61		0			0.95	2.54	77.3	0.97	8.9	25.9	28.2	45.9	clay
	-6	4.5	1.68	5.6	5.52	0.35	0.14	0.23		88			0.29	1.20	2.8	0.83	142.6	22.0	25.5	52.5	clay
	-7	6.13	3.61	4.54	0	7.11	2.61	0.19	0.02		0.2		0.53	2.55	76.8	0.98	21.3	18.7	35.9	45.3	clay
	-8	6.27	2.96	1.21	0	11.18	1.78	0.18	0.04		0.4		0.32	1.61	51.0	0.72	6.3	23.6	27.7	48.7	clay
	-9	6.28	3.14	4.11	0	5.33	3.86	0.23	0.03		0.3		0.27	1.41	43.1	0.42	9.4	34.0	30.2	35.8	c.l.
	-10	6.17	3.92	16.94	0	6.97	3.60	0.47	0.03		0.3		0.62	1.41	52.0	0.36	8.3	17.5	31.4	51.1	clay
	-11	4.5	4.90	4.3	5.50	0.60	0.32	0.23		83			0.32	1.38	14.2	1.53	90.0	3.8	20.9	75.3	clay
	-12	5.2	4.85	10.9	0.73	3.03	3.24	0.29		10			0.53	1.88	64.9	0.73	14.4	15.4	30.9	53.7	clay
	-13	5.92	4.57	1.59	0	5.74	4.05	0.38	0.04		0.4		0.40	3.30	91.6	0.69	8.2	17.4	30.2	52.4	clay
Oudomxay	-1	6.3	2.58	1.9	0	9.46	1.74	0.19	0.11	0	1.0		0.41	1.72	91.0	1.56	66.2	8.1	66.4	25.5	Si.l.
	-2	6.5	3.12	18.2	0	5.52	2.39	0.63		0			0.64	2.69	103.9	0.45	16.2	28.1	36.2	35.7	c.l.
	-3	4.8	3.17	1.5	4.63	0.65	0.37	0.24		79			0.30	1.09	41.1	0.46	25.4	11.7	27.2	61.1	clay
	-4	4.7	2.62	15.1	0.10	9.62	2.72	0.45		1			0.82	4.06	44.6	0.72	20.7	21.5	37.1	41.3	clay
	-5	4.6	5.08	2.1	3.69	1.02	0.77	0.44		62			0.55	2.04	45.7	1.40	66.4	10.1	32.3	57.7	clay
	-6	4.43	6.60	1.83	6.50	0.44	0.24	0.27	-	87			0.42	1.06	21.9	0.92	60.6	16.8	17.0	66.2	clay
	-7	5.77	4.95	10.07	0	3.96	3.17	0.95	0.03		0.4		0.62	3.58	84.6	0.47	9.3	24.6	23.3	52.0	clay
	-8	4.9	0.17	0.8	3.38	0	0	0.04		99			0.27	0.38	0.4	0.25	7.2	25.1	47.0	27.9	c.l.
	-9	4.8	2.51	1.3	4.68	1.39	1.06	0.33		63			0.34	2.07	66.6	1.74	42.2	9.3	28.4	62.3	clay

[1] s.l. = sandy loam c.l. = clay loam s.c. = sandy clay si.l. = silt loam

Table 13. Chemical and physical characteristics of cassava soils in Laos, 2001-2006. (continued)

			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]
Xieng Khouang	-1	5.1	5.67	10.7	0.47	6.72	2.20	0.47		5			0.31	2.44	8.9	0.46	13.4	25.6	31.7	42.7	clay
	-2	5.2	6.92	1.4	2.65	0.44	0.12	0.22		77			0.30	0.63	3.1	0.48	41.4	37.9	25.0	37.1	c.l.
	-3	4.3	4.79	0.9	3.22	0.21	0.06	0.17		88			0.30	0.47	2.0	0.55	46.0	27.7	31.3	41.0	clay
	-4	4.87	4.76	0.90	2.55	0.46	0.29	0.08		75			0.24	0.67	1.2	0.45	39.0	34.6	22.4	43.0	clay
	-5	5.6	5.36	3.6	0	0.88	0.30	0.64		0											
	-6	5.1	2.56	1.4	2.92	0.60	0.18	0.15		76			0.26	0.81	14.3	0.90	27.0	29.1	23.1	47.8	clay
	-7	4.5	2.22	1.4	2.13	0.57	0.18	0.17		70			0.30	0.63	13.7	0.52	59.2	43.7	26.7	29.6	c.l.
	-8	4.5	2.62	1.5	3.18	0.51	0.19	0.18		78			0.28	0.67	13.0	0.83	26.5	22.5	27.0	50.5	clay
	-9	5.2	5.29	1.4	1.61	0.26	0.08	0.20		75			0.59	0.63	10.3	0.80	22.7	64.2	12.0	23.8	s.c.l.
	-10	4.74	8.41	0.89	3.12	0.49	0.17	0.15		79			0.40	0.66	11.9	0.51	12.9	53.7	16.7	29.6	s.c.l.
	-11	4.78	2.73	1.66	1.46	0.32	0.20	0.05		72			0.25	0.33	4.9	0.27	41.6	55.0	21.3	23.7	s.c.l.
	-12	4.48	5.32	6.55	3.07	0.39	0.11	0.11		83			0.27	0.60	4.7	0.61	28.5	39.4	21.4	39.2	c.l.
	-13	4.72	4.87	1.33	3.48	0.33	0.12	0.17		85			0.36	0.43	12.0	0.55	29.9	35.5	26.6	37.9	c.l.
	-14	4.94	5.88	18.11	2.44	1.04	0.49	0.16		59			0.35	0.92	12.3	0.71	22.2	36.7	15.9	47.4	clay
	-15	4.82	5.29	1.93	2.39	0.54	0.28	0.10		72			0.29	2.60	8.2	0.82	28.4	51.0	10.7	38.2	s.c.
	-16	5.32	5.02	5.54	0.94	3.22	1.56	0.64		15			0.44	1.63	27.3	1.16	42.9	40.9	14.5	44.6	clay
	-17	4.7	3.67	0.2	3.14	0.49	0.14	0.19		86			0.45	1.55	4.6	1.06	79.0	27.6	30.9	41.5	clay
	-18	4.92	3.81	0.95	2.55	0.67	0.43	0.12	-	68			0.21	0.64	4.8	0.49	41.1	22.5	24.5	53.0	clay
	-19	4.72	7.17	0.50	2.65	0.61	0.38	0.18	-	69			0.38	1.68	4.0	0.78	54.1	32.1	14.4	53.5	clay
	-20	5.6	5.54	1.2	0	5.37	1.22	0.26		0			0.71	0.72	18.4	0.51	45.9	48.6	13.3	38.1	s.c.
	-21	4.88	5.89	3.67	2.03	1.19	0.57	0.51	-	47			0.40	2.83	20.6	1.59	154.2	38.1	13.3	48.6	clay
	-22	4.93	3.89	3.65	2.39	0.85	0.30	0.16		65			0.22	0.73	9.4	0.46	32.9	33.2	18.4	48.4	clay
Bolikhamxay	-1	4.61	2.45	4.23	1.30	0.57	0.16	0.16		59			0.25	2.44	19.9	0.74	52.0	38.7	23.6	37.7	c.l.
	-2	4.67	1.84	2.35	2.03	0.33	0.11	0.08		80			0.20	0.33	4.1	0.21	122.0	36.4	36.1	27.5	c.l.
Khamnuan	-1	4.88	1.66	1.85	1.30	0.89	0.35	0.11		49			0.26	0.43	30.2	0.22	138.8	50.7	25.1	24.2	s.c.l.
	-2	4.27	1.13	0.16	7.90	0.17	0.06	0.09		96			0.20	0.32	4.2	0.18	38.0	9.6	25.7	64.7	clay
	-3	5.33	3.43	6.72	0.52	4.87	1.14	0.42		7			0.41	0.87	97.0	0.27	38.1	32.1	28.0	39.9	c.l.
Savannakhet	-1	5.70	1.77	18.70	0	1.92	0.59	0.18	0.01	0	0.4		0.46	0.74	19.8	0.16	16.0	60.9	15.0	24.1	s.c.l.

[1] s.c.l. = sandy clay loam
c.l. = clay loam

Table 14. Soil samples taken in Thailand from 2001 to 2006.

Sample no.		Sample location and description	Date
Roy-et	-1	Phoo Chai, Kham Pha Ung, Phu Khaw Thong; variety trial Mr. Phrom	Sept 03
	-2	Roy-et FCR station; micronutrient trial 2002 Rep I	May 02
	-3	Roy-et FCR station; micronutrient trial 2002 Rep II	May 02
	-4	Roy-et FCR station; micronutrient trial 2002 Rep III	May 02
	-5	Roy-et FCR station; micronutrient trial 2002 Rep IV	May 02
Maha-Sarakham	-1	Maha Sarakham FCR station; micronutrient trial 2002 Rep I	May 02
	-2	Maha Sarakham FCR station; micronutrient trial 2002 Rep II	May 02
	-3	Maha Sarakham FCR station; micronutrient trial 2002 Rep III	May 02
	-4	Maha Sarakham FCR station; micronutrient trial 2002 Rep IV	May 02
Kalasin	-1	Sahatsakhan, Huay Suea Ten; cassava with vetiver hedgerows	Aug 01
	-2	Sahatsakhan district, Huay Suea Ten village; field with recently planted *Canavalia*	Jul 02
	-3	Sahatsakhan, district, Huay Suea Ten village; adjacent cassava after *Canavalia*	Jul 02
	-4	Mueang district, Kalasin FCR station; micronutrient trial Rep I	May 02
	-5	Mueang district, Kalasin FCR station; micronutrient trial Rep II	May 02
	-6	Mueang district, Kalasin FCR station; micronutrient trial Rep III	May 02
	-7	Mueang district, Kalasin FCR station; micronutrient trial Rep IV	May 02
	-8	Sahatsakhan, Noon Sawaat; Mr. Prasit, cassava field after green manure	Dec 02
	-9	Sahatsakhan, Noon Sawaat; Mr. Prasit, cassava field without green manure	Dec 02
	-10	Sahatsakhan, Huay Suea Ten; Mr Niphon, in small gully, cassava P deficient	Dec 02
	-11	Namon; Noon Thiang; Mr. Thongsak variety trial; very hard soil	Dec 02
	-12	Namon; Noon Thiang; Mr. Prachum, outside green manure trial; white sandy soil	Dec 02
	-13	Namon; Noon Thiang; behind cassava field school; white/red sandy soil, very poor	Dec 02
	-14	Huay Pueng, Nikhom, Huay Faa; FPR fertilizer trial Mrs. Sukchai; F_0	Sept 03
	-15	Mueng district, Kalasin FCR station; bentonite trial Rep I, 0-10 cm	Jun 04
	-16	Mueng district, Kalasin FCR station; bentonite trial Rep I, 10-20 cm	Jun 04
	-17	Mueng district, Kalasin FCR station; bentonite trial Rep I, 20-30 cm	Jun 04
	-18	Mueng district, Kalasin FCR station; bentonite trial Rep II, 0-10 cm	Jun 04
	-19	Mueng district, Kalasin FCR station; bentonite trial Rep II, 10-20 cm	Jun 04
	-20	Mueng district, Kalasin FCR station; bentonite trial Rep II, 20-30 cm	Jun 04
	-21	Mueng district, Kalasin FCR station; bentonite trial Rep III, 0-10 cm	Jun 04
	-22	Mueng district, Kalasin FCR station; bentonite trial Rep III, 10-20 cm	Jun 04
	-23	Mueng district, Kalasin FCR station; bentonite trial Rep III, 20-30 cm	Jun 04
Khon Kaen	-1	Khon Kaen FCRC; long-term NPK trial, 27 th year- T_1	May 02
	-2	Khon Kaen FCRC; long-term NPK trial, 27 th year- T_2	May 02
	-3	Khon Kaen FCRC; long-term NPK trial, 27 th year- T_3	May 02
	-4	Khon Kaen FCRC; long-term NPK trial, 27 th year- T_4	May 02
	-5	Khon Kaen FCRC; long-term NPK trial, 27 th year- T_5	May 02
	-6	Khon Kaen FCRC; long-term NPK trial, 27 th year- T_6	May 02
	-7	Khon Kaen FCRC; long-term NPK trial, 27 th year- T_7	May 02
	-8	Khon Kaen FCRC; long-term NPK trial, 27 th year- T_8	May 02

[1)] M_1 = continuous cassava monoculture
M_2 = rotation cassava /peanut-pigeon pea
M_3 = continuous cassava intercropped with peanut

-1 = no fertilizers or amendments
-2 = chemical fertilizers
-4 = chemical fertilizers+amendments of compost, lime and rock phosphate in years 1, 5 and 9

Table 14. Soil samples taken in Thailand from 2001 to 2006 (continued).

Sample no.		Sample location and description	Date
Khon Kaen	-9	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_1-1[1)]	Dec 02
	-10	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_1-2	Dec 02
	-11	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_1-4	Dec 02
	-12	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_2-1	Dec 02
	-13	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_2-2	Dec 02
	-14	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_2-4	Dec 02
	-15	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_3-1	Dec 02
	-16	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_3-2	Dec 02
	-17	Khon Kaen FCRC; long-term soil management trial, 0-20 cm, M_3-4	Dec 02
	-18	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_1-1	Dec 02
	-19	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_1-2	Dec 02
	-20	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_1-4	Dec 02
	-21	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_2-1	Dec 02
	-22	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_2-2	Dec 02
	-23	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_2-4	Dec 02
	-24	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_3-1	Dec 02
	-25	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_3-2	Dec 02
	-26	Khon Kaen FCRC; long-term soil management trial, 25-40 cm, M_3-4	Dec 02
	-27	Khon Kaen FCRC; long-term NPK trial, 0-20 cm, mix Rep II and III, T_1	Dec 02
	-28	Khon Kaen FCRC; long-term NPK trial, 0-20 cm, mix Rep II and III, T_2	Dec 02
	-29	Khon Kaen FCRC; long-term NPK trial, 0-20 cm, mix Rep II and III, T_3	Dec 02
	-30	Khon Kaen FCRC; long-term NPK trial, 0-20 cm, mix Rep II and III, T_4	Dec 02
	-31	Khon Kaen FCRC; long-term NPK trial, 0-20 cm, mix Rep II and III, T_5	Dec 02
	-32	Khon Kaen FCRC; long-term NPK trial, 0-20 cm, mix Rep II and III, T_6	Dec 02
	-33	Khon Kaen FCRC; long-term NPK trial, 0-20 cm, mix Rep II and III, T_7	Dec 02
	-34	Khon Kaen FCRC; long-term NPK trial, 0-20 cm, mix Rep II and III, T_8	Dec 02
	-35	Khon Kaen FCRC; long-term NPK trial, 25-40 cm, mix Rep II and III, T_1	Dec 02
	-36	Khon Kaen FCRC; long-term NPK trial, 25-40 cm, mix Rep II and III, T_2	Dec 02
	-37	Khon Kaen FCRC; long-term NPK trial, 25-40 cm, mix Rep II and III, T_3	Dec 02
	-38	Khon Kaen FCRC; long-term NPK trial, 25-40 cm, mix Rep II and III, T_4	Dec 02
	-39	Khon Kaen FCRC; long-term NPK trial, 25-40 cm, mix Rep II and III, T_5	Dec 02
	-40	Khon Kaen FCRC; long-term NPK trial, 25-40 cm, mix Rep II and III, T_6	Dec 02
	-41	Khon Kaen FCRC; long-term NPK trial, 25-40 cm, mix Rep II and III, T_7	Dec 02
	-42	Khon Kaen FCRC; long-term NPK trial, 25-40 cm, mix Rep II and III, T_8	Dec 02
	-43	Khon Kaen FCRC; variety trial for leaf production-T2002-1 Rep I	May 02
	-44	Khon Kaen FCRC; variety trial for leaf production-T2002-1 Rep II	May 02
	-45	Khon Kaen FCRC; variety trial for leaf production-T2002-1 Rep III	May 02
	-46	Khon Kaen FCRC; variety trial for leaf production-T2002-1 Rep IV	May 02
	-47	Khon Kaen FCRC; planting density trial for leaf prod. T-2002-4 Rep I	May 02
	-48	Khon Kaen FCRC; planting density trial for leaf prod. T-2002-4 Rep II	May 02
	-49	Khon Kaen FCRC; planting density trial for leaf prod. T-2002-4 Rep III	May 02
	-50	Khon Kaen FCRC; planting density trial for leaf prod. T-2002-4 Rep IV	May 02
	-51	Khon Kaen FCRC; cutting height/frequency trial for leaf prod. T-2002-5 Rep I	May 02
	-52	Khon Kaen FCRC; cutting height/frequency trial for leaf prod. T-2002-5 Rep II	May 02
	-53	Khon Kaen FCRC; cutting height/frequency trial for leaf prod. T-2002-5 Rep III	May 02
	-54	Khon Kaen FCRC; cutting height/frequency trial for leaf prod. T-2002-5 Rep IV	May 02

Table 14. Soil samples taken in Thailand from 2001 to 2006 (continued).

Sample no.		Sample location and description	Date
Khon Kaen	-55	Khon Kaen FCRC; NPK trial for leaf production T-2002-6 Rep I	May 02
	-56	Khon Kaen FCRC; NPK trial for leaf production T-2002-6 Rep II	May 02
	-57	Khon Kaen FCRC; NPK trial for leaf production T-2002-6 Rep III	May 02
	-58	Khon Kaen FCRC; NPK trial for leaf production T-2002-6 Rep IV	May 02
	-59	Khon Kaen FCRC; NPK leaf trial, before 2d year T_1	Jun 03
	-60	Khon Kaen FCRC; NPK leaf trial, before 2d year T_2	Jun 03
	-61	Khon Kaen FCRC; NPK leaf trial, before 2d year T_3	Jun 03
	-62	Khon Kaen FCRC; NPK leaf trial, before 2d year T_4	Jun 03
	-63	Khon Kaen FCRC; NPK leaf trial, before 2d year T_5	Jun 03
	-64	Khon Kaen FCRC; NPK leaf trial, before 2d year T_6	Jun 03
	-65	Khon Kaen FCRC; NPK leaf trial, before 2d year T_7	Jun 03
	-66	Khon Kaen FCRC; NPK leaf trial, before 2d year T_8	Jun 03
	-67	Khon Kaen FCRC; NPK leaf trial, before 2d year T_9	Jun 03
	-68	Khon Kaen FCRC; NPK leaf trial, before 2d year T_{10}	Jun 03
	-69	Khon Kaen FCRC; NPK leaf trial, before 2d year T_{11}	Jun 03
	-70	Khon Kaen FCRC; NPK leaf trial, before 2d year T_{12}	Jun 03
N. Ratchasima	-1	Huay Bong, TTDI Center; long-term erosion trial I-1; before 6 th planting	Mar 01
	-2	Huay Bong, TTDI Center; long-term erosion trial I-2; before 6 th planting	Mar 01
	-3	Huay Bong, TTDI Center; long-term erosion trial I-3; before 6 th planting	Mar 01
	-4	Huay Bong, TTDI Center; long-term erosion trial I-4; before 6 th planting	Mar 01
	-5	Huay Bong, TTDI Center; long-term erosion trial I-5; before 6 th planting	Mar 01
	-6	Huay Bong, TTDI Center; long-term erosion trial I-6; before 6 th planting	Mar 01
	-7	Huay Bong, TTDI Center; long-term erosion trial II-1; before 6 th planting	Mar 01
	-8	Huay Bong, TTDI Center; long-term erosion trial II-2; before 6 th planting	Mar 01
	-9	Huay Bong, TTDI Center; long-term erosion trial II-3; before 6 th planting	Mar 01
	-10	Huay Bong, TTDI Center; long-term erosion trial II-4; before 6 th planting	Mar 01
	-11	Huay Bong, TTDI Center; long-term erosion trial II-5; before 6 th planting	Mar 01
	-12	Huay Bong, TTDI Center; long-term erosion trial II-6; before 6 th planting	Mar 01
	-13	Huay Bong, TTDI Center; land preparation trial I-1	Aug 01
	-14	Huay Bong, TTDI Center; land preparation trial II-1	Aug 01
	-15	Huay Bong, TTDI Center; land preparation trial III-1	Aug 01
	-16	Huay Bong, TTDI Center; land preparation trial IV-1	Aug 01
	-17	Huay Bong, TTDI Center; micronutrient trial I	Aug 01
	-18	Huay Bong, TTDI Center; micronutrient trial II	Aug 01
	-19	Huay Bong, TTDI Center; micronutrient trial III	Aug 01
	-20	Huay Bong, TTDI Center; micronutrient trial IV	Aug 01
	-21	Huay Bong, TTDI Center; cassava leaf production trial	Aug 01
	-22	Huay Bong, TTDI Center; long-term erosion trial – I-1; before 7 th planting	Feb 02
	-23	Huay Bong, TTDI Center; long-term erosion trial – I-2; before 7 th planting	Feb 02
	-24	Huay Bong, TTDI Center; long-term erosion trial – I-3; before 7 th planting	Feb 02
	-25	Huay Bong, TTDI Center; long-term erosion trial – I-4; before 7 th planting	Feb 02
	-26	Huay Bong, TTDI Center; long-term erosion trial – I-5; before 7 th planting	Feb 02
	-27	Huay Bong, TTDI Center; long-term erosion trial – I-6; before 7 th planting	Feb 02
	-28	Huay Bong, TTDI Center; long-term erosion trial – II-1; before 7 th planting	Feb 02
	-29	Huay Bong, TTDI Center; long-term erosion trial – II-2; before 7 th planting	Feb 02
	-30	Huay Bong, TTDI Center; long-term erosion trial – II-3; before 7 th planting	Feb 02

Table 14. Soil samples taken in Thailand from 2001 to 2006 (continued).

Sample no.		Sample location and description	Date
N. Ratchasima	-31	Huay Bong, TTDI Center; long-term erosion trial – II-4; before 7 th planting	Feb 02
	-32	Huay Bong, TTDI Center; long-term erosion trial – II-5; before 7 th planting	Feb 02
	-33	Huay Bong, TTDI Center; long-term erosion trial – II-6; before 7 th planting	Feb 02
	-34	Banmai Samrong; long-term NPK trial, 28 th year-T_1	May 02
	-35	Banmai Samrong; long-term NPK trial, 28 th year-T_2	May 02
	-36	Banmai Samrong; long-term NPK trial, 28 th year-T_3	May 02
	-37	Banmai Samrong; long-term NPK trial, 28 th year-T_4	May 02
	-38	Banmai Samrong; long-term NPK trial, 28 th year-T_5	May 02
	-39	Banmai Samrong; long-term NPK trial, 28 th year-T_6	May 02
	-40	Banmai Samrong; long-term NPK trial, 28 th year-T_7	May 02
	-41	Banmai Samrong; long-term NPK trial, 28 th year-T_8	May 02
	-42	Huay Bong, TTDI; plot next to land preparation trial, yellow cassava	Oct 02
	-43	Huay Bong, TTDI; soil with white crust in II-T2 of soil preparation trial	Oct 02
	-44	Huay Bong, TTDI; long term erosion trial – I-1; before 8 th planting	May 03
	-45	Huay Bong, TTDI; long term erosion trial – I-2; before 8 th planting	May 03
	-46	Huay Bong, TTDI; long term erosion trial – I-3; before 8 th planting	May 03
	-47	Huay Bong, TTDI; long term erosion trial – I-4; before 8 th planting	May 03
	-48	Huay Bong, TTDI; long term erosion trial – I-5; before 8 th planting	May 03
	-49	Huay Bong, TTDI; long term erosion trial – I-6; before 8 th planting	May 03
	-50	Huay Bong, TTDI; long term erosion trial – II-1; before 8 th planting	May 03
	-51	Huay Bong, TTDI; long term erosion trial – II-2; before 8 th planting	May 03
	-52	Huay Bong, TTDI; long term erosion trial – II-3; before 8 th planting	May 03
	-53	Huay Bong, TTDI; long term erosion trial – II-4; before 8 th planting	May 03
	-54	Huay Bong, TTDI; long term erosion trial – II-5; before 8 th planting	May 03
	-55	Huay Bong, TTDI; long term erosion trial – II-6; before 8 th planting	May 03
	-56	Huay Bong, TTDI, lot 44 with yellow cassava plants	Aug 03
	-57	Hugy Bong, TTDI, lot 44 with green plants nearby	Aug 03
	-58	Huay Bong, TTDI, new plot for EFFEM Food leaf trials	Apr 04
	-59	Tepharak, Bueng Prue; Mr. Suthin FPR erosion trial	Sept 03
	-60	Sii Khiew, Paanglako; Mr. Lamyai Sritrakul, sandy soil, serious gullies	Sept 03
	-61	Daan Khun Thot, Khut Dook; Mr. Suem Kaapkhunthot, next to gully	Sept 03
	-62	Banmai Samrong; Zn application trial Rep I	May 04
	-63	Banmai Samrong; Zn application trial Rep II	May 04
	-64	Banmai Samrong; Zn application trial Rep III	May 04
	-65	Banmai Samrong; Zn application trial Rep IV	May 04
	-66	Huay Bong, TTDI; long-term erosion trial- I –1; at end 10/th planting	Feb 06
	-67	Huay Bong, TTDI; long-term erosion trial- I –2; at end 10/th planting	Feb 06
	-68	Huay Bong, TTDI; long-term erosion trial- I –3; at end 10/th planting	Feb 06
	-69	Huay Bong, TTDI; long-term erosion trial- I –4; at end 10/th planting	Feb 06
	-70	Huay Bong, TTDI; long-term erosion trial- I –5; at end 10/th planting	Feb 06
	-71	Huay Bong, TTDI; long-term erosion trial- I –6; at end 10/th planting	Feb 06
	-72	Huay Bong, TTDI; long-term erosion trial- II –1; at end 10/th planting	Feb 06
	-73	Huay Bong, TTDI; long-term erosion trial- II –2; at end 10/th planting	Feb 06
	-74	Huay Bong, TTDI; long-term erosion trial- II –3; at end 10/th planting	Feb 06
	-75	Huay Bong, TTDI; long-term erosion trial- II –4; at end 10/th planting	Feb 06
	-76	Huay Bong, TTDI; long-term erosion trial- II –5; at end 10/th planting	Feb 06
	-77	Huay Bong, TTDI; long-term erosion trial- II –6; at end 10/th planting	Feb 06

Table 14. Soil samples taken in Thailand from 2001 to 2006 (continued).

Sample no.		Sample location and description	Date
Chayaphum	-1	Thepsatit, Khook Anu, below FPR green manure trial, reddish sandy soil	Aug 01
	-2	Thepsatit, Nayaang Klak, Khook Anu; FPR variety trial, red sandy loam	Aug 01
	-3	Thepsatit, Nayaang Klak, Khook Anu; R5 variety trial Mr. Chanthong	Apr 02
	-4	Thepsatit, Nayaang Klak, Khook Anu; erosion trial Mr. Lun	Apr 02
	-5	Thepsatit, Huay Yaay Yiew; Mrs. Mani Ruengrak FPR erosion trial, clay loam	Sept 03
Kamphengpet	-1	Khanuwaralakburi; sandy grey soil with severe gulleys	Aug 01
Kanchanaburi	-1	Lawkhwan, Baan Nongkae; FPR weed control trial, sandy loam	Aug 01
	-2	Lawkhwan, Baan Nongkae; FPR erosion trial, red clay soil	Aug 01
	-3	Lawkhwan, Baan Nongkae; FPR variety trial, grey sandy soil	Aug 01
	-4	Lawkhwan, Thung Krabam; FPR variety trial Mrs. Sompong, high yield	Sept 03
	-5	Lawkhwan, Thung Krabam; FPR fertilizer trial Mr. Lek, F_0; poor growth	Sept 03
	-6	Lawkhwan, Thung Krabam; FPR green manure trial, Mr. Bunyuen, no GM	Sept 03
	-7	Lawkhwan, Thung Krabam; FPR green manure trial, Mr. Bunyuen, Canavalia	Sept 03
	-8	Lawkhwan, Thung Krabam; FPR green manure trial, Mr. Bunyuen, cowpea	Sept 03
	-9	Lawkhwan, Thung Krabam; FPR green manure trial, Mr. Bunyuen, mungbean	Sept 03
	-10	Lawkhwan, Thung Krabam; yellow cassava on termite hill, white sandy loam	Sept 03
	-11	Lawkhwan, Thung Krabam; nearby green cassava; white sandy loam	Sept 03
	-12	Say Yook; FPR variety trial Mrs. Lalita, excessive top growth, clay soil	Sept 03
	-13	Say Yook; near FPR erosion trial Mr. Chu; K deficiency in Rayong 5, red clay	Sept 03
Ratchaburi	-1	Baan Poong, Poong Yo village; FPR erosion trial Mr. Chamrung, poor cassava	Aug 03
	-2	Baan Poong, Poong Yo village; FPR fertilizer+manure trial, good growth	Aug 03
Chachoengsao	-1	Khaw Hin Sorn; land preparation trial Rep I	Jul 01
	-2	Khaw Hin Sorn; land preparation trial Rep II	Jul 01
	-3	Khaw Hin Sorn; land preparation trial Rep III	Jul 01
	-4	Khaw Hin Sorn; new land preparation trial	May 02
	-5	Sanaam Chai Khet, Thaachiwitmai; Mr. Chamlong, harvested cassava field	Nov 01
	-6	Sanaam Chai Khet, Thaachiwitmai; Mr. Somchai, cassava field above vetiver	Nov 01
	-7	Thaa Takiab, Nong Yai village; rocky soil on 20% slope with vetiver	Aug 01
Prachinburi	-1	Nadi, Kaeng Dinso; soil sedimenta above vetiver in gully	Sept 03
	-2	Nadi, Kaeng Dinso; soil in cassava field near gully	Sept 03
Sra Kaew	-1	Wang Nam Yen, Wang Sombuun; C+Canavalia, K deficiency symptoms	Sept 03
Rayong	-1	Rayong FCRC; cassava variety trial for leaf production	May 01
	-2	Rayong; land preparation trial-Rep I	Jun 01
	-3	Rayong; land preparation trial-Rep II	Jun 01
	-4	Rayong; land preparation trial-Rep III	Jun 01
	-5	Rayong; land preparation trial-Rep IV	June 01
	-6	Rayong FCRC; long-term NPK trial – T_1	May 02
	-7	Rayong FCRC; long-term NPK trial – T_2	May 02
	-8	Rayong FCRC; long-term NPK trial – T_3	May 02
	-9	Rayong FCRC; long-term NPK trial – T_4	May 02
	-10	Rayong FCRC; long-term NPK trial – T_5	May 02
	-11	Rayong FCRC; long-term NPK trial – T_6	May 02
	-12	Rayong FCRC; long-term NPK trial – T_7	May 02

Table 14. Soil samples taken in Thailand from 2001 to 2006 (continued).

Sample no.	Sample location and description	Date
-13	Rayong FCRC; long-term NPK trial – T_8	May 02
-14	Rayong, FCRC; variety trial for leaf production Rep I	May 02
-15	Rayong, FCRC; variety trial for leaf production Rep II	May 02
-16	Rayong, FCRC; variety trial for leaf production Rep III	May 02
-17	Rayong, FCRC; variety trial for leaf production Rep IV	May 02
-18	Rayong, FCRC; cutting height/frequency trial for leaf production Rep I	May 02
-19	Rayong, FCRC; cutting height/frequency trial for leaf production Rep II	May 02
-20	Rayong, FCRC; cutting height/frequency trial for leaf production Rep III	May 02
-21	Rayong, FCRC; cutting height/frequency trial for leaf production Rep IV	May 02
-22	Rayong, FCRC; NPK trial for leaf production Rep I	May 02
-23	Rayong, FCRC; NPK trial for leaf production Rep II	May 02
-24	Rayong, FCRC; NPK trial for leaf production Rep III	May 02
-25	Rayong, FCRC; NPK trial for leaf production Rep IV	May 02
-26	Rayong, FCRC; planting density trial for leaf production Rep I	May 02
-27	Rayong, FCRC; planting density trial for leaf production Rep II	May 02
-28	Rayong, FCRC; planting density trial for leaf production Rep III	May 02
-29	Rayong, FCRC; planting density trial for leaf production Rep IV	May 02
-30	Rayong FCRC; long-term NPK trial, mix Rep II and III, 0-20 cm, T_1	Dec 02
-31	Rayong FCRC; long-term NPK trial, mix Rep II and III, 0-20 cm, T_2	Dec 02
-32	Rayong FCRC; long-term NPK trial, mix Rep II and III, 0-20 cm, T_3	Dec 02
-33	Rayong FCRC; long-term NPK trial, mix Rep II and III, 0-20 cm, T_4	Dec 02
-34	Rayong FCRC; long-term NPK trial, mix Rep II and III, 0-20 cm, T_5	Dec 02
-35	Rayong FCRC; long-term NPK trial, mix Rep II and III, 0-20 cm, T_6	Dec 02
-36	Rayong FCRC; long-term NPK trial, mix Rep II and III, 0-20 cm, T_7	Dec 02
-37	Rayong FCRC; long-term NPK trial, mix Rep II and III, 0-20 cm, T_8	Dec 02
-38	Rayong FCRC; long-term NPK trial, mix Rep II and III, 25-40 cm, T_1	Dec 02
-39	Rayong FCRC; long-term NPK trial, mix Rep II and III, 25-40 cm, T_2	Dec 02
-40	Rayong FCRC; long-term NPK trial, mix Rep II and III, 25-40 cm, T_3	Dec 02
-41	Rayong FCRC; long-term NPK trial, mix Rep II and III, 25-40 cm, T_4	Dec 02
-42	Rayong FCRC; long-term NPK trial, mix Rep II and III, 25-40 cm, T_5	Dec 02
-43	Rayong FCRC; long-term NPK trial, mix Rep II and III, 25-40 cm, T_6	Dec 02
-44	Rayong FCRC; long-term NPK trial, mix Rep II and III, 25-40 cm, T_7	Dec 02
-45	Rayong FCRC; long-term NPK trial, mix Rep II and III, 25-40 cm, T_8	Dec 02
-46	Rayong FCRC, NPK leaf trial-before 2d year – T_1	May 03
-47	Rayong FCRC, NPK leaf trial-before 2d year – T_2	May 03
-48	Rayong FCRC, NPK leaf trial-before 2d year – T_3	May 03
-49	Rayong FCRC, NPK leaf trial-before 2d year – T_4	May 03
-50	Rayong FCRC, NPK leaf trial-before 2d year – T_5	May 03
-51	Rayong FCRC, NPK leaf trial-before 2d year – T_6	May 03
-52	Rayong FCRC, NPK leaf trial-before 2d year – T_7	May 03
-53	Rayong FCRC, NPK leaf trial-before 2d year – T_8	May 03
-54	Rayong FCRC, NPK leaf trial-before 2d year – T_9	May 03
-55	Rayong FCRC, NPK leaf trial-before 2d year – T_{10}	May 03
-56	Rayong FCRC, NPK leaf trial-before 2d year – T_{11}	May 03
-57	Rayong FCRC, NPK leaf trial-before 2d year – T_{12}	May 03

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006.

		←Chemical characteristics→																←Physical characteristics→			
			%	ppm	←me/100 g→					%	%	mmhos /cm	←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)]
Roy-et	-1	5.6	1.01	10.5	0	0.87	0.21	0.04	0.03	0	2.6		0.32	0.50	32.8	0.37	10.0	67.0	13.8	19.2	s.l.
	-2	6.1	0.38	82.0	0	0.91	0.18	0.11	0.03	0	2.4		0.58	1.87	33.2	0.49	55.8	68.9	16.3	14.8	s.l.
	-3	6.2	0.41	73.4	0	0.69	0.19	0.09	0.02	0	2.0		0.71	0.63	16.4	0.60	70.0	67.7	17.5	14.8	s.l.
	-4	6.5	0.37	60.4	0	1.04	0.26	0.11	0.02	0	1.4		0.72	1.20	34.5	0.45	34.3	69.0	16.2	14.8	s.l.
	-5	6.6	0.31	83.1	0	0.83	0.22	0.10	0.02	0	1.7		0.52	1.01	21.8	0.61	78.1	67.7	17.5	14.8	s.l.
M. Sarakham	-1	6.5	0.37	34.7	0	1.04	0.13	0.11	0.03	0	2.2	0.04	0.43	1.48	51.8	0.37	6.2	73.9	12.5	13.6	s.l.
	-2	6.4	0.34	45.2	0	1.44	0.17	0.13	0.03	0	1.7	0.07	0.75	1.88	49.2	0.45	7.1	74.0	12.5	13.5	s.l.
	-3	6.5	0.26	35.1	0	1.29	0.13	0.11	0.02	0	1.3	0.03	0.46	1.38	51.8	0.37	7.2	74.0	12.5	13.5	s.l.
	-4	6.5	0.23	33.9	0	0.86	0.11	0.10	0.02	0	1.8	0.03	0.35	1.45	54.5	0.45	8.7	73.9	12.5	13.6	s.l.
Kalasin	-1	6.2	0.66	7.3	0	0.57	0.21	0.11	0.30	0		0.28	0.80	0.60	31.8	0.21	9.2	64.7	22.6	12.7	s.l.
	-2	5.3	0.46	6.7	0.21	0.39	0.17	0.08		25			0.26	0.12	5.5	0.16	49.3	64.1	18.1	17.9	s.l.
	-3	5.2	0.73	10.4	0.36	0.50	0.17	0.09		32			0.40	0.30	12.7	0.16	35.6	58.9	22.7	18.4	s.l.
	-4	5.3	0.38	80.1	0.10	0.58	0.06	0.07	0.03	12	3.2	0.31	0.36	6.22	21.8	0.26	55.8	68.8	12.7	18.5	s.l.
	-5	5.3	0.41	86.9	0.16	0.51	0.04	0.07	0.02	20	2.2	0.32	0.36	9.57	21.0	0.28	57.3	69.0	12.6	18.4	s.l.
	-6	5.4	0.41	66.3	0.10	0.57	0.07	0.08	0.03	12	3.3	0.28	0.43	3.90	22.1	0.25	69.1	66.4	13.9	19.7	s.l.
	-7	5.4	0.37	109.9	0.16	0.59	0.08	0.09	0.03	17	3.1	0.31	0.45	8.52	26.4	0.34	71.1	69.0	12.6	18.4	s.l.
	-8	6.1	0.39	19.1	0	0.36	0.18	0.06	-	0	-	-	0.43	0.46	29.3	0.14	12.5	69.0	15.4	15.6	s.l.
	-9	6.2	0.62	43.5	0	0.67	0.17	0.05	-	0	-	-	0.42	2.54	28.8	0.42	30.1	71.4	14.2	14.4	s.l.
	-10	4.8	0.20	6.6	1.56	0.55	0.98	0.13	-	48	-	-	0.19	0.06	10.9	0.20	6.7	59.9	6.3	33.0	s.c.l.
	-11	5.2	1.08	15.7	0.16	1.74	0.39	0.10	-	7	-	-	0.39	0.45	41.5	0.22	9.6	62.6	22.6	14.8	s.l.
	-12	5.4	0.34	10.1	0.10	0.47	0.15	0.07	-	13	-	-	0.30	0.26	29.2	0.19	24.6	62.6	22.6	14.8	s.l.
	-13	5.7	0.04	6.9	0	0.18	0.03	0.02	-	0	-	-	0.42	0.15	6.4	0.11	26.3	81.5	5.0	13.5	s.l.
	-14	6.6	0.48	6.0	0	0.62	0.17	0.03	0.03	0	3.5		0.34	0.43	22.5	0.40	8.4	73.4	11.3	15.3	s.l.
	-15	5.2	0.64	102.1	0.31	0.27	0.04	0.20		38			0.30	2.61	9.1	0.34	96.2	66.5	18.3	15.2	s.l.
	-16	5.1	0.50	103.4	0.36	0.24	0.04	0.19		43			0.39	3.30	8.6	0.31	90.5	66.5	18.3	15.2	s.l.
	-17	5.4	0.76	150.0	0.07	0.86	0.09	0.17		6			0.38	2.57	13.6	0.60	140.4	67.8	19.5	12.7	s.l.
	-18	5.3	0.65	150.0	0.16	0.81	0.09	0.21		13			0.47	2.93	13.5	0.46	119.2	67.7	18.3	14.0	s.l.

s.l. =sandy loam; s.c.l. = sandy clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006 (continued).

		Chemical characteristics																Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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)]
Kalasin	-19	5.4	0.32	99.2	0.26	0.30	0.04	0.16		34			0.36	2.51	22.3	0.32	76.5	65.3	19.5	15.2	s.l.
	-20	5.1	0.32	89.5	0.31	0.35	0.04	0.15		36			0.31	1.66	5.7	0.35	62.6	65.3	19.5	15.2	s.l.
	-21	5.2	0.81	157.7	0.10	1.08	0.11	0.22		7			0.48	4.45	17.9	0.50	108.6	69.2	18.2	12.6	s.l.
	-22	5.6	0.79	167.0	0	1.43	0.16	0.13	0.19	0	9.9		0.52	4.17	21.9	0.49	94.9	69.2	17.0	13.8	s.l.
	-23	5.5	0.32	110.5	0.16	0.63	0.13	0.19		14			0.40	2.80	16.8	0.39	88.3	69.2	17.0	13.8	s.l.
Khon Kaen	-1	5.9	0.91	5.6	0	0.69	0.18	0.04		0											
	-2	4.2	0.97	9.6	0.94	0.22	0.06	0.04		75											
	-3	4.1	0.86	59.2	1.04	0.17	0.05	0.03		81											
	-4	4.3	0.64	2.5	1.14	0.11	0.03	0.07		84											
	-5	4.8	0.91	53.8	0.73	0.25	0.04	0.06		68		0.27	0.81	0.39	3.8	0.20	6.3	70.3	9.5	20.2	s.c.l.
	-6	6.7	1.42	261.7	0	4.48	0.47	0.13		0											
	-7	5.0	1.18	55.2	0.42	0.69	0.19	0.07		31											
	-8	5.7	0.78	5.3	0	0.74	0.33	0.04		0											
	-9	5.8	0.30	2.1	0	0.71	0.19	0.03	0.01	0		-	0.40	0.39	17.8	0.35	5.0	72.6	13.8	13.6	s.l.
	-10	5.3	0.30	31.8	0.16	0.31	0.12	0.07	-	24		-	0.41	0.29	27.2	0.28	11.0	71.5	15.0	13.5	s.l.
	-11	5.6	0.32	54.4	0	0.84	0.07	0.04	0.02	0		-	-	-	-		-	-	-	-	-
	-12	5.2	0.40	3.4	0.21	0.17	0.12	0.03	-	40		-	-	-	-	-	-	-	-	-	-
	-13	5.1	0.47	45.7	0.42	0.32	0.19	0.08	-	42		-	-	-	-	-	-	-	-	-	-
	-14	5.2	0.66	91.5	0.13	1.04	0.18	0.08	-	9		-	0.53	6.92	43.9	1.73	12.8	67.7	18.8	13.5	s.l.
	-15	5.6	0.41	4.1	0	0.69	0.23	0.04	0.01	0		-	-	-	-	-	-	-	-	-	-
	-16	5.1	0.55	47.0	0.21	0.44	0.20	0.11	-	22		-	-	-	-	-	-	-	-	-	-
	-17	5.1	0.50	79.2	0.16	0.92	0.15	0.06	-	12		-	-	-	-	-	-	-	-	-	-
	-18	5.7	0.08	3.0	0	0.65	0.22	0.03	0.01	0		-	0.50	0.14	11.6	0.29	4.5	67.7	17.5	14.8	s.l.
	-19	5.0	0.17	32.5	0.44	0.48	0.18	0.08	-	37		-	-	-	-	-	-	-	-	-	-
	-20	5.9	0.28	15.9	0	1.97	0.31	0.07	0.01	0		-	-	-	-	-	-	-	-	-	-
	-21	5.3	0.15	3.2	0.36	0.16	0.11	0.04	-	54		-	-	-	-	-	-	-	-	-	-
	-22	4.9	0.24	28.1	0.54	0.26	0.13	0.06	-	55		-	-	-	-	-	-	-	-	-	-
	-23	5.3	0.43	67.4	0.10	1.12	0.22	0.06	-	7		-	0.50	5.68	26.7	1.65	10.2	67.7	16.3	16.1	s.l.
	-24	5.8	0.33	2.5	0	0.94	0.41	0.04	0.01	0		-	-	-	-	-	-	-	-	-	-

s.l. =sandy loam; s.c.l. = sandy clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics																Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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]
Khon Kaen	-25	5.4	0.10	22.7	0.10	0.44	0.18	0.08	-	13	-	-	-	-	-	-	-	-	-	-	-
	-26	5.4	0.11	34.5	0.10	0.84	0.14	0.05	-	9	-	-	-	-	-	-	-	-	-	-	-
	-27	5.1	0.31	5.1	0.63	0.62	0.16	0.03	-	44	-	-	0.59	0.42	18.9	0.27	5.5	62.6	17.6	19.8	s.l.
	-28	4.0	0.35	5.3	1.56	0.06	0.06	0.03	-	91	-	-	-	-	-	-	-	-	-	-	-
	-29	4.2	0.33	53.6	0.83	0.10	0.07	0.03	-	81	-	-	-	-	-	-	-	-	-	-	-
	-30	4.2	0.48	3.9	1.04	0.13	0.09	0.08	-	78	-	-	-	-	-	-	-	-	-	-	-
	-31	4.4	0.47	37.7	0.62	0.19	0.09	0.06	-	65	-	-	0.39	0.43	6.1	0.33	4.9	-	-	-	-
	-32	6.3	0.94	212.0	0	3.43	0.21	0.05	0.02	0	<0.1	-	0.65	30.88	29.4	6.00	21.9	-	-	-	-
	-33	5.2	0.56	53.0	0.44	0.34	0.13	0.05	-	46	-	-	0.45	0.57	10.7	0.34	5.7	-	-	-	-
	-34	5.6	0.31	11.3	0	0.84	0.24	0.03	0.01	0	<0.1	-	-	-	-	-	-	-	-	-	-
	-35	5.1	0.42	3.8	0.94	0.67	0.15	0.03	-	53	-	-	0.59	0.13	4.8	0.30	2.9	58.7	15.5	25.7	s.c.l.
	-36	3.9	0.34	3.3	1.87	0.05	0.06	0.03	-	93	-	-	-	-	-	-	-	-	-	-	-
	-37	4.2	0.40	27.7	1.66	0.11	0.08	0.03	-	88	-	-	-	-	-	-	-	-	-	-	-
	-38	3.9	0.46	2.1	1.98	0.10	0.07	0.05	-	90	-	-	-	-	-	-	-	-	-	-	-
	-39	4.1	0.36	19.5	1.14	0.14	0.07	0.04	-	82	-	-	0.39	0.18	2.1	0.27	4.9	-	-	-	-
	-40	5.8	0.51	51.7	0	2.37	0.20	0.06	0.01	0	<0.1	-	1.10	11.98	13.6	3.33	9.0	-	-	-	-
	-41	4.6	0.51	36.3	0.94	0.42	0.17	0.05	-	59	-	-	0.65	0.46	8.6	0.44	4.3	-	-	-	-
	-42	5.4	0.33	5.1	0.07	1.53	0.41	0.03	-	3	-	-	-	-	-	-	-	-	-	-	-
	-43	5.8	0.38	27.0	0	0.89	0.15	0.07	0.03	0	2.6		0.51	0.78	31.0	0.36	9.9	65.1	15.1	19.8	s.l.
	-44	5.9	0.35	18.3	0	0.96	0.13	0.05	0.02	0	1.7		0.48	0.50	22.4	0.41	13.8	68.9	17.5	13.6	s.l.
	-45	6.1	0.40	21.4	0	1.04	0.13	0.06	0.03	0	2.4		0.70	0.48	20.1	0.41	6.8	68.9	16.3	14.8	s.l.
	-46	6.0	0.38	19.0	0	1.13	0.12	0.04	0.03	0	2.2		0.79	0.74	26.0	0.65	12.5	68.9	16.3	14.8	s.l.
	-47	5.9	0.47	22.6	0	0.89	0.17	0.06	0.01	0	0.8		0.48	0.55	32.5	0.49	9.3	66.8	17.6	15.6	s.l.
	-48	5.9	0.36	28.6	0	0.95	0.20	0.07	0.02	0	0.8		0.50	0.62	23.7	0.60	6.8	66.9	18.8	14.3	s.l.
	-49	5.9	0.46	26.4	0	1.03	0.18	0.06	0.03	0	2.3		0.52	0.74	27.6	0.59	12.6	66.8	17.6	15.6	s.l.
	-50	6.0	0.45	26.8	0	1.01	0.16	0.06	0.01	0	0.8		0.42	0.68	28.9	0.52	10.5	68.1	16.3	15.6	s.l.

s.l. =sandy loam; s.c.l. = sandy clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics															Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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]
Khon Kaen	-51	5.7	0.44	23.6	0	1.01	0.21	0.08	0.02	0	1.5		0.52	0.63	33.0	0.73	6.2	68.0	15.7	16.3	s.l.
	-52	5.9	0.47	33.9	0	1.03	0.22	0.09	0.02	0	1.5		0.52	0.85	34.6	0.44	7.8	66.7	18.2	15.1	s.l.
	-53	6.1	0.38	14.8	0	1.11	0.16	0.05	0.01	0	0.8		0.47	0.58	30.5	0.58	5.6	65.5	18.8	15.7	s.l.
	-54	6.0	0.60	22.3	0	1.21	0.19	0.08	0.02	0	1.3		0.50	0.80	27.9	0.47	7.2	64.3	20.0	15.6	s.l.
	-55	6.1	0.42	17.9	0	1.08	0.16	0.05	0.02	0	1.5		0.56	0.62	28.2	0.39	8.1	68.1	17.5	14.4	s.l.
	-56	6.1	0.50	16.5	0	0.99	0.14	0.05	0.02	0	1.7		0.38	0.69	22.1	0.37	8.3	68.1	16.3	15.6	s.l.
	-57	6.1	0.49	17.5	0	1.33	0.17	0.05	0.01	0	0.7		0.51	0.64	21.9	0.40	9.0	68.0	16.3	15.7	s.l.
	-58	5.9	0.44	17.0	0	0.97	0.14	0.05	0.01	0	0.9		0.39	0.56	28.8	0.37	10.0	68.1	17.5	14.4	s.l.
	-59	5.5	0.59	18.0	0	0.85	0.14	0.07	0.01	-	0		0.50	0.80	15.2	0.41	8.9	71.0	14.4	14.6	s.l.
	-60	5.4	0.73	41.7	0	0.77	0.11	0.10	0.01	-	0										
	-61	5.3	0.62	35.5	0.21	0.77	0.10	0.11	0	18	0										
	-62	5.2	0.67	36.9	0.26	0.77	0.10	0.12	0	21	0										
	-63	4.9	0.60	38.0	0.44	0.55	0.07	0.11	0	38	0										
	-64	5.4	0.66	19.1	0.27	0.70	0.08	0.13	0	23	0										
	-65	5.1	0.68	28.3	0.27	0.63	0.08	0.12	0	25	0										
	-66	5.0	0.61	64.3	0.30	0.70	0.09	0.11	0	25	0										
	-67	5.0	0.71	40.2	0.69	0.71	0.10	0.05	0	44	0										
	-68	5.0	0.66	54.3	0.31	0.68	0.09	0.08	0	27	0										
	-69	5.0	0.63	39.2	0.23	0.75	0.10	0.17	0	18	0										
	-70	4.9	0.60	76.5	0.28	0.67	0.07	0.16	0	24	0	-	0.48	1.03	19.0	0.40	15.0	72.3	10.6	17.1	s.l.
N. Ratchasima	-1	7.0	1.02	4.6	0	4.52	0.97	0.23	0.03	4	<0.1		0.71	0.72	58.2	0.43	24.4	57.1	22.6	20.3	s.c.l.
	-2	5.6	1.18	13.6	0	8.10	1.23	0.41	0.04	0	<0.1		0.77	1.75	70.8	0.47	25.8	55.9	22.4	21.7	s.c.l.
	-3	5.9	1.13	9.9	0	6.16	1.11	0.27	0.05	0	<0.1		0.85	1.06	62.2	0.41	34.5	56.2	24.8	19.0	s.l.
	-4	6.2	1.05	6.0	0	3.31	0.70	0.29	0.02	0	<0.1		0.71	0.53	48.1	0.27	16.7	58.6	23.6	17.8	s.l.
	-5	6.2	0.99	7.7	0	5.41	0.80	0.27	0.09	0	<0.1		0.75	0.54	44.7	0.44	60.5	57.5	26.0	16.5	s.l.

s.l. =sandy loam; s.c.l. = sandy clay loam; c.l. = clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics															Physical characteristics			
			%	ppm		me/100 g				%	%	mmhos /cm	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)]
N. Ratchasima	-6	6.4	1.10	7.0	0	4.94	0.99	0.28	0.03	0	<0.1		0.76	0.69	55.6	0.34	18.7	58.7	23.5	17.8	s.l.
	-7	6.7	1.25	12.0	0	11.81	0.81	0.40	0.02	0	<0.1		0.81	0.87	68.6	0.33	11.1	53.6	28.6	17.8	s.l.
	-8	6.8	0.89	9.7	0	3.93	0.64	0.28	0.06	0	<0.1		0.77	1.04	29.4	0.25	31.0	56.2	28.6	15.2	s.l.
	-9	6.7	1.10	25.6	0	7.11	0.82	0.35	0.02	0	<0.1		0.80	1.00	56.6	0.31	9.3	54.9	27.3	17.8	s.l.
	-10	6.7	1.12	15.9	0	10.14	0.79	0.40	0.03	0	<0.1		0.84	1.33	57.5	0.35	18.1	53.4	28.7	17.9	s.l.
	-11	6.9	1.12	11.2	0	5.24	0.73	0.39	0.02	0	<0.1		1.03	0.71	39.8	0.30	19.6	58.7	26.0	15.3	s.l.
	-12	6.7	1.07	9.6	0	6.80	0.88	0.30	0.04	0	<0.1		1.15	0.71	52.8	0.31	12.6	58.6	26.1	15.3	s.l.
	-13	6.2	1.86	152.0	0	11.55	1.00	0.65	-	0	-		1.09	13.06	55.7	0.15	7.1	56.3	25.8	17.9	s.l.
	-14	6.2	1.14	8.7	0	5.25	0.62	0.36	-	0	-	1.14	0.72	0.63	42.8	0.15	3.6	51.4	30.7	17.8	s.l.
	-15	6.6	1.49	7.2	0	12.03	0.65	0.38	-	0	-		0.81	0.50	51.8	0.16	6.9	44.7	33.5	21.8	loam
	-16	6.7	1.41	7.0	0	7.75	0.63	0.45	-	0	-	1.22	0.77	0.72	59.0	0.18	4.4	46.5	30.5	23.0	loam
	-17	6.8	1.98	24.0	0	22.88	0.92	0.72	-	0	-		0.81	0.06	14.0	0.04	0.2	32.0	33.3	34.7	c.l.
	-18	6.8	1.76	31.6	0	18.34	0.80	0.64	-	0	-		1.13	1.15	46.4	0.14	1.7	41.3	33.1	25.6	loam
	-19	6.9	2.08	24.7	0	22.50	0.95	0.83	-	0	-		0.96	0.06	14.2	0.03	0.2	30.5	38.5	31.0	c.l.
	-20	6.9	2.01	20.7	0	17.93	0.98	0.72	-	0	-		0.82	0.73	47.8	0.04	0.9	37.0	29.5	33.5	c.l.
	-21	6.9	1.69	28.1	0	15.60	0.81	0.54	-	0	-		0.77	0.93	57.1	0.11	1.3	50.7	26.3	23.0	s.c.l.
	-22	6.6	1.16	5.8	0	4.80	0.85	0.23	0.04	0	0.7	0.39	0.66	0.73	34.0	0.38	17.8	58.7	17.6	23.7	s.c.l.
	-23	6.8	1.34	11.6	0	8.40	1.10	0.38	0.05	0	0.5	0.83	0.86	2.35	44.3	0.38	13.2	56.1	16.4	27.5	s.c.l.
	-24	7.1	1.34	8.7	0	6.27	1.10	0.26	0.04	0	0.5	0.85	0.78	1.12	43.4	0.34	24.9	61.8	15.1	23.1	s.c.l.
	-25	6.9	1.18	6.0	0	2.61	0.59	0.24	0.04	0	1.1	0.63	1.54	0.52	27.4	0.21	14.8	63.8	13.8	22.4	s.c.l.
	-26	7.0	1.02	9.8	0	4.85	0.78	0.27	0.05	0	0.8	1.04	0.71	0.55	29.7	0.31	50.6	62.7	13.8	23.6	s.c.l.
	-27	7.1	1.26	7.3	0	6.14	1.10	0.28	0.07	0	0.9	0.84	0.83	1.02	37.1	0.35	26.7	62.6	12.6	24.9	s.c.l.
	-28	7.3	1.45	9.8	0	13.72	0.92	0.34	0.05	0	0.3	0.76	0.84	0.77	51.7	0.28	8.8	55.9	16.5	27.6	s.c.l.
	-29	7.1	0.94	11.6	0	2.34	0.52	0.21	0.05	0	1.6	0.75	0.72	0.72	19.9	0.24	28.8	68.7	9.0	22.3	s.c.l.
	-30	7.2	1.24	9.7	0	7.03	0.90	0.28	0.02	0	0.2	0.80	0.74	0.86	40.3	0.32	6.9	53.8	12.7	33.5	s.c.l.

s.l. =sandy loam; s.c.l. = sandy clay loam; c.l. = clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics																Physical characteristics			
			%	ppm		me/100 g				%	%	mmhos /cm	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)]
N. Ratchasima	-31	7.3	1.26	11.8	0	11.44	0.97	0.33	0.03	0	0.2	0.84	0.78	0.86	52.5	0.28	10.8	53.8	16.5	29.9	s.c.l.
	-32	7.3	1.07	7.0	0	4.32	0.73	0.30	0.04	0	0.7	0.78	0.41	0.74	38.7	0.37	19.4	58.6	16.6	24.8	s.c.l.
	-33	7.4	0.97	10.8	0	10.30	1.15	0.32	0.04	0	0.3	0.88	0.74	0.87	42.7	0.32	22.1	53.8	16.5	29.7	s.c.l.
	-34	6.2	0.78	27.6	0	4.65	0.68	0.21	0.03	0	0.5										
	-35	6.2	0.91	18.6	0	4.71	0.74	0.20	0.03	0	0.5										
	-36	6.3	1.21	84.7	0	5.88	0.61	0.20	0.03	0	0.4										
	-37	6.3	0.94	21.1	0	5.16	0.74	0.35	0.05	0	0.8										
	-38	6.3	1.07	74.4	0	4.51	0.66	0.29	0.04	0	0.7	1.17	0.50	1.02	44.3	0.30	11.2	51.9	22.8	25.3	s.c.l.
	-39	6.6	1.78	292.4	0	8.90	1.08	0.43	0.05	0	0.5										
	-40	6.8	0.99	83.7	0	7.37	0.77	0.42	0.06	0	0.7										
	-41	7.0	0.83	38.9	0	4.80	0.75	0.26	0.03	0	0.5										
	-42	6.8	2.19	17.9	0	15.59	0.73	0.47	0.02	0	0.1	0.58	1.10	0.47	44.8	0.08	0.4	44.4	21.1	34.5	c.l.
	-43	7.3	1.81	25.0	0	14.36	0.49	0.42	0.02	0	0.1	0.66	1.15	0.48	58.1	0.07	0.1	52.5	17.6	29.9	s.c.l.
	-44	6.6	1.05	6.0	0	5.10	0.86	0.23	0.02	0	0.3		0.44	0.83	25.6	0.44	16.2	59.0	22.5	18.5	s.l.
	-45	7.1	1.38	14.4	0	9.55	1.17	0.38	0.02	0	0.2		0.76	1.37	45.9	0.48	13.9	57.5	18.8	23.7	s.c.l.
	-46	7.2	1.16	15.7	0	8.19	1.28	0.31	0.05	0	0.5		0.58	1.91	34.5	0.53	22.2	56.4	22.5	21.1	s.c.l.
	-47	7.2	1.12	15.7	0	3.75	0.69	0.23	0.02	0	0.4		0.49	0.69	31.1	0.35	18.6	58.3	23.9	17.8	s.l.
	-48	7.2	1.13	14.4	0	5.61	0.88	0.35	0.03	0	0.4		0.51	0.58	32.5	0.48	46.0	59.6	22.6	17.8	s.l.
	-49	7.1	1.24	13.4	0	4.74	0.98	0.31	0.03	0	0.5		0.56	0.80	35.4	0.44	20.4	59.6	18.9	21.6	s.c.l.
	-50	7.4	1.41	10.5	0	13.46	0.84	0.37	0.02	0	0.1		0.60	0.92	48.9	0.38	9.3	50.3	20.3	29.4	s.c.l.
	-51	7.4	0.89	10.8	0	5.02	0.68	0.27	0.03	0	0.5		0.64	0.81	18.8	0.41	47.5	59.5	22.7	17.8	s.l.
	-52	7.3	1.33	25.7	0	8.40	0.93	0.32	0.02	0	0.2		0.74	1.17	32.1	0.45	12.3	54.1	23.4	22.4	s.c.l.
	-53	7.4	1.19	13.0	0	13.58	0.96	0.34	0.02	0	0.1		0.59	1.06	39.1	0.46	10.2	52.9	23.4	23.7	s.c.l.
	-54	7.5	1.26	9.1	0	7.25	0.90	0.39	0.03	0	0.4		0.77	1.09	33.2	0.44	29.2	57.0	23.3	19.7	s.l.
	-55	7.5	1.18	16.1	0	12.79	1.22	0.42	0.03	0	0.2		0.75	0.98	44.2	0.45	13.2	51.8	20.8	27.4	s.c.l.

s.l. =sandy loam; c.l. = clay loam; s.c.l. = sandy clay loam; si. c.l. = silty clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics																Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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)]
N. Ratchasima	-56	6.6	0.78	14.2	0	11.88	0.54	0.29	0.03	0	0.2	0.31	0.70	0.87	43.0	0.51	9.0	50.3	32.2	17.5	loam
	-57	6.8	0.98	20.8	0	16.56	0.65	0.44	0.04	0	0.2	0.48	0.91	0.91	54.4	0.34	1.8	49.2	32.1	18.7	loam
	-58	5.9	0.69	11.8	0	1.58	0.27	0.21	0.03	0	1.4		0.57	0.84	34.6	0.45	9.2	68.3	16.3	14.4	s.l.
	-59	7.0	1.16	8.2	0	23.29	2.50	0.30	0.06	0	0.2		0.94	0.00	8.8	0.00	0.0	24.7	31.8	43.5	clay
	-60	6.7	0.44	118.1	0	0.76	0.14	0.10	0.01	0	1.0		0.23	2.72	17.0	0.39	25.8	77.8	8.1	14.1	s.l.
	-61	6.3	0.81	9.9	0	2.33	1.07	0.27	0.02	0	0.5		0.32	0.40	49.5	0.27	9.6	61.3	18.2	20.5	s.l.
	-62	7.3	1.21	34.7	0	25.08	0.61	0.56	0.13	0	0.5		0.52	0	0.6	0.02	0	16.2	51.8	32.0	si.c.l.
	-63	7.6	0.93	63.1	0	21.07	0.55	0.48	0.07	0	0.3		0.63	0.15	19.9	0.10	0.17	26.7	43.9	29.4	c.l.
	-64	7.7	1.38	89.1	0	20.40	0.58	0.52	0.05	0	0.2		0.40	0.31	22.4	0.08	0.25	25.7	45.0	29.3	c.l.
	-65	7.9	1.18	59.8	0	23.55	0.62	0.56	0.06	0	0.2		0.52	0.03	2.3	0.06	0.02	18.6	44.2	37.2	s.i.c.l.
	-66	6.32	0.48	2.66	0	4.46	0.64	0.12	0.06	0	1.1		0.27	0.65	20.0	0.41	12.3	64.6	12.6	22.8	s.c.l.
	-67	6.33	0.71	14.64	0	9.23	0.90	0.31	0.02	0	0.2										
	-68	6.50	0.60	18.35	0	5.48	0.81	0.18	0.02	0	0.3										
	-69	6.52	0.42	3.23	0	2.46	0.48	0.13	0.02	0	0.6										
	-70	6.86	0.34	5.60	0	2.47	0.49	0.19	0.02	0	0.6										
	-71	6.78	0.52	5.11	0	3.55	0.70	0.19	0.02	0	0.4										
	-72	6.79	0.62	9.01	0	9.60	0.60	0.21	0.01	0	0.1		0.34	0.85	30.4	0.32	6.1	54.3	19.0	26.7	s.c.l.
	-73	6.84	0.29	7.03	0	2.42	0.45	0.16	0.01	0	0.6										
	-74	6.81	0.71	43.51	0	7.11	0.82	0.22	0.04	0	0.5										
	-75	6.83	0.65	9.82	0	6.18	0.69	0.25	0.02	0	0.3										
	-76	6.74	0.54	3.89	0	4.11	0.56	0.25	0.02	0	0.4										
	-77	6.80	0.59	13.94	0	8.79	0.72	0.26	0.02	0	0.2										
Chaiyaphum	-1	5.8	0.89	130.8	0	1.12	0.41	0.29	0.30	0	14.1		0.81	3.29	8.5	0.16	67.0	52.1	34.0	14.0	loam
	-2	6.1	1.13	5.3	0	4.50	1.05	0.32	0.29	0	4.7		0.74	0.69	76.0	0.27	5.4	51.9	30.3	17.8	loam
	-3	6.0	1.32	4.6	0	3.71	1.25	0.26	0.04	0	0.8	0.41	0.48	0.63	76.0	0.24	5.1	48.7	22.6	28.7	s.c.l.

s.l. =sandy loam; c.l. = clay loam; s.c.l. = sandy clay loam; si. c.l. = silty clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics																Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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)]
Chaiyaphum	-4	6.2	1.16	3.7	0	4.81	1.28	0.18	0.04	0	0.6	0.51	0.68	0.56	42.0	0.12	5.5	56.1	20.2	23.7	s.c.l.
	-5	7.0	0.81	14.5	0	2.72	1.21	0.14	0.03	0	0.7		0.58	3.10	92.3	0.64	13.5	45.5	34.0	20.5	loam
Kamphengphet	-1	5.4	0.85	25.6	0.16	1.13	0.22	0.16		10			0.77	1.44	31.6	0.18	12.1	71.0	16.3	12.7	s.l.
Kanchanaburi	-1	6.4	0.88	8.1	0	3.34	0.37	0.26	0.30	0	2.4		0.92	2.02	120.1	0.63	4.6	60.00	26.9	13.1	s.l.
	-2	5.5	2.22	2.7	0	3.59	3.20	0.50	0.33	0	4.3	0.45	0.93	1.09	90.0	1.12	8.6	36.3	17.8	45.9	clay
	-3	5.7	0.77	4.0	0	0.63	0.16	0.08	0.25	0	22.3	0.39	0.77	0.25	5.7	0.11	6.5	77.3	11.3	11.4	s.l.
	-4	6.6	1.43	4.1	0	11.38	3.29	0.51	0.09	0	0.6		0.38	0.89	57.9	1.22	7.3	30.1	21.7	48.2	clay
	-5	6.8	1.56	6.2	0	6.37	0.99	0.49	0.03	0	0.4		0.54	2.73	138.4	2.49	7.7	22.2	49.5	28.3	c.l.
	-6	6.9	0.69	12.5	0	2.11	0.41	0.26	0.02	0	0.7		0.45	1.15	74.2	0.88	5.9	60.8	23.8	15.4	s.l.
	-7	6.8	0.80	14.9	0	2.75	0.41	0.23	0.03	0	0.9		0.58	1.45	83.6	1.14	5.8	54.4	30.2	15.4	s.l.
	-8	6.8	0.83	11.5	0	2.17	0.47	0.25	0.02	0	0.7		0.54	1.42	88.0	0.76	6.3	56.8	26.5	16.7	s.l.
	-9	6.8	1.05	9.0	0	3.06	0.52	0.27	0.05	0	1.3		0.58	1.65	82.5	0.93	6.8	54.3	30.2	15.5	s.l.
	-10	7.3	1.20	48.3	0	16.82	1.57	0.55	0.03	0	0.2		0.86	0.00	39.1	0.03	0.0	55.3	31.7	13.0	s.l.
	-11	7.3	0.90	14.8	0	4.87	0.49	0.13	0.04	0	0.7		0.59	0.70	50.1	0.30	1.6	64.4	22.7	12.9	s.l.
	-12	5.9	3.04	3.2	0	3.89	2.13	0.45	0.05	0	0.8		0.41	3.76	148.4	0.65	10.9	17.9	30.0	52.1	clay
	-13	5.1	5.48	25.5	1.49	2.31	1.36	0.10	-	0			0.43	2.40	220.4	0.46	3.9	10.9	25.9	63.2	clay
Ratchaburi	-1	5.6	0.57	2.5	0	0.71	0.26	0.12	0.03	0	2.6		0.29	0.57	13.0	0.37	7.7	73.3	13.1	13.6	s.l.
	-2	6.0	1.46	13.2	0	5.84	0.79	0.36	0.03	0	0.4		0.84	1.51	67.9	0.31	3.2	53.0	30.9	16.2	s.l.
Chachoengsao	-1	5.2	1.46	16.3	0.21	1.48	0.32	0.05		10			0.74	2.15	34.1	1.16	14.9	68.0	19.3	12.7	s.l.
	-2	5.6	0.66	13.8	0	0.86	0.21	0.08	0.27	0	19.0	0.42									
	-3	5.6	1.15	42.1	0	1.17	0.30	0.11	0.31	0	16.4	0.59									
	-4	5.0	1.28	6.5	0.08	1.36	0.27	0.19	-	4	-	-	0.65	0.75	45.5	0.19	17.8	67.7	11.3	21.0	s.c.l.
	-5	6.1	3.04	5.8	0	3.84	0.92	0.20	0.03	0	0.6		1.00	1.19	58.2	0.20	4.3	52.2	21.7	28.1	s.c.l.
	-6	6.7	1.48	2.9	0	6.86	1.12	0.12	0.04	0	0.5		0.79	1.47	103.1	0.87	11.0	53.5	17.7	28.8	s.c.l.
	-7	5.7	2.40	2.4	0	3.49	1.10	0.42	0.31	0	5.8		1.01	0.85	47.8	0.59	20.1	39.1	39.2	21.7	loam

s.l. =sandy loam; c.l. = clay loam; s.c.l. = sandy clay loam; si. c.l. = silty clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics																Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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]
Prachinburi	-1	5.4	1.05	6.7	0.99	0.35	0.09	0.04	-	67			0.32	0.56	3.0	0.25	38.9	63.9	8.1	28.0	s.c.l.
	-2	4.6	1.14	7.1	1.35	0.21	0.04	0.04	-	82			0.22	0.37	1.5	0.20	46.5	61.5	9.3	29.2	s.c.l.
Sra Kaew	-1	6.6	3.08	1.6	0	36.4	10.5	0.27	0.09	0	1.8		0.52	0.12	15.6	0.07	0.0	11.9	24.7	63.4	clay
Rayong	-1	4.7	1.10	50.4	0.78	0.80	0.19	0.09		42			0.96	1.78	10.7	0.47	20.2	57.2	7.8	35.2	s.c.
	-2	5.3	0.59	15.4	0.16	0.25	0.08	0.10		27			0.18	0.79	37.0	0.13	6.7	71.5	12.5	16.0	s.l.
	-3	5.2	0.62	19.9	0.10	0.35	0.08	0.10		16											
	-4	5.2	0.72	9.2	0.10	0.39	0.09	0.09		15											
	-5	6.4	0.72	10.7	0	2.01	0.29	0.10		0											
	-6	5.2	1.69	15.9	0.43	1.02	0.22	0.03													
	-7	4.4	0.91	15.5	1.04	0.63	0.13	0.03													
	-8	4.5	0.88	96.9	0.65	1.05	0.23	0.05													
	-9	4.4	0.99	20.9	0.94	0.73	0.12	0.07													
	-10	4.5	0.97	80.7	0.76	1.01	0.24	0.09		36		0.46	1.06	3.67	11.4	0.96	19.9	62.0	15.8	22.2	s.c.l.
	-11	6.8	1.69	347.3	0	4.71	0.52	0.24	0.03		0.5										
	-12	5.0	1.42	86.7	0.52	0.94	0.21	0.08													
	-13	5.0	1.16	20.2	0.52	0.84	0.27	0.05													
	-14	5.1	1.06	48.7	0.11	1.29	0.31	0.10					0.80	3.24	16.1	0.58	23.6	62.6	5.8	31.6	s.c.l.
	-15	5.1	0.97	77.8	0.11	1.30	0.25	0.11													
	-16	5.0	0.84	54.1	0.27	1.27	0.26	0.10													
	-17	5.2	0.75	112.3	0.22	1.29	0.22	0.09													
	-18	5.2	1.14	82.4	0.33	1.32	0.32	0.12													
	-19	5.4	1.57	50.2	0.11	1.56	0.33	0.13													

s.l. =sandy loam; c.l. = clay loam; s.c.l. = sandy clay loam; si. c.l. = silty clay loam

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics																Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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)]
Rayong	-20	5.1	1.13	102.3	0.11	1.30	0.27	0.09													
	-21	5.0	1.24	55.4	0.16	1.25	0.27	0.11													
	-22	5.2	1.14	71.9	0.11	1.28	0.29	0.13					0.89	7.22	21.4	1.56	61.0	65.2	5.8	29.0	s.c.l.
	-23	5.3	1.36	71.9	0.08	1.11	0.23	0.17													
	-24	5.3	1.30	73.2	0.08	1.57	0.37	0.13													
	-25	5.2	1.37	87.4	0.11	1.26	0.25	0.11													
	-26	5.1	1.16	50.2	0.22	1.08	0.26	0.09					0.79	3.65	16.1	0.85	26.2	64.0	4.5	31.5	s.c.l.
	-27	5.3	1.39	103.8	0.11	1.49	0.31	0.11													
	-28	5.3	1.29	56.0	0.13	1.20	0.24	0.12													
	-29	5.3	1.30	73.2	0.05	1.51	0.30	0.10													
	-30	5.2	0.76	8.3	0.13	1.26	0.28	0.03	-		-	-	0.61	3.41	13.8	1.36	21.9	58.8	26.8	14.4	s.l.
	-31	3.6	1.00	18.4	1.35	0.27	0.12	0.04	-		-	-	-	-	-	-	-	-	-	-	-
	-32	3.8	1.06	109.0	1.04	0.51	0.14	0.04	-		-	-	-	-	-	-	-	-	-	-	-
	-33	4.3	1.12	28.6	0.52	0.94	0.17	0.07	-		-	-	-	-	-	-	-	-	-	-	-
	-34	4.5	1.07	79.8	0.62	1.21	0.30	0.10	-		-	-	0.82	2.99	17.3	1.34	25.9	-	-	-	-
	-35	6.3	1.67	214.1	0	4.99	0.39	0.16	0.02		-	-	0.84	21.22	45.2	2.09	20.6	-	-	-	-
	-36	5.1	1.41	82.9	0.21	1.62	0.37	0.14	-		-	-	0.97	5.29	31.2	1.57	29.8	-	-	-	-
	-37	5.1	0.99	18.7	0.21	1.08	0.37	0.05	-		-	-	-	-	-	-	-	-	-	-	-
	-38	5.4	0.87	11.6	0.10	1.26	0.30	0.03	-		-	-	0.66	3.09	13.7	1.44	39.6	60.0	24.3	15.7	s.l.
	-39	3.5	0.90	12.3	1.46	0.21	0.08	0.03	-		-	-	-	-	-	-	-	-	-	-	-
	-40	3.8	0.94	39.0	1.35	0.35	0.10	0.03	-		-	-	-	-	-	-	-	-	-	-	-
	-41	4.3	0.84	11.7	0.66	0.91	0.16	0.07	-		-	-	-	-	-	-	-	-	-	-	-
	-42	4.1	0.74	28.4	1.04	0.79	0.25	0.06	-		-	-	0.86	0.72	5.6	0.66	24.7	-	-	-	-
	-43	5.7	0.77	77.8	0	3.89	0.34	0.18	0.02		-	-	1.39	8.56	26.9	1.44	27.9	-	-	-	-
	-44	4.7	0.82	36.1	0.44	1.51	0.37	0.08	-		-	-	0.93	1.79	16.1	0.84	29.6	-	-	-	-

s.c.l. = sandy clay loam; c.l. = clay loam; s.l. = sandy loam; s.c. = sandy clay

Table 15. Chemical and physical characteristics of cassava soils in Thailand, 2001-2006. (continued)

		Chemical characteristics																Physical characteristics			
			%	ppm	me/100 g					%	%	mmhos /cm	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)]
Rayong	-45	5.0	0.74	6.7	0.36	0.96	0.32	0.03	-		-	-	-	-	-	-	-	-	-	-	-
	-46	5.6	1.25	72.5	0	1.49	0.25	0.06	0.02	0	0	-	0.62	6.19	19.1	1.41	52.7	64.7	13.1	22.2	s.c.l.
	-47	5.8	1.18	127.5	0	1.56	0.22	0.13	0.02	0	0	-									
	-48	5.7	1.25	121.5	0	1.49	0.24	0.12	0.02	0	0	-									
	-49	5.6	1.06	125.8	0	1.13	0.15	0.10	0.01	0	0	-									
	-50	5.2	1.14	102.7	0.69	1.02	0.16	0.12	0	35	0	-									
	-51	5.6	1.19	81.5	0	1.45	0.19	0.10	0.02	0	0	-									
	-52	5.5	1.24	108.8	0	1.42	0.20	0.12	0.01	0	0	-									
	-53	5.3	1.21	166.3	0.26	1.21	0.18	0.13	0	15	0	-									
	-54	5.6	1.30	148.3	0	1.39	0.19	0.06	0.03	0	0	-									
	-55	5.6	1.21	94.3	0	1.41	0.20	0.08	0.02	0	0	-									
	-56	5.4	1.23	124.9	0	1.19	0.17	0.19	0.01	0	0	-									
	-57	5.1	1.18	122.4	0.31	1.04	0.14	0.14	0	19	0	-	0.64	5.69	22.6	1.51	66.6	64.7	8.1	27.1	s.c.l.

s.c.l. = sandy clay loam; c.l. = clay loam; s.l. = sandy loam; s.c. = sandy clay

Table 16. Soil samples taken in Vietnam from 2001 to 2005.

Sample no.		Sample location and description	Date
Thai Nguyen	-1	Thai Nguyen Univ; FYM trial, before 2d year, T_1	Mar 02
	-2	Thai Nguyen Univ; FYM trial, before 2d year, T_2	Mar 02
	-3	Thai Nguyen Univ; FYM trial, before 2d year, T_3	Mar 02
	-4	Thai Nguyen Univ; FYM trial, before 2d year, T_4	Mar 02
	-5	Thai Nguyen Univ; FYM trial, before 2d year, T_5	Mar 02
	-6	Thai Nguyen Univ; FYM trial, before 2d year, T_6	Mar 02
	-7	Thai Nguyen Univ; FYM trial, before 2d year, T_7	Mar 02
	-8	Thai Nguyen Univ; FYM trial, before 2d year, T_8	Mar 02
	-9	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_1	Mar 02
	-10	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_2	Mar 02
	-11	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_3	Mar 02
	-12	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_4	Mar 02
	-13	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_5	Mar 02
	-14	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_6	Mar 02
	-15	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_7	Mar 02
	-16	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_8	Mar 02
	-17	Thai Nguyen Univ; long-term NPK trial, before 13 th year ,T_9	Mar 02
	-18	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_{10}	Mar 02
	-19	Thai Nguyen Univ;.long-term NPK trial, before 13 th year, T_{11}	Mar 02
	-20	Thai Nguyen Univ; long-term NPK trial, before 13 th year, T_{12}	Mar 02
	-21	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_1	Mar 05
	-22	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_2	Mar 05
	-23	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_3	Mar 05
	-24	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_4	Mar 05
	-25	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_5	Mar 05
	-26	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_6	Mar 05
	-27	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_7	Mar 05
	-28	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_8	Mar 05
	-29	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_9	Mar 05
	-30	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_{10}	Mar 05
	-31	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_{11}	Mar 05
	-32	Thai Nguyen Univ.; long-term NPK trial, beore 16 th year, T_{12}	Mar 05
Tuyen Quang	-1	Son Duong district, Hong Tien; FPR fertilizer trial, check plot	Apr 01
	-2	Son Duong district, Hong Tien; FPR variety trial Mr. Khuong Minh Tran	Apr 01
	-3	Son Duong district, Hong Tien; FPR fertilizer trial, check plot	Oct 01
	-4	Son Duong district, Thuong Am, Hong Tien; FPR erosion trial Mr. Trieu, dark clay loam	Jun 03
	-5	Son Duong district, Thuong Am, Hong Tien; FPR erosion trial Mr. Nhien, black-grey si.l.	Jun 03
Yen Bai	-1	Van Yen district, Dau A; field outside city, near river, yellow loam	Feb 02
	-2	Van Yen district, Dau A; on hillside outside city for cassava + cinnamon	Feb 02
	-3	Van Yen district, Mau Dang; near starch factory, cassava+vetiver hedgerows	Feb 02
	-4	Van Yen district, Caukhai village; red clay soil, cassava Mg deficient	Aug 02
	-5	Van Yen district, An Binh, Cau Mang; dark-brown clay loam on steep slope, C+peanut	Jun 03
	-6	Van Yen district, An Binh, Cau Mang; dark-red clay loam, cassava field	Oct 03
Phu Tho	-1	Phu Ninh district, Bao Thanh; FPR fert. trial Mr. Le Van Sinh, T_5	Apr 01
	-2	Phu Ninh district, Bao Thanh; FPR fert. trial Mr. Hoang Minh Chien, check plot	Apr 01
	-3	Phu Ninh district, Bao Thanh; FPR erosion trial	Oct 01
	-4	Thanh Ba district, Kieu Tung village; Fo in NPK trial Mr. Luu Huy Cam	Aug 02
	-5	Thanh Ba district, Kieu Tung village; opposite hill FPR erosion trial, poor cassava	Aug 02

Table 16. Soil samples taken in Vietnam from 2001 to 2005 (continued)

Sample no.		Sample location and description	Date
Hoa Binh	-1	Suong Son district, Dong Rang; MSEC site, 65% slope with vetiver	Aug 01
	-2	Lac Son district; Suat Hoa commune; 10 ha demonstration plot, C+peanut	Jun 03
Thanh Hoa	-1	Nhu Xuan district, Yen Cat commune; FPR erosion trial on 30% slope, yellow clay soil	Jun 03
	-2	Nhu Xuan district, Bai Tranh commune; demonstration plot, KM 98-1, brown clay loam	Jun 03
	-3	Nhu Xuan district, Bai Tranh commune; hillside opposite 2d demon. plot, poor cassava	Jun 03
Hue	-1	A-Luoi district, Hong Ha, Kon Tom village; Mrs. Kan Xiong-yellow clay loam	Mar 01
	-2	A-Luoi district, Hong Ha, Kon Tom village; Mrs. Tran Minh Xuong (extensionist)	Mar 01
	-3	A-Luoi district, Huong Phong; 5 ha multipliation field, sandy loam, some P/K deficiency	Jun 03
	-4	A-Luoi disrtict, Hong Ha, Mr Dang Van Plun field with hedgerows; yellow clay loam	Jun 03
	-5	A-Luoi district, Hong Ha, Paring village; large cassava field along river	Jun 05
	-6	Nam Dong district, Thuong Long; Mr. Taruong Lu erosion trial	Mar 01
	-7	Nam Dong district, Thuong Long; Mr. Taruong Lu erosion trial, Mg def	Jun 05
	-8	Nam Dong district, Thuong Long; Mr Ho Thi En erosion trial on 27% slope	Mar 01
	-9	Nam Dong dictrict, Thuong Long; Mr Voi's field on steep slope, P def.	Feb 02
	-10	Huong Tra district, Huong Van com., Lai Bang village; variety trial, sandy loam	Feb 02
	-11	Huong Tra district, Huong Van com., Lai Bang village; KM 94 multiplication, C+P	Feb 02
	-12	Huong Tra district, Huong Van commune; white sandy soil, KM140-2 with red mite	Aug 02
	-13	Huong Tra district, Quang Than commune; pure white sand, cassava on high ridges	Aug 02
	-14	Huong Tra district; Huong Van commune; field behind commune office, yellow sandy loam	Jun 03
	-15	Huong Tra district; Tu Ha town; across road from cement factory, Mn deficiency symptoms	Jun 03
Baria-Vungtau	-1	Chau Duc district, Son Binh; FPR erosion trial, sandy soil with laterite	Aug 01
	-2	Chau Duc district, Suoi Rao; FPR erosion trial, sandy clay	Aug 01
	-3	Chau Duc district, Son Binh; FPR fert. trial check plot, dark brown clay	Feb 02
	-4	Chau Duc district, Son Binh commune; grey sandy loam, KM 98-5 multiplication	Aug 02
	-5	Chau Duc district, Suoi Rao; Mrs. Vo Thi Ly, C+peanut, red soil with plinthite	Jun 03
	-6	Chau Duc district, Suoi Rao; Mr. Pham Tien Huygh erosion trial; sediment in C+maize plot	Jun 03
	-7	Chau Duc district, Son Binh; check in fert. trial, sandy loam; Mg defic. or herbicide damage	Jun 03
Dong Nai	-1	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_1	May 01
	-2	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_2	May 01
	-3	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_3	May 01
	-4	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_4	May 01
	-5	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_5	May 01
	-6	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_6	May 01
	-7	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_7	May 01
	-8	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_8	May 01
	-9	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_9	May 01
	-10	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_{10}	May 01
	-11	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_{11}	May 01
	-12	Thong Nhat district, Hung Loc Center; NPK trial, 12th year, T_{12}	May 01
	-13	Thong Nhat district, Hung Loc Center; soil improvement trial, 10th year, T_1	May 01
	-14	Thong Nhat district, Hung Loc Center; soil improvement trial, 10th year, T_2	May 01
	-15	Thong Nhat district, Hung Loc Center; soil improvement trial, 10th year, T_3	May 01
	-16	Thong Nhat district, Hung Loc Center; soil improvement trial, 10th year, T_4	May 01
	-17	Thong Nhat district, Hung Loc Center; soil improvement trial, 10th year, T_5	May 01
	-18	Thong Nhat district, Hung Loc Center; soil improvement trial, 10th year, T_6	May 01
	-19	Thong Nhat district, Hun gLoc Center; soil improvement trial, 10th year, T_7	May 01
	-20	Thong Nhat district, Hung Loc Center; soil improvement trial, 10th year, T_8	May 01

Table 16. Soil samples taken in Vietnam from 2001 to 2005. (continued)

Sample no.		Sample location and description	Date
Dong Nai	-21	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_1	Mar 02
	-22	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_2	Mar 02
	-23	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_3	Mar 02
	-24	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_4	Mar 02
	-25	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_5	Mar 02
	-26	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_6	Mar 02
	-27	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_7	Mar 02
	-28	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_8	Mar 02
	-29	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_9	Mar 02
	-30	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_{10}	Mar 02
	-31	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_{11}	Mar 02
	-32	Thong Nhat district, Hung Loc Center; long-term NPK trial, 13th year, T_{12}	Mar 02
	-33	Thong Nhat, Hung Loc Center; soil improvement trial, 11th year, C monoculture	Mar 02
	-34	Thong Nhat, Hung Loc Center; soil improvement trial, 11th year, C+pigeon pea	Mar 02
	-35	Thong Nhat, Hung Loc Center; soil improvement trial, 11th year, C+mucuna	Mar 02
	-36	Thong Nhat, Hung Loc Center; soil improvement trial, 11th year, C+peanut	Mar 02
	-37	Thong Nhat, Hung Loc Center; soil improvement trial, 11th year, C+cowpea	Mar 02
	-38	Thong Nhat, Hung Loc Center; soil improvement trial, 11th year, C+*Canavalia*	Mar 02
	-39	Thong Nhat, Hung Loc Center; soil improvement trial, 11th year, *Leucaena*	Mar 02
	-40	Thong Nhat, Hung Loc Center; soil improvement trial, 11th year, *Gliricidia*	Mar 02
	-41	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, no fertilizer T_1	Mar 03
	-42	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, no fertilizer T_2	Mar 03
	-43	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, no fertilizer T_3	Mar 03
	-44	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, no fertilizer T_4	Mar 03
	-45	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, no fertilizer T_5	Mar 03
	-46	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, no fertilizer T_6	Mar 03
	-47	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, no fertilizer T_7	Mar 03
	-48	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, no fertilizer T_8	Mar 03
	-49	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, with fertilizer T_1	Mar 03
	-50	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, with fertilizer T_2	Mar 03
	-51	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, with fertilizer T_3	Mar 03
	-52	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, with fertilizer T_4	Mar 03
	-53	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, with fertilizer T_5	Mar 03
	-54	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, with fertilizer T_6	Mar 03
	-55	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, with fertilizer T_7	Mar 03
	-56	Thong Nhat, Hung Loc Center; soil improvement trial, 12th year, with fertilizer T_8	Mar 03
	-57	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_1	Mar 03
	-58	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_2	Mar 03
	-59	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_3	Mar 03
	-60	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_4	Mar 03
	-61	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_5	Mar 03
	-62	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_6	Mar 03
	-63	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_7	Mar 03
	-64	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_8	Mar 03
	-65	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_9	Mar 03
	-66	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_{10}	Mar 03
	-67	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_{11}	Mar 03
	-68	Thong Nhat district, Hung Loc Center; long-term NPK trial, 14th year, T_{12}	Mar 03

Table 16. Soil samples taken in Vietnam from 2001 to 2005 (continued)

Sample no.		Sample location and description	Date
Dong Nai	-69	Thong Nhat district, Hung Loc Center; soil erosion trial T_1	Mar 03
	-70	Thong Nhat district, Hung Loc Center; soil erosion trial T_2	Mar 03
	-71	Thong Nhat district, Hung Loc Center; soil erosion trial T_3	Mar 03
	-72	Thong Nhat district, Hung Loc Center; soil erosion trial T_4	Mar 03
	-73	Thong Nhat district, Hung Loc Center; soil erosion trial T_5	Mar 03
	-74	Thong Nhat district, Hung Loc Center; soil erosion trial T_6	Mar 03
	-75	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_1	May 04
	-76	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_2	May 04
	-77	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_3	May 04
	-78	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_4	May 04
	-79	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_5	May 04
	-80	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_6	May 04
	-81	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_7	May 04
	-82	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_8	May 04
	-83	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_9	May 04
	-84	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_{10}	May 04
	-85	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_{11}	May 04
	-86	Thong Nhat district, Hung Loc Center; long-term NPK trial, –15th year, T_{12}	May 04
	-87	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_1	May 05
	-88	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_2	May 05
	-89	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_3	May 05
	-90	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_4	May 05
	-91	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_5	May 05
	-92	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_6	May 05
	-93	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_7	May 05
	-94	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_8	May 05
	-95	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_9	May 05
	-96	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_{10}	May 05
	-97	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_{11}	May 05
	-98	Thong Nhat district, Hung Loc Center; long-term NPK trial, –16th year, T_{12}	May 05
	-99	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, with fertilizer T_1	May 05
	-100	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, with fertilizer T_2	May 05
	-101	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, with fertilizer T_3	May 05
	-102	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, with fertilizer T_4	May 05
	-103	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, with fertilizer T_5	May 05
	-104	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, with fertilizer T_6	May 05
	-105	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, with fertilizer T_7	May 05
	-106	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, with fertilizer T_8	May 05
	-107	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, no fertilizer T_1	May 05
	-108	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, no fertilizer T_2	May 05
	-109	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, no fertilizer T_3	May 05
	-110	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, no fertilizer T_4	May 05
	-111	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, no fertilizer T_5	May 05
	-112	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, no fertilizer T_6	May 05
	-113	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, no fertilizer T_7	May 05
	-114	Thong Nhat district, Hung Loc Center; soil improvement trial, –14th year, no fertilizer T_8	May 05

Table 16. Soil samples taken in Vietnam from 2001 to 2005 (continued)

Sample no.		Sample location and description	Date
	-115	Thong Nhat district, Hung Loc Center; soil erosion trial T_1	May 05
	-116	Thong Nhat district, Hung Loc Center; soil erosion trial T_2	May 05
	-117	Thong Nhat district, Hung Loc Center; soil erosion trial T_3	May 05
	-118	Thong Nhat district, Hung Loc Center; soil erosion trial T_4	May 05
	-119	Thong Nhat district, Hung Loc Center; soil erosion trial T_5	May 05
	-120	Thong Nhat district, Hung Loc Center; soil erosion trial T_6	May 05
Binh Phuoc	-1	Dong Xoai district, Dong Tam; clay soil below erosion trial	Aug 01
	-2	Dong Xoai district, Dong Tam; erosion trial with *Paspalum*, Mr. Le Rong Thanh	Aug 01
	-3	Dong Xoai district, Dong Tam, FPR variety trial, yellow clay loam	Dec 01
	-4	Dong Xoai district, Minh Lap; variety trial Mr. Le Xuan Huyen, black brown clay	Aug 01
	-5	Dong Xoai district, Minh Lap village; dark-grey clay loam, C+young rubber	Aug 02
	-6	Dong Xoai district, Dong Tam village; stony reddish grey soil, C+vetiver hedgerows	Aug 02
	-7	Chan Thanh district, Minh Lap; near FPR plastic trial, yellow-brown soil with phinthite	Jun 03

Table 17. Chemical and physical characteristics of cassava soils in Vietnam, 2001-2005.

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Thai Nguyen	-1	4.8	1.75	11.1	0.52	2.52	0.08	0.03	16									
	-2	5.3	2.07	11.5	0.21	3.43	0.08	0.04	6									
	-3	5.4	1.78	9.9	0.31	2.76	0.09	0.04	10									
	-4	5.4	2.72	11.7	0.31	3.46	0.12	0.05	8									
	-5	5.4	2.26	9.6	0.52	2.95	0.10	0.05	14									
	-6	5.4	2.02	10.2	0.42	2.80	0.08	0.05	12									
	-7	5.3	2.07	12.6	0.73	2.36	0.10	0.06	22									
	-8	5.0	1.94	12.0	0.62	2.46	0.09	0.05	19	0.31	0.84	3.0	0.30	80.8	61.7	20.2	18.7	s.l.
	-9	4.7	2.32	21.7	2.29	0.52	0.21	0.09	74									
	-10	4.6	2.34	11.3	2.81	0.42	0.08	0.05	84									
	-11	4.5	2.04	17.2	2.08	0.40	0.09	0.06	79									
	-12	4.4	1.96	22.1	2.31	0.46	0.14	0.05	78									
	-13	4.7	2.58	116.1	1.58	1.13	0.65	0.08	46									
	-14	4.7	1.99	10.4	1.87	0.58	0.15	0.05	70									
	-15	4.9	2.21	57.8	1.63	1.15	0.34	0.06	51									
	-16	4.6	2.37	9.4	2.60	0.39	0.08	0.07	82									
	-17	4.6	2.80	34.2	2.18	0.66	0.23	0.07	69									
	-18	4.3	2.83	6.0	2.50	0.30	0.07	0.08	85									
	-19	4.6	2.75	37.5	2.08	0.55	0.23	0.10	70									
	-20	4.6	2.64	25.9	2.39	0.49	0.13	0.06	78	0.62	0.93	2.4	0.25	87.8	58.7	18.9	22.4	s.c.l.
	-21	4.29	1.50	4.25	3.10	0.19	0.03	0.06	92	0.19	0.84	1.4	0.33	69.4	55.8	19.0	25.2	s.c.l.
	-22	4.58	1.28	7.16	2.19	0.42	0.10	0.03	80									
	-23	4.65	1.25	5.14	2.86	0.33	0.05	0.02	88									
	-24	4.96	1.18	15.05	1.46	0.86	0.15	0.03	58									
	-25	4.96	1.22	34.81	1.46	0.85	0.28	0.03	56									
	-26	4.71	1.23	20.93	2.55	0.61	0.23	0.04	74									
	-27	4.68	1.23	15.84	2.03	0.48	0.17	0.04	75									

Table 17. Chemical and physical characteristics of cassava soils in Vietnam, 2001-2005.

Sample no.		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Thai Nguyen	-28	4.51	1.47	8.79	2.71	0.37	0.07	0.04	85									
	-29	4.87	1.27	17.62	1.66	0.67	0.22	0.04	64									
	-30	4.51	1.17	7.25	2.89	0.31	0.08	0.04	87									
	-31	4.66	1.18	23.92	2.39	0.58	0.13	0.02	77									
	-32	4.67	1.16	10.71	2.67	0.47	0.13	0.03	81	0.24	0.96	2.5	0.22	68.5	55.7	29.1	15.2	s.l.
Tuyen Quang	-1	4.9	2.16	3.6	0.52	1.91	0.78	0.13	15	0.85	1.22	186.8	0.48	21.9	45.6	25.0	29.4	s.c.l.
	-2	5.3	4.00	1.7	0.21	14.29	3.84	0.21	1	0.62	1.90	169.0	0.47	8.6	38.9	28.3	32.8	c.l.
	-3	5.6	2.24	1.8	0	2.18	0.61	0.12	0	0.63	1.26	79.6	0.46	39.5	44.0	23.2	32.8	c.l.
	-4	5.7	4.01	1.9	0	16.77	4.11	0.21	0	0.45	2.24	101.0	0.47	5.2	29.1	32.4	38.5	c.l.
	-5	6.0	2.75	3.8	0	5.72	1.21	0.19	0	0.52	3.53	153.3	0.94	14.3	37.0	29.2	33.8	c.l.
Yen Bai	-1	4.8	1.59	17.4	0.75	2.03	0.34	0.11	23	0.40	2.89	91.3	1.31	40.0	23.4	47.9	28.7	c.l.
	-2	4.2	3.42	4.4	1.87	0.80	0.20	0.17	61	0.50	0.91	41.8	2.16	14.4	19.7	16.6	63.7	clay
	-3	4.0	3.66	11.3	3.97	0.60	0.20	0.14	81	0.44	1.08	15.5	0.97	40.1	46.6	1.2	52.2	s.l.
	-4	4.1	3.75	9.8	4.37	0.38	0.10	0.10	88	0.46	0.96	12.5	1.06	45.2	24.0	21.1	54.9	clay
	-5	4.9	2.63	5.2	1.62	0.40	0.15	0.35	64	0.29	1.55	59.3	1.05	38.9	32.1	30.4	37.6	c.l.
	-6	4.9	2.99	5.7	2.13	0.53	0.19	0.27	68	0.89	2.99	46.3	1.20	49.3	30.8	32.2	37.0	c.l.
Phu Tho	-1	4.9	1.59	98.8	0.83	1.97	0.21	1.04	20	1.21	0.81	8.9	0.40	17.4	52.1	22.4	25.5	s.c.l.
	-2	4.4	1.95	56.9	1.35	0.98	0.14	0.37	47	1.06	1.28	7.4	0.52	15.0	42.1	8.5	49.4	clay
	-3	5.4	1.70	5.2	2.29	0.30	0.08	0.04	85	0.53	0.79	2.1	0.57	13.9	36.3	6.7	57.0	clay
	-4	4.5	2.17	3.8	6.03	0.74	0.12	0.08	87	0.47	0.88	6.7	0.32	46.3	21.5	19.8	58.7	clay
	-5	4.4	1.86	1.6	5.20	0.71	0.12	0.08	85	0.38	0.52	3.6	0.47	25.4	24.0	16.0	60.0	clay
Hoa Binh	-1	5.1	4.45	0.8	1.14	1.74	1.55	0.13	25	0.96	2.55	190.0	11.39	49.2	21.4	42.4	36.2	c.l.
	-2	5.9	2.48	3.9	0	6.12	1.15	0.11	0	0.31	1.88	209.6	2.30	16.2	20.0	31.9	48.1	clay

Table 17. Chemical and physical characteristics of cassava soils in Vietnam, 2001-2005 (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Thanh Hoa	-1	4.2	3.99	5.5	7.02	0.60	0.19	0.13	88	0.49	1.52	19.2	1.52	107.2	7.3	19.1	73.6	clay
	-2	4.6	4.84	107.0	0.80	3.46	1.13	0.26	14	0.66	6.16	108.6	1.51	14.4	14.8	28.5	56.7	clay
	-3	5.0	5.34	104.0	0.32	4.12	2.39	0.21	5	0.79	3.92	157.7	0.93	8.3	16.9	24.8	58.3	clay
Hue	-1	4.7	2.30	2.8	1.09	0.46	0.28	0.19	54	0.57	1.28	48.2	1.17	53.0	39.5	32.7	27.8	c.l.
	-2	4.7	2.27	1.0	3.33	1.81	1.21	0.19	51	0.52	1.07	60.8	0.88	72.3	48.9	22.9	28.2	s.c.l.
	-3	4.8	2.21	7.1	1.63	0.25	0.11	0.07	79	0.24	0.77	3.3	0.83	203.2	42.5	28.9	28.6	c.l.
	-4	4.5	3.33	1.2	2.23	0.66	0.46	0.22	62	0.32	3.14	48.7	2.59	90.8	37.4	23.4	39.2	c.l.
	-5	4.7	2.12	1.7	1.92	0.28	0.27	0.07	76	0.19	1.49	17.5	1.69	64.9	20.3	49.4	30.3	c.l.
	-6	4.8	3.50	1.6	5.20	0.20	0.16	0.14	91	0.77	1.75	6.3	0.92	56.2	28.6	26.7	44.7	clay
	-7	4.1	2.97	1.6	4.65	0.05	0.05	0.14	95	0.44	1.07	2.5	0.90	49.4	25.6	28.4	46.0	clay
	-8	4.2	3.10	3.8	2.39	0.39	0.23	0.21	74	0.55	1.75	32.2	0.58	62.6	42.8	21.6	35.6	c.l.
	-9	4.3	3.83	1.4	4.16	0.31	0.23	0.11	86	0.44	1.87	19.5	0.23	85.3	37.7	23.0	39.3	c.l.
	-10	4.4	1.59	12.7	0.42	0.50	0.15	0.07	37	0.37	0.76	2.7	0.41	74.1	47.7	36.3	16.0	loam
	-11	5.1	1.48	9.7	0.21	0.79	0.12	0.06	18	0.50	0.59	2.5	0.30	81.7	54.0	27.5	18.5	s.l.
	-12	4.7	0.75	18.2	0.26	0.38	0.06	0.16	30	0.44	0.29	1.2	0.09	15.3	62.8	20.8	16.4	s.l.
	-13	4.5	0.80	5.6	0.31	0.14	0.02	0.02	63	0.60	0.51	0.2	0.03	12.3	85.4	2.0	12.6	l.s.
	-14	5.3	0.71	21.9	0.16	1.74	0.34	0.11	7	0.27	1.12	33.2	1.21	41.2	58.2	23.2	18.6	s.l.
	-15	6.3	0.48	89.8	0	5.03	0.10	0.11	0	0.69	1.55	10.1	0.79	80.8	65.8	19.4	14.8	s.l.
Baria Vungtau	-1	5.1	1.54	3.7	0.62	0.75	0.30	0.08	35	0.68	0.45	14.8	0.32	30.8	69.7	11.3	19.0	s.l.
	-2	5.0	2.97	7.8	0.73	2.26	0.88	0.19	18	0.81	1.19	46.1	0.69	42.2	42.7	19.1	38.2	c.l.
	-3	5.2	3.85	1.7	0.10	7.50	2.74	0.39	1	0.81	11.67	170.2	0.98	11.8	9.4	25.0	65.6	clay
	-4	4.7	0.82	16.6	0.62	0.41	0.09	0.06	52	0.37	0.49	16.6	0.08	29.2	71.5	9.5	19.0	s.l.
	-5	5.3	2.85	15.9	0.71	1.70	0.46	0.48	21	0.57	1.84	107.3	0.62	18.6	24.1	19.8	56.1	clay
	-6	5.3	5.03	11.1	0.45	2.65	0.72	0.33	11	0.78	2.12	294.1	2.36	571.9	8.2	41.2	50.6	si.c
	-7	5.0	0.90	13.9	0.42	0.32	0.08	0.08	47	0.23	0.55	13.8	0.47	13.6	77.1	5.6	17.3	s.l.

Table 17. Chemical and physical characteristics of cassava soils in Vietnam, 2001-2004. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Dong Nai	-1	4.5	2.10	14.7	2.70	0.54	0.23	0.12	75									
	-2	4.4	2.40	30.1	2.81	0.62	0.17	0.19	74									
	-3	4.2	2.30	33.3	2.60	0.64	0.18	0.16	73									
	-4	4.4	2.30	38.2	2.70	0.70	0.19	0.15	72									
	-5	4.4	2.50	27.9	2.70	0.68	0.17	0.15	73									
	-6	4.3	2.50	13.6	3.12	0.38	0.14	0.17	82									
	-7	4.4	2.40	21.4	2.91	0.45	0.12	0.19	79									
	-8	4.5	2.70	72.1	2.29	1.35	0.26	0.18	56									
	-9	4.3	2.70	33.8	2.91	0.49	0.15	0.10	80									
	-10	4.3	2.30	37.5	2.91	0.46	0.11	0.11	81									
	-11	4.4	2.40	28.9	2.39	0.85	0.19	0.23	65									
	-12	4.3	2.20	37.3	2.44	0.80	0.17	0.19	68	0.74	1.11	26.7	0.61	10.4	11.2	14.8	74.0	clay
	-13	4.7	2.50	10.7	2.08	0.99	0.31	0.17	59									
	-14	4.7	2.70	10.3	1.98	1.14	0.34	0.20	54									
	-15	4.6	2.50	10.2	1.87	1.25	0.36	0.18	51									
	-16	4.6	2.40	10.7	2.29	1.05	0.28	0.16	61									
	-17	4.7	2.40	9.9	2.08	1.17	0.31	0.21	55									
	-18	4.6	2.50	9.0	1.87	0.96	0.30	0.17	57									
	-19	4.4	2.80	10.1	1.70	1.36	0.55	0.30	43									
	-20	4.5	2.80	9.8	1.77	1.43	0.51	0.21	45	0.53	1.42	24.9	0.74	9.9	12.1	15.3	72.6	clay
	-21	4.7	2.28	18.0	2.96	0.51	0.25	0.22	75									
	-22	4.5	2.37	34.9	2.91	0.53	0.17	0.18	77									
	-23	4.4	2.21	29.1	2.91	0.54	0.18	0.16	77									
	-24	4.3	2.38	30.6	2.81	0.58	0.18	0.14	75									
	-25	4.3	2.16	32.6	2.86	0.59	0.18	0.13	76									
	-26	4.2	2.45	18.5	3.12	0.38	0.13	0.17	82									
	-27	4.3	2.33	25.2	3.02	0.47	0.13	0.16	80									
	-28	4.5	2.29	63.9	2.28	1.19	0.28	0.16	58									

Table 17. Chemical and physical characteristics of cassava soils Vietnam, 2001-2004. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Dong Nai	-29	4.4	2.21	38.1	3.33	0.48	0.16	0.10	82									
	-30	4.3	2.19	36.5	3.02	0.45	0.11	0.12	82									
	-31	4.4	2.17	32.8	2.39	0.80	0.19	0.22	66									
	-32	4.3	2.33	37.6	2.60	0.79	0.18	0.21	69	0.51	1.21	54.8	0.57	10.7	9.7	9.6	80.7	clay
	-33	4.7	2.48	12.6	2.17	1.01	0.35	0.16	59									
	-34	4.5	2.61	12.3	2.28	1.05	0.36	0.18	59									
	-35	4.4	2.50	13.2	1.96	1.05	0.37	0.17	55									
	-36	4.4	2.37	13.4	2.39	0.73	0.27	0.16	67									
	-37	4.5	2.35	12.2	1.87	0.97	0.32	0.20	55									
	-38	4.5	2.33	11.6	2.29	0.91	0.32	0.16	62									
	-39	4.2	2.80	15.6	1.74	1.11	0.57	0.32	46									
	-40	4.4	2.75	12.9	1.74	1.22	0.48	0.22	47	0.65	1.61	67.7	0.67	10.3	9.7	10.9	79.4	clay
	-41	4.8	2.82	9.5	2.29	0.91	0.28	0.16	63	0.54	1.85	63.8	1.07	14.3				
	-42	4.6	2.88	10.8	2.50	0.73	0.22	0.14	70									
	-43	4.6	2.97	9.8	2.15	0.93	0.34	0.25	59									
	-44	4.7	2.73	11.3	2.21	0.94	0.31	0.15	61									
	-45	4.6	2.97	11.4	2.29	0.92	0.29	0.17	62									
	-46	4.7	2.70	8.7	2.26	0.92	0.33	0.12	62									
	-47	4.6	3.22	12.5	2.14	1.07	0.42	0.25	55									
	-48	4.7	3.11	10.0	2.07	1.05	0.38	0.20	56	0.76	2.10	72.2	1.01	14.2	0	8.8	91.2	clay
	-49	4.7	2.84	10.9	2.24	1.11	0.26	0.17	59	0.58	2.74	74.9	1.11	15.0	0	4.5	95.5	clay
	-50	4.7	2.81	11.9	2.00	1.03	0.27	0.21	57									
	-51	4.6	2.84	18.9	2.00	1.26	0.25	0.24	53									
	-52	4.6	5.65	12.9	2.36	0.97	0.27	0.24	61									
	-53	4.5	2.61	10.4	2.42	0.85	0.20	0.21	66									
	-54	4.6	2.76	11.0	2.00	1.09	0.30	0.18	56									
	-55	4.8	3.30	24.2	1.59	1.39	0.47	0.38	42									

Table 17. Chemical and physical characteristics of cassava soils Vietnam, 2001-2004. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Dong Nai	-56	4.7	3.02	8.9	2.21	1.06	0.35	0.21	58	0.63	1.60	70.1	1.05	13.2	0	4.6	95.4	clay
	-57	4.6	3.00	19.2	3.00	0.49	0.18	0.13	79	0.60	1.44	57.6	0.79	14.0	0	7.3	92.7	clay
	-58	4.5	2.74	40.0	2.86	0.62	0.12	0.21	75									
	-59	4.6	1.68	33.5	2.60	0.73	0.17	0.18	71									
	-60	4.5	2.71	33.0	2.60	0.56	0.11	0.15	76									
	-61	4.6	2.73	47.6	2.40	1.11	0.22	0.20	61									
	-62	4.4	2.59	19.6	3.09	0.31	0.07	0.16	85									
	-63	4.6	2.86	29.3	3.00	0.53	0.11	0.21	78									
	-64	4.5	2.69	83.3	2.53	1.13	0.18	0.15	63									
	-65	4.6	2.68	42.6	2.87	0.59	0.15	0.12	77									
	-66	4.5	2.75	35.9	2.89	0.49	0.08	0.11	81									
	-67	4.4	2.67	36.1	2.80	0.71	0.14	0.23	72									
	-68	4.6	2.75	64.6	2.50	1.05	0.17	0.21	64	0.58	1.69	61.9	0.85	14.7	0	56	91.4	clay
	-69	4.9	3.25	12.6	1.36	2.20	0.69	0.19	31	0.66	2.22	124.4	0.89	16.9	7.7	17.8	74.5	clay
	-70	4.8	3.08	20.5	1.58	2.22	0.54	0.23	35									
	-71	4.9	3.13	11.9	0.98	2.30	0.75	0.19	23									
	-72	4.9	3.45	19.6	1.03	2.81	0.75	0.20	22									
	-73	5.0	3.68	12.3	0.80	3.12	0.97	0.28	15									
	-74	5.0	3.18	14.0	1.47	2.32	0.72	0.21	31	0.72	2.27	112.7	0.83	17.7	5.1	15.2	79.6	clay
	-75	4.7	2.35	20.0	2.39	0.57	0.18	0.28	70									
	-76	4.6	2.10	36.7	2.29	0.66	0.15	0.28	68									
	-77	4.5	2.41	34.0	2.18	0.69	0.18	0.29	65									
	-78	4.5	2.18	37.0	2.39	0.72	0.14	0.26	68									
	-79	4.5	2.49	38.5	2.29	0.83	0.14	0.27	65									
	-80	4.5	2.25	12.0	2.44	0.43	0.12	0.36	73									
	-81	4.3	2.27	23.5	2.60	0.60	0.11	0.27	73									

Table 17. Chemical and physical characteristics of cassava soils Vietnam, 2001-2004. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Dong Nai	-82	4.4	2.47	58.8	2.03	1.03	0.18	0.21	59									
	-83	4.4	2.24	54.6	2.34	0.75	0.14	0.17	69									
	-84	4.5	2.17	31.8	2.39	0.59	0.12	0.21	72									
	-85	4.5	2.33	40.2	2.03	0.82	0.16	0.43	59									
	-86	4.5	2.30	21.3	2.50	0.53	0.12	0.29	73									
	-87	4.03	2.02	22.24	3.33	0.43	0.16	0.10	83									
	-88	4.10	1.98	47.98	2.96	0.69	0.14	0.13	76									
	-89	4.07	1.86	28.26	2.91	0.66	0.17	0.12	75									
	-90	4.01	1.71	33.17	3.07	0.64	0.12	0.11	78									
	-91	3.97	1.75	32.08	2.91	0.64	0.13	0.11	77									
	-92	3.95	1.67	16.99	3.07	0.39	0.12	0.14	83									
	-93	4.10	1.55	147.68	2.13	2.07	0.11	0.12	48									
	-94	3.93	1.44	66.40	2.76	0.92	0.14	0.13	70									
	-95	3.88	1.82	50.32	3.12	0.59	0.12	0.08	80									
	-96	3.98	1.55	30.23	3.12	0.55	0.09	0.09	81									
	-97	3.95	1.82	41.60	2.91	0.86	0.15	0.15	71									
	-98	4.06	1.66	90.91	2.44	1.51	0.17	0.16	57	0.41	1.71	83.3	0.83	14.9	1.6	18.4	80.0	clay
	-99	4.12	1.46	16.38	2.50	0.84	0.19	0.14	68									
	-100	4.13	1.38	14.81	2.65	0.69	0.17	0.12	73									

1) s.c.l. = sandy clay loam
c.l. = clay loam
s.l. = sandy loam
l.s. = loamy sand

Table 17. Chemical and physical characteristics of cassava soils Vietnam, 2001-2005. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Dong Nai	-101	4.05	1.46	17.32	2.39	1.00	0.28	0.20	62									
	-102	3.93	1.26	14.97	2.76	0.71	0.17	0.13	73									
	-103	4.02	1.15	26.89	2.50	1.02	0.22	0.13	65									
	-104	4.18	0.83	14.99	2.55	0.81	0.21	0.13	69									
	-105	4.02	2.65	22.33	2.44	1.12	0.33	0.17	60									
	-106	4.11	2.22	14.83	2.39	0.89	0.27	0.16	64									
	-107	4.11	1.60	14.96	1.87	0.96	0.60	0.86	44	0.49	1.98	179.9	0.96	14.3	1.2	15.9	82.9	clay
	-108	4.15	1.52	11.98	2.60	0.66	0.23	0.10	72									
	-109	4.04	1.71	11.46	2.76	0.63	0.21	0.08	75									
	-110	4.12	1.63	8.63	2.91	0.60	0.21	0.08	77									
	-111	4.17	1.64	10.13	2.76	0.70	0.23	0.11	73									
	-112	4.04	1.48	10.51	2.70	0.61	0.23	0.09	74									
	-113	3.94	2.22	15.33	2.55	1.14	0.41	0.16	60									
	-114	4.14	1.76	10.39	2.44	0.96	0.39	0.17	62	0.47	2.26	129.4	1.02	13.2	1.7	15.5	82.8	clay
	-115	4.25	2.64	16.70	1.82	2.39	0.69	0.13	36									
	-116	4.23	2.58	15.82	2.13	1.90	0.51	0.12	46									
	-117	4.22	2.81	20.83	1.77	2.13	0.67	0.16	37									
	-118	4.24	2.72	24.95	1.40	2.83	0.77	0.18	27									
	-119	4.33	2.76	153.47	0.99	3.66	0.76	0.19	17									
	-120	4.29	2.85	29.62	1.30	3.04	0.81	0.20	24	0.47	3.10	140.9	1.13	15.6	4.1	18.1	77.8	clay
Binh Phuoc	-1	4.9	3.40	2.4	1.87	0.98	0.59	0.29	50	0.77	0.95	11.7	0.62	142.0	15.7	30.6	53.7	clay
	-2	4.6	2.65	2.2	3.02	0.32	0.13	0.18	83	0.78	0.41	3.9	0.67	115.2	23.6	24.1	52.3	clay
	-3	4.8	3.34	1.4	1.82	0.73	0.34	0.15	60	0.48	0.55	7.7	0.86	202.8	25.9	26.5	47.6	clay
	-4	5.1	4.65	3.8	0.73	8.00	5.49	0.24	5	0.71	7.72	152.3	1.05	11.0	15.6	32.9	51.5	clay
	-5	4.3	2.94	13.9	3.43	0.27	0.08	0.07	89	0.59	0.23	4.7	0.13	53.6	31.8	9.6	58.6	clay
	-6	4.7	4.70	4.2	2.07	1.33	1.09	0.36	43	0.63	1.56	46.5	0.62	45.6	18.7	28.8	52.5	clay
	-7	5.0	3.58	30.8	0.69	2.80	1.04	0.65	13	0.45	17.16	76.1	5.09	11.5	-	-	-	-

[1)] s.c.l. = sandy clay loam; c.l. = clay loam; s.l. = sandy loam; l.s. = loamy sand

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