Sustainable Cassava Production in Asia for Multiple Uses and for Multiple Markets

Proceedings of the Ninth Regional Workshop held in Nanning, Guangxi, China PR

27 Nov - 3 Dec 2011

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Sustainable Cassava Production in Asia for Multiple Uses and for Multiple Markets

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Sustainable Cassava Production in Asia

For Multiple Uses and for Multiple Markets

Proceedings of the Ninth Regional Cassava Workshop
held in Nanning, Guangxi, People's Republic of China

27 November to 3 December, 2011

Editor: Reinhardt H. Howeler

Organized by the International Center for Tropical Agriculture (CIAT)
and the Chinese Cassava Agro-technology Research System (CCARS)

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Cover photos:

Top: R.H. Howeler: Harvest of intercropped upland rice and maize in Yogyakarta, Indonesia
Bottom: R.H. Howeler: Colorful cassava starch sheets drying in the sun in an artisanal noodle making shop in Tbong Khmum district of Kampong Cham province in Cambodia

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PREFACE

The 9th Regional Cassava Workshop was held from 27 November to 3 December, 2011, in Nanning, Guangxi, China PR. These triennial meetings have been held since the first one in Bangkok, Thailand, in 1984, with the objective of bringing together the principal cassava researchers in the various countries in Asia in order to share experiences and learn from each other. Initially, these researchers were mainly cassava breeders and agronomists that were conducting collaborative experiments with the two Asian-based CIAT scientists. These initial workshops proved to be successful, not only in disseminating technical knowledge but also in creating friendships among participants, which stimulated more collaboration among various institutes working on cassava within each country, as well as between countries. It also prevented duplication of efforts, as countries with weak cassava research programs could learn a lot from colleagues in countries that were more advanced in cassava research, especially Thailand and India. In subsequent years, the issues discussed at these workshops broadened to include not only research on cassava production but also on utilization and marketing aspects as well as on more effective ways of technology transfer to enhance the adoption of the new varieties and agronomic practices to increase yields and farm income. Over the years, the number of collaborating countries also increased, first with the opening up of China in the late 1980s, followed by Vietnam in the 1990s, and Lao PDR, Cambodia, and East Timor in the first decade of the 21st Century.

With the CIAT Cassava Office located in Bangkok, the well-developed Thai cassava research programs, both at the Department of Agriculture and at Kasetsart University, played a major role in helping other countries strengthen their own cassava research capacity. With the consent of the Thai authorities in 1989, CIAT was allowed to take some of the newly developed Thai cassava varieties for testing in Vietnam; this was followed by Lao PDR, Cambodia, and East Timor. Some of these high-yielding varieties, especially Kasetsart 50 and Rayong 60, were found to be much more productive than most of the local varieties. Although these two industrial varieties were not very suitable for direct human consumption, they could still be used for animal feeding and especially for processing into starch, modified starch, sweeteners, mono-sodium glutamate, and many other products, including bio-ethanol. As demand for these products increased, farmers started to adopt these new varieties together with better agronomic practices, and cassava yields started to increase very markedly in almost all countries in Asia. Average cassava yields in Asia were about 13 t/ha in 1994 but had increased to 21 t/ha in 2013, while the cassava harvested area also had increased about 10%, from 3.8 to 4.2 million hectares. This increased the annual gross income of cassava farmers in Asia by about 2 billion US dollars due to higher yields in 2013 as compared to 1994. This was achieved, at least in part, by the hard work and close collaboration between cassava researchers and extensionists in the cassava growing countries in Asia, which was fostered by these triennial workshops.

The 9th Regional Workshop in 2011 was somewhat different from the previous workshops in that it had a strong participation from young cassava researchers that had just completed their post-graduate degrees, as well as those that had previously not been represented. As such, there was much greater emphasis on research about cassava disease and pest problems as these have become of much greater concern than in the past. There was also more emphasis on the use of molecular breeding strategies and techniques, as this new field is becoming increasingly more important in improving the efficiency of cassava varietal improvement. Thus, the 9th Regional Workshop provided an opportunity for a new generation of cassava researchers to present their latest results.

The publication of the Proceedings of this Workshop was delayed about four years due to several unforeseen circumstances. However, it was considered useful to publish the papers presented in order to maintain a historical record of the progress made over the years in cassava research in Asia and to distribute this information as widely as possible in order to contribute to the further development of cassava in the region and beyond. Unfortunately, the paper entitled "Recent changes in the cassava sector in Vietnam" by Dr. Nguyen Van Bo could not be presented at the Workshop. Since this is an important topic, I have asked Dr. Hoang Kim to write a paper on the current situation of cassava in Vietnam, which is included in the Proceedings. Also, because cassava production and processing in several countries has so rapidly developed since the papers were presented in 2011, several authors were asked to update their data to the current situation in 2015. This will provide more up-to-date information, which may help in planning future research for the further development of the cassava sector in the years to come.

Reinhardt Howeler
CIAT emeritus
December 2015

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WELCOME ADDRESS BY ROD LEFROY, CIAT

Dr. Chen, Vice Governor of Guangxi Province, Mr. Ohno, Executive Director of the Nippon Foundation, distinguished guests and fellow participants.

On behalf of the Organizing Committee and of CIAT it is my great honor to extend a very warm welcome to all of you to the 9th Triennial Regional Cassava Research Workshop in Nanning. In 1984 the first such workshop was held in Bangkok and now, some 27 years later, after some very large changes in the cassava sector in Asia, we gather in Nanning for this workshop entitled "Sustainable Cassava Production in Asia for Multiple Uses and for Multiple Markets".

Before proceeding any further, I would like to take this opportunity to thank The Nippon Foundation for their continued and generous support to research and development on cassava in Asia over many years. This workshop was possible because of support from The Nippon Foundation as well as the generous support of many Chinese institutions and agencies connected to cassava production and processing.

The detailed on-the-ground organizing for the workshop has been undertaken largely by the Guangxi Subtropical Crops Research Institute (GSCRI), and for this I would like to extend our thanks to the Director, Mr. Huang, to Mr. Tian, and to their staff. They have done a magnificent job in getting everything organized. I would also like to thank my colleagues on the Organizing Committee, and most particularly Dr. Tin Maung Aye.

We are very pleased to see so many people at this workshop. There are more than 115 international participants from 15 countries, as well as many cassava specialists and representatives from industry in China, making an expected total of around 200 participants. While most of the participants are from Asia, we are pleased to welcome participants from Africa as well. Also, I would like to welcome colleagues from CIAT headquarters in Colombia and from our sister center based in Africa, IITA, the International Institute for Tropical Agriculture.

In 2012 CIAT will celebrate 45 years since the center was established. For over 30 of these years there has been very active collaborative research on cassava with many partners, including many people in this room and the institutions that they represent. This period has seen huge changes in the cassava sector, both globally and in the region. From 1975 to 2008, the area planted to cassava in the region has increased more than 1 million ha, or more than one third, the average yield has doubled in many countries and on average has increased by about 60%, the overall production has increased by 140%, and the markets and uses of cassava have shifted from human food and animal feed to include a very wide array of uses by a wide array of industries. It is always very difficult to estimate the impact of research, but a recent attempt suggests that the value of all of the collaborative research undertaken on cassava in this region is estimated as at least US$12 billion, which in turn has had a huge impact on the livelihoods of millions of farming households.

We now face a very dynamic cassava sector in this region and globally, which faces many opportunities as well as many challenges. This workshop provides an excellent opportunity for many groups from a wide range of countries and interests to get together and discuss the current and future needs for research and development across the industry for the benefit of national governments, of industry, and of smallholder farmers.

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

Now, I would like to call on Mr. Huang, the Director of the Guangxi Sub-tropical Crops Research Institute, to make a welcome address.

REDESIGNING RESEARCH AND CAPACITY BUILDING TO DRIVE INCOME GROWTH FOR SMALLHOLDER CASSAVA PRODUCERS

Clair Hershey[1]

ABSTRACT

The basis for the growth of demand for cassava products varies by continent and by country. In Africa, which produces over half the world's cassava, demand has been closely linked to population growth and the expansion of traditional markets. In the Americas, production growth has been linked mainly to industrial markets, while traditional food markets have remained relatively flat. Asia has led the way in demonstrating that cassava can be a vehicle for growth based on value-added cassava traits and value-added products. Market growth and market diversity have considerable potential to increase profitability for farmers. Maximizing this profitability, in a sustainable and environmentally sound manner, requires solid research support. The cassava research environment is changing. The research needs and opportunities include: increasing yields, stabilizing yields in view of constraints such as new pests and diseases, and traits for specialty markets. Climate change brings additional challenges. These new directions for research also require new capacity-building at various levels – for research institutions, for growers and for industry. This paper outlines a renewed strategic effort by CIAT and its partners in Asia and elsewhere. Well-designed and adequately funded research and capacity building in cassava will provide higher income to producers through technologies that respond to new market opportunities, and protection of the environment through sustainable crop and soil management.

KEYNOTE ADDRESS

On behalf of the Cassava Program of the International Center for Tropical Agriculture (CIAT), I want to add my welcome to this 9th regional workshop. We are proud and pleased to have been closely associated with each of these triennial workshops since the very first one in Bangkok in 1984.

This series of workshops, continuing now for a quarter of a century, is a remarkable accomplishment and a tribute to the relatively small but dedicated group of cassava scientists, teachers, entrepreneurs, research managers, policymakers and others. Those of you who have been in this from the beginning understand very well the kinds of results and impacts this group has accomplished, and the lives that are better because of improvements made to the crop and to its multiple end uses. I want to recognize and congratulate the organizers and sponsors of this 9th workshop for a job well-done. The program for this week looks informative and inspiring, and we will certainly all go away from here with new information, new connections and new enthusiasm for the work that lies ahead.

The accomplishments in cassava technology development of the last four decades have been remarkable, but there is much more to be done to support the people who rely on cassava for a significant part of their livelihoods. I think everyone also understands that we

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live in a different world today and that we can't expect to optimize progress by doing things the same way as ten or twenty years ago.

Cassava is in a unique position to respond to some of the trends that challenge the global agricultural and food sectors today. These include:

- Higher food prices and food security challenges for urban poor
- Income generation for poor farmers
- Rising costs of inputs and the need for greater resource use efficiency
- Variable rainfall patterns and higher temperatures due to climate change; and
- Demands for renewable, eco-efficient energy sources

In this talk I want to reflect on where we are today as a group of cassava scientists, entrepreneurs and others represented here; some of the challenges and opportunities we face; and how we will move effectively toward the goals of the next 5 to 10 years. And especially I want to comment on how CIAT plans to be a part of this.

This is somewhat of a landmark meeting. It is the second held in China, the first being in Danzhou in 1996. We have here some of the key people who have been dedicated to cassava research and development since the crop began taking off in the 1970s. They have made huge contributions to development in the region. We have the generation that began the process of developing new varieties in the 1970s, and now sees them planted on over 2 million hectares and adding more than 17 billion US$ to the regional economy in the last two decades. This is one of the great agricultural success stories of recent times. We have the generation that developed productive and sustainable agronomic and soil management packages, from a baseline of very little information 40 years ago. And the policy-makers and heads of industry who had the vision to see cassava as a basis for several major industrial products that would dramatically expand markets, and bring higher income to the small-holder cassava producers.

Others of you are just beginning your careers and face a very different set of -opportunities and challenges. We are in a critical transition time – the older generation needs to assure that their knowledge and expertise are passed on, and at the same time embrace and support the development of new leadership. The new generation needs to figure out how to integrate their skills in advanced science with the conventional approaches that continue to contribute to progress in many cases. Together we have to face this challenge of bringing in a new generation of scientists – building on the past; taking the best from it and adding the new technologies, the new capacity and the new energy and enthusiasm of the next generation researchers.

The production landscape, the markets and the research environment are changing quickly. What has not changed is that cassava continues to be a vehicle for development to support small farmers in Asia. This defines the core goals and the overall strategy of most of the institutions represented here this week.

Since I am here representing the Cassava Program of CIAT, I especially want to reflect on *our* role in cassava development in Asia – past present and future. Many of you collaborate with CIAT in one way or another and I hope this can be a forum for us to understand the best ways to make that collaboration as productive as possible.

I don't want to spend too much time reviewing the past. This has been very well documented in the proceedings of the last eight regional workshops and in many other published papers. But it is useful to put our current goals into an historical context. I want to look at some of the changes during the last forty years that bring us to tomorrow's challenges and opportunities.

Changes in the Production Landscape

Thirty or 40 years ago it was common to see comments in the literature that referred to cassava as a *rustic* crop that required little care and had few pest or insect problems. We learned pretty quickly, as cassava research expanded dramatically in the 1970s and 1980s, that this clearly was not true, especially in Africa and the Americas. We now understand that when the crop is grown in small isolated fields, in an area where it has been selected for adaptation over many generations, pests and diseases are in fact often a minor or non-existent problem. And it certainly may be possible to achieve stable but low yields without inputs. But much has changed in the way cassava is grown, and in the opportunities for pests and pathogens to move across continents and regions. Developing the crop into a profitable enterprise requires an intensification of production that can completely change the mix and the intensity of both biotic and abiotic constraints.

Continuing changes will probably make pests and diseases an ever more important set of constraints in Asia. Until recently, you have had the luxury of not having to worry too much about pests and diseases. There have been some exceptions, of course, like moderate levels of bacterial blight in several countries, and the Indian cassava mosaic disease on the sub-continent.

We've had serious wake-up calls in the past few years, beginning with the discovery of the mealybug in Thailand, and now tentative reports of the cassava green mite and a new whitefly species. The witches broom phytoplasm seems to be spreading in Vietnam, Cambodia and Thailand.

What does this mean for our research strategy? First of all, it means that we need to work together. Pests and diseases don't recognize political boundaries, and our approaches to management need to cross these boundaries as well. We also believe that maintaining close association with CIAT will be essential, because of our location in the evolutionary homeland of both cassava and its pests, in South America. We have there the varieties that farmers have selected for resistance to many of the major pests and diseases. We have been working for many years to identify resistance and to transfer those genes to high-yielding and high quality types. This does not mean that we can pull out ready-to-use varieties for any situation, but it does mean that we may be able to provide sources of resistance in materials that are improved from what is available in landrace varieties.

This is a big challenge, and we can't underestimate the difficulty of meeting a new pest challenge through breeding. Even with modern molecular techniques for detection and screening, we are still limited in how fast we can accomplish our goals of resistance breeding.

The Americas are also home to the many biological control agents that coevolved with cassava pests, and the effective example of *Anagyrus lopezii* to control the mealybug is just one of many such biocontrol agents.

The broad principles of crop management are well-established, and much of the future research will be localized and participatory – to optimize location-specific solutions. Training in participatory methods has a key role. At the same time, more centralized research will also remain important for identifying new solutions in mechanization, weed control, water management and others.

Changes in our Perception of the Effects of Climate Change and Protection of the Environment

Awareness of the effects of climate change on agriculture has only gained momentum in the past decade. Cassava has traits that make it especially well-adapted to climate change, especially its inherent drought tolerance and tolerance of high temperatures. It has no part of its growing period during which it is highly susceptible to drought or high temperatures, as is the case for most seed-propagated crops. We should expect, and be prepared for, the expansion of cassava into regions where other crops begin to have unacceptable rates of failure, especially from increasing drought. Models developed by CIAT's climate change group indicate that the main effect of climate change on cassava is likely to be shifts in balance of various pests and diseases and their overall increasing pressures.

From the earliest days, we understood that soil fertility maintenance and erosion control would be critical components of sustainable cassava cultivation. There has been considerable progress in our scientific understanding and in developing technologies to address these issues. However, we have a long way to go before there is an acceptable level of adoption of appropriate practices at the farm level. Research results alone will not drive this adoption, but it will require a combination of education, policy and even more scientifically verified and farmer-accepted options to address these issues adequately.

Changes in Technology in the Broader Environment

We are all aware that advances in technology are dramatically changing the way we do research, for example, in the areas of:

- Communications and information management
- Molecular tools, including sequencing and development of markers for breeding
- Understanding of evolution and genetic diversity of the crop and of its biological constraints, and
- Sensitivity, speed and costs of diagnostic techniques, such as quantifying nutritional and biochemical factors.

All these trends directly impact our capacity in cassava technology development. But we also need to recognize that the best approach to solving problems is not always through the most sophisticated tools. We need to create solutions from the best combination of traditional and modern approaches.

CIAT's cassava breeder, Hernan Ceballos, who many of you know, likes to show a slide that illustrates the gap between progress in our capacity for the development and application of molecular and conventional technologies in breeding. On the one side of the slide he shows a rocket taking off into space, indicating the rate of development of molecular tools. On the other side he shows a tortoise, slowly plodding along, representing conventional trait screening and breeding techniques.

Several weeks ago I reviewed a draft paper from someone working in a molecular and tissue culture lab. One of the first statements in the introduction of that paper was that *conventional breeding has contributed little to the improvement of cassava*. This was meant to be a basic argument to support the idea that molecular and tissue culture tools were now needed. I edited this statement to say that conventional breeding has contributed *immensely* to the improvement of cassava, but new tools can accelerate the progress. Somehow this message isn't getting out, even to people working in cassava labs, and much less to people who are not familiar with cassava at all. We have heard a lot in past workshops about cassava breeding progress in Asia, and I'm sure we'll hear more again this week. What we need to understand is that molecular tools are needed not because conventional breeding has failed, and certainly not because molecular approaches on their own can produce new varieties, but that we can move faster and we can move more effectively toward some breeding goals if we strike the right balance between the two. There is no justification for situations where conventional and molecular breeders work in parallel and in isolation from each other.

Changes in the Marketplace

Much of our research is driven by marketplace demands. Farmers produce what is profitable, and what is profitable depends to a large degree on what industry needs. Science has the capacity to either drive markets or to respond to markets, and usually does some of both.

Forty years ago in Thailand, cassava was a generic commodity. The emerging market of chips and pellets for animal feed didn't at first distinguish between different varieties or their different root traits. But breeders knew that the industry would benefit from higher starch content varieties, and should be willing to pay a premium, so that both industry and farmers would benefit. This differential pricing for starch content was eventually negotiated and it now hardly seems possible that there was a time when this starch content premium did not exist.

But this is probably only the beginning of market differentiation for cassava traits. As the industry becomes more sophisticated, other traits will become economically important. The additional value of some of these should be reflected back on the farm gate price. One that we are most familiar with at the moment is the amylose-free, or *waxy* cassava. We will hear a few talks about this trait and its potential in the marketplace. It appears there are many products where an amylose-free cassava starch may have advantages over conventional cassava starch, and over waxy starch from other crops. Much of the information from this research is proprietary, but the publicly available information is very encouraging.

Other value-added traits with ongoing research include contents of vitamin A and protein, and resistance to post-harvest deterioration. These have all been extensively reported in these workshops. But these traits only scratch the surface of what is potentially available in the CIAT genebank, or what can probably be developed through mutation or transgenics. We need a close collaboration between public and private sectors to understand the kinds of traits to prioritize, and to support the evaluation of genebanks for genetic variation.

Changes in the Way we Develop Scientific Capacity

One of the things I do outside my job in CIATs cassava program is that I edit and produce a plant breeding newsletter sponsored by Cornell University and FAO. (And this is a little commercial in case you are interested in subscribing – it's free!). During my search for articles in the November issue, I came across three stories that caught my attention in terms of trends in our system of education for training plant breeders. I'm sure the same trends exist in other disciplines.

1. The first article summarized a recently published study on the needs for the training of more plant breeders. This study was based on a Delphi survey from the University of California at Davis, and points out that there is a serious deficit in the training of plant breeders, and especially those with the capacity to integrate conventional and modern techniques and methods.
2. The second news item was from the dean of the college of Agriculture at Cornell, announcing that the five biologically-based departments, including the Department of Plant Breeding and Genetics, would be merging into a single unit. They are still very early in this process, but the implications seem quite significant for the training of plant breeders. The university expects that the synergies gained through integration among departments can enhance the current breadth and depth of individual departments. But we also know that this is primarily a response to some very difficult financial issues for the public education system in the US, and that agriculture is attracting fewer and fewer students. Cornell is historically one of the most respected institutions worldwide for the training of plant breeders (I need to say that, since I am a Cornell alumnus), and is probably leading a trend in consolidation of departments, including those in agriculture.
3. Finally, a third contribution to the newsletter announced that a consortium of universities is jointly developing an online training program in plant breeding. There is the growing perception that fewer and fewer universities have the ability on their own to offer comprehensive training in plant breeding. There are already limited on-line offerings by individual universities, such as Nebraska, Iowa, North Carolina State and UC Davis. This new initiative will take the best from a number of universities and make it available globally. This is an idea in the early stages and it remains to be seen how it will develop, but it is part of a broader trend of tearing down the boundaries that exist among institutions and among locations around the world.

These three articles are indicative of broad trends in postgraduate agricultural education today: a focus on upstream science, reduction in faculty, and filling gaps through web-based and other distance-learning courses. These are trends that we need to adapt to and learn from in the research world of cassava as well. We have to create linkages among geographically disperse centers of knowledge and of research excellence to optimize capacity building for cassava research.

Changes in Institutional Support to Research

In the 1970s and 1980s, most national programs in cassava were just starting to build their capacity, and the private sector was all but unknown in supporting research or extension. In the early years, CIAT tried to be "all things to all people". We had a complete interdisciplinary team consisting of an economist, breeder(s), agronomist, soil scientist, entomologist, pathologist and physiologist. Along with IITA, our sister center in Nigeria, we were *the center of the universe* so to speak, in the cassava world. CIAT held large training events, bringing to Colombia full teams from national programs for extended periods, and these teams often then developed their own research programs in Latin America, Asia and Africa after the CGIAR model.

In the breeding section at CIAT we aimed for global coverage in terms of the types of agro-ecosystems for varietal adaptation. For each of these ago-ecological zones we developed broadly adapted populations, and sent out hundreds of thousands of seeds to national programs for their local selection and development. This had varying degrees of success, usually depending on the capacity of national programs to follow through with a comprehensive and long-term selection for local adaptation and farmer and market needs. Too often, the resources of the national partners were inadequate and varieties were slow to reach farmers. However, in Asia there was a great deal of success in several countries, most notably initially in Thailand.

What is different today? How do we envision the CIAT role as a partner for cassava research and development? First, CIAT's research and capacity-building portfolio has changed considerably in the past decade. The comprehensive interdisciplinary team has been reduced to a small core team of scientists.

CIAT and IITA may once have been the best at what we did in cassava research because we had large multidisciplinary teams and well-funded projects, and no one else did. Now we have to be the best at what we do by connecting many people in diverse places, whose skills and resources are complementary. We still have comparative advantages in our ability to innovate in some areas, but in a *hyper-connected* world, everyone has access to nearly the same skills and information. We now see ourselves less as a global center of cassava technology development, but rather as one of many partners in a global effort, where we have special capacity and responsibility. Our strong comparative advantages remain our international, apolitical status, our long history of comprehensive training and research experience, and our location in the evolutionary homeland of cassava and its pest and pathogen constraints. We expect to continue to have a lot to offer and a lot to learn by developing complementary partnerships among both the stronger and the less strong programs in the region.

Changes in the Organization of our Research System for Cassava

I want to take a few minutes to describe what is being called a *reform* of the international agricultural research center system (or the CGIAR), in which CIAT is one of 15 centers. This is a very complex process and I only want to touch on a few aspects of this reform that will affect the ways in which CIAT's cassava program will operate and collaborate with partners in Asia.

In very simple terms, the CGIAR system is reorganizing its programs in ways that are intended to take advantage of synergies among centers and programs. Along with a broad range of partners, CGIAR has determined that there should be large synergies to be gained by a closer association among the four centers that work on the vegetatively propagated crops, including cassava. The other crops in this program are potato, sweet potato, bananas and plantains, yams and various minor species, mainly from the Andes. The new program will formally begin in early 2012 and will be called the CGIAR Research Program for Roots, Tubers and Bananas, or CRP-RTB. It will involve International Potato Center (CIP) in Peru as the lead center, CIAT, the International Institute for Tropical Agriculture (IITA) in Nigeria, and Bioversity International in Rome. These crops share some common constraints and opportunities, and a more coordinated and integrated research effort should produce faster results more efficiently.

What does this new organization mean for you? Probably initially, those of you who work closely with us won't see too much that is different. But over time, we expect you to see some benefits from this new way that we'll do business. The Program will focus on seven broad themes where there are good possibilities for synergies among the vegetatively propagated crops. These are: management of genetic resources; genetic improvement; pest and disease management; propagation systems; crop and soil management; post-harvest issues; and partnerships. The proposal that outlines the synergies among the crops and among the centers lists dozens of research activities in which we can expect to work more effectively as compared to individual centers working on individual crops.

We need to be realistic and concentrate initially on those areas that in fact give the highest payoff to investment. I want to mention a few examples. In germplasm conservation, there are many similarities among the vegatively propagated crops, and many of the techniques and facilities can be shared. Although most Asian programs don't manage large germplasm collections, you should benefit from more cost-effective conservation techniques. Pest and disease management will become better through shared information systems and coordination among centers for use of diagnostic tools.

The main product of all these crops is a starchy root, tuber or fruit, and the studies of starch biosynthesis and genetics, and the variations in starch functional properties will be made more effective by collaboration.

And of course all these crops have the common feature of vegetative propagation, with common advantages of facilitated breeding, but disadvantages of perishability of planting material, and degeneration of quality of planting material due to the accumulation of biotic constraints, especially viruses.

By more closely coordinating work between CIAT and IITA in Nigeria, you will have better access to information and technologies generated in Africa, and *vice versa*. The Root, Tuber and Banana Program will bring new possibilities to Asian programs to collaborate, learn and gain access to technologies. It is a program that is fundamentally based on the ability of partnerships to solve problems more effectively and efficiently.

This is the Time to Invest for Lasting Impact

You have a unique opportunity in history to respond to and support long-term market demand and sustainable production practices in Asia. We see several types of growth taking place in Asia at the moment. In the more mature cassava economies like Thailand, growth is relatively systematic, and the spread of technology is coordinated and managed. In Cambodia, on the other hand, there is explosive growth in the area planted to cassava. Most of this is planted to new varieties, but the support system to provide and promote an integrated technology package is very weak. The market demand is driving growth that is completely beyond the capacity of local research and extension to keep up. It's like an airplane that has taken off on a mission but has not bothered to check whether there is fuel on board, whether the aircraft is mechanically sound, and without a copilot. The passengers are the small farmers who will enjoy the ride for a while but with some doubt about whether or not they'll reach their destination or will have to make an emergency landing along the way for repairs and refueling.

The countries experiencing this rapid expansion in area planted face huge challenges in providing broad-scale technical support. It will only happen with a concerted and coordinated effort involving both the public and private sectors. But it is clearly an investment worth making. The evidence shows that if you invest well in research, the gains will far exceed the amount invested. But it has to be with a long-term view. Two- or three-year projects typically just scratch the surface in meeting development needs.

Each country has to decide for themselves how they want the benefits from research to be distributed. At CIAT, we believe there is a good argument to be made for research strategies and policies aimed at benefitting smallholder farmers, who make up the great bulk of cassava producers. The whole country benefits when the standard of living of the rural population rises.

Everyone has to pitch in, both out of self-interest and because it is the right thing to do for reaching broader development goals. Industry needs to recognize their capacity to fill gaps that might logically be filled by extension services in more advanced economies. They can support clean seed production of high yielding varieties, they can provide technical support on crop and soil management, and they may even extend credit for input purchases to assure good production. Both growers and industry have a strong interest in avoiding broad fluctuations in area planted, in productivity and in market prices. Measures to stabilize these factors need not be through government subsidies or price controls, but might be managed through grower contracts, and industry support to optimize growers' productivity and sustainability.

The rest of the world is keenly observing what is going on in Asia. It's rare to go to a conference in Latin America or Africa in which there is not some reference to the Asian cassava phenomenon. You can be proud of this and you can use this knowledge and experience to support global development, which in the end brings up everyone's standard of living. I am sure we will hear during the rest of this workshop about the many ways that cassava-based development is continuing and growing, and benefitting ever more people, and the new technologies and initiatives that will sustain it.

RESEARCH AND DEVELOPMENT IN THE DYNAMIC CASSAVA SECTOR OF SOUTHEAST ASIA

Tin Maung Aye[1], Keith Fahrney[1] and Rod Lefroy[1]

ABSTRACT

The outlook for global demand for cassava is for continued strong growth and, as such, there is potential for further expansion of cassava production in Southeast Asia and beyond. Production uncertainties and constraints have combined with expectations of strong global demand to sustain reasonably high prices for cassava and cassava products, although price volatility remains a concern, especially for smallholder farmers. Cassava production is a very attractive option for smallholders, many of whom have relatively few other options for raising income and linking effectively to markets. For this reason, governments and development agencies should be increasing their interest in cassava as a potential pathway out of poverty for the many rural poor. While this interest is increasing, there is scope for greater focus.

Further growth in cassava production in Southeast Asia, particularly in Cambodia, Lao PDR and Myanmar, is expected as a result of strong demand from neighboring countries such as China, Thailand, and Vietnam, and from the processing industries that are evolving in Cambodia and emerging in Lao PDR and Myanmar. To maintain the attractiveness of cassava as a feedstock for a range of processing industries, cassava production must be highly cost effective and more environmentally friendly so as to allay concerns about land degradation.

Applied research and development continues to be undertaken by CIAT and partners in a number of projects in Lao PDR, Cambodia and Myanmar. The main foci of the work on cassava production are on evaluation of germplasm to ensure that the most appropriate varieties are identified for each location, that information is available for the next improved varieties to be selected and that improved management options appropriate for each location can be recommended, including soil fertility management, intercropping, crop rotations, management of planting material, weeding, and more. In addition, there is work related to on-farm utilization of cassava, value adding by farmers and utilization of processing wastes to help both industry and smallholders.

Farmer Participatory Research and Extension (FPR&E) methodologies are used in these activities, which are undertaken in collaboration with provincial and district agriculture staff so as to increase the chances for local innovation and adoption. Due attention is also focused on the best way to manage other issues, such as socio-economic, ethnic and political situations, which have to be considered to ensure both appropriateness and adoption.

Key words: Cassava, outlook, R&D, Southeast Asia.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is widely grown in the tropical and sub-tropical countries in Asia. More than eight million farmers grow cassava in Asia, more than three million farmers in the Greater Mekong Subregion, including an unknown number in Myanmar. Another 1.5 million households in southern China and another three million

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households in Indonesia grow cassava. It is estimated that cassava farmers in Asia receive more than US$1.7 billion per year additional gross income due to higher yields obtained in 2009 as compared to 1994 (Howeler, 2014); this is the result of the adoption of higher yielding varieties and more effective agronomic practices. Cassava has become an increasingly important crop in terms of both rural livelihoods and economic development throughout the region. In 2013, about 30% of world cassava production was in Asia, 56% in Africa and 14% in Latin America.

This paper presents research and development in the dynamic cassava sector of Southeast Asia, which helps us to understand the current situation of cassava production; specifically, it highlights the available improved varieties, better agronomic practices and constraints for smallholder farmers in their cassava production systems.

CASSAVA OUTLOOK

Beyond its food and feed value, cassava is also important for a range of industrial purposes when it is converted into starch, sweeteners and ethanol. Cassava production in most of Southeast Asia is now a largely commercial activity to meet the rapidly growing domestic and regional demands for animal feed, starch products, and biofuel. As a result, cassava is in high demand locally and for export, especially to China.

Currently, China alone needs more than eight million tons of cassava chips per year. China is the world's largest importer of cassava dry chips and starch, accounting for about 65% of the global trade of cassava dry chips and 7% of the global trade in starch. Production uncertainties and constraints have combined with expectations of strong global demand to sustain reasonably high prices for cassava and cassava products, although price volatility remains a concern, especially for smallholder farmers. Nevertheless, cassava remains an important food-security crop in specific sub-regions. The outlook for global demand in cassava is for continued strong growth and, as such, there is potential for further expansion of cassava production in Southeast Asia and beyond.

Cassava Production and Utilization in China

Cassava is a crop of major economic importance in China and highly valuable for its starch. It grows in a large area of the southern part of China, especially in the provinces of Guangdong, Guangxi, Hainan and Yunnan. Other provinces of China, such as Fujian, Jiangxi, Hunan, Sichuan, and Guizhou also have land available for cassava production. Although these five provinces are mountainous and thus not suitable for many other food crops such as rice, they can be used for cassava cultivation. Generally, cassava can grow only within 30° S and 30° N of the equator, which is limiting the production of cassava in the central and northern parts of China.

In 2013 China produced about 4.6 million tonnes of fresh cassava roots (FAOSTAT, 2015), of which Guangxi and Guangdong accounted for about 90% of the total production. China required about 33.6 million tonnes of fresh cassava; it produced about 4.6 million tonnes while importing, mainly in the form of dry chips or starch, another 29 million tonnes of fresh root equivalent (FAOSTAT, 2015). The imports accounted for about 86% of China's total cassava usage. Because of climatic conditions, China could not produce enough cassava to satisfy their industrial needs as cassava can be grown only in the southern parts of the country.

The increasing demand for cassava in China is driven by the strong demand by the ethanol sector. In 2012, an estimated 780 million liters of ethanol could be produced from cassava in China, requiring close to 6 million tonnes of dried cassava. In 2013, China imported about 29 million tonnes of cassava fresh root equivalent (**Figure. 1**), most of which were imported from Thailand and Vietnam (FAOSTAT, 2015). The bulk of Thailand's cassava exports to China occurs in the form of dried cassava (cassava chips rather than pellets), and is used as an input in the production of animal feed and biofuels.

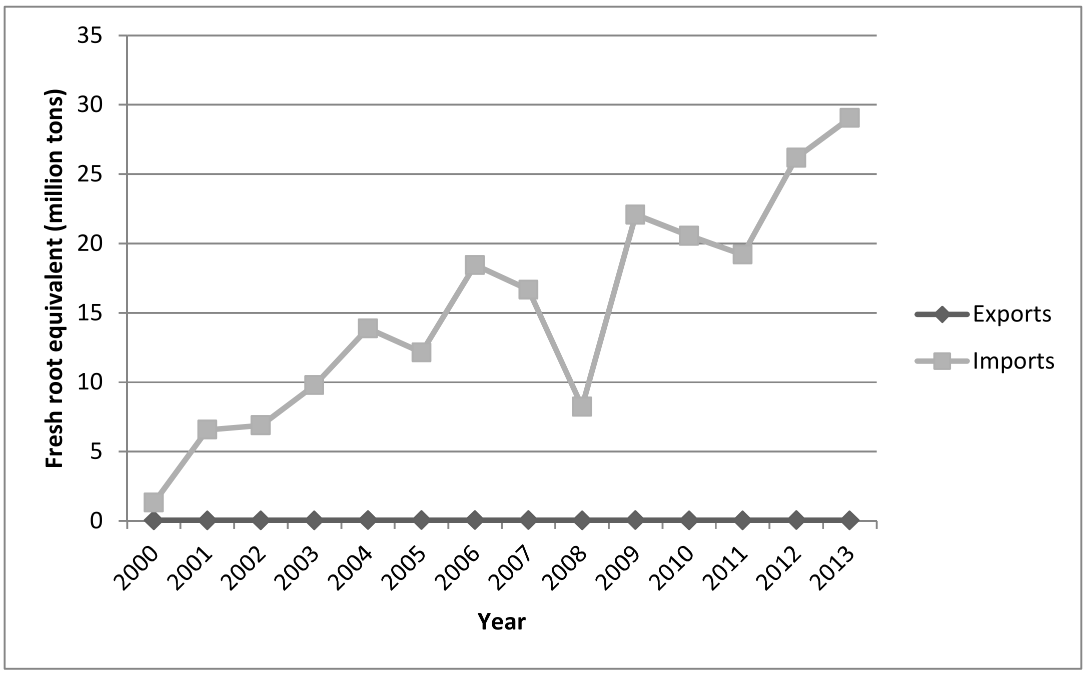

Figure 1. Cassava exports and imports by China from 2000 to 2013.
***Source**: FAOSTAT, 2015.*

Chip exports to China occur on a spot-price basis, which provides far less predictability. This is because of the tendency of Chinese importers to renege on shipping agreements when the market price falls below contract price, leaving exporters (example: Thai exporters) to bear the cost of storage and quality deterioration. Similar patterns are to be found with regard to starch exports.

The demand and requirement of dry cassava chips exported to the Chinese market are both in terms of quality and quantity. The quality requirement of dry cassava chips exported to China is that the starch content is at least 67%. Dry chips must meet the Chinese government's import and export standards, especially inspection and quarantine standards issued by the State Administration of Quality Supervision, Inspection and Quarantine Import and Export Food Safety Bureau.

The main uses of cassava in China are for production of animal feed, other uses (ethanol and non-food starch) and food (**Figure 2**). Modified starch is used mainly in the paper and textile industries, as well as in a host of food products requiring special starch characteristics.

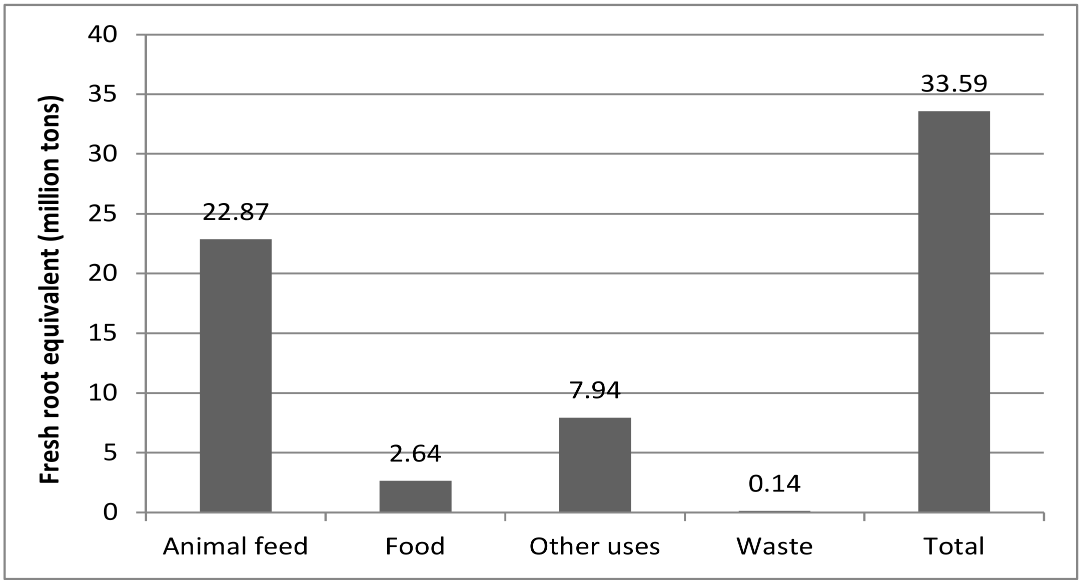

Figure 2. Total utilization of cassava in China in 2013.
***Source:** FAOSTAT, 2015.*

Cassava as an Attractive Crop for Smallholder Farmers

Cassava can grow on poor soils and once it is established, it becomes a drought tolerant and water efficient crop. As a relatively undemanding crop in terms of its needed inputs, cassava can be considered an excellent pro-poor crop compared to other upland crops (Ung Sopheap *et al*., 2012; Howeler *et al*., 2013; Howeler and Aye, 2014). The crop has high-yield potential and can be grown under a wide range of upland conditions. It grows reasonably well at low soil fertility and in areas with low or unpredictable rainfall − conditions which limit the growth of many other food and feed crops. Cassava can grow well in relatively simple production systems, while its wide range of uses for farmers also contribute to its pro-poor status.

While traditionally a subsistence crop, cassava has become a very important cash crop in Southeast Asia in terms of smallholder income and rural livelihoods, with significant contributions to regional and national economies. The global trade in cassava products (starch and dried cassava chips) has increased substantially in recent years and is now valued at around USD 3.5 billion annually (FAOSTAT, 2015). There has been a rapid increase in demand linked to the consumption of starch-based products (including sweeteners, plywood, paper and cardboard, processed foods and bioplastics). Both production and consumption of traded cassava is concentrated in Asia, which accounts for over 95% of world exports.

Cassava Production in Southeast Asia

Cassava has been both a mechanism for livelihood improvement at the household level, and a national source of income in developing Southeast Asian countries. The impact of cassava production in Southeast Asia has been immense. The major producing countries are Thailand and Indonesia, followed by Vietnam and Cambodia.

Thailand and Indonesia cultivate over 1,000,000 ha of cassava in each country and produce about 3.0 and 2.4 million tonnes of fresh roots, respectively; they remain the first and second largest producers of cassava in Asia in 2013 (**Table 1**). Vietnam grows over 500,000 ha of cassava, producing in 2013 about 9.7 million tonnes, and is the world's second largest exporter of cassava products in the world (MOIT, 2013). The area under cassava has markedly been increasing in Cambodia, Lao PDR and Myanmar. Cassava has become an important source of cash income for resource-poor farmers in many parts of Southeast Asia.

Production of the crop has greatly increased during the past ten years due to a combination of increased demand for both domestic utilization and export. In terms of total production, cassava has now become one of the most important crops in the region. Cassava production data of individual countries in Asia are presented in **Table 1**.

Table 1. Cassava production, area, and yield in various countries in Asia in 2003 and 2013.

Country	Area harvested ('000 ha)		Production ('000 tonnes)		Fresh root yield (t/ha)	
	2003	2013	2003	2013	2003	2013
Total Asia	**3,384**	**4,182**	**55,452**	**88,221**	**16.38**	**21.10**
Cambodia	25	350	331	8,000	13.21	22.86
China	250	286	4,015	4,599	16.02	16.10
India	207	207	5,426	7,237	26.21	34.96
Indonesia	1,245	1,066	18,524	23,937	14.88	22.46
Lao PDR	1	45	4	1,120	5.85	25.17
Malaysia	5	3	93	45	20.22	14.52
Myanmar	12	49	138	630	11.25	12.86
Philippines	209	217	1,622	2,361	7.75	10.89
Sri Lanka	26	24	229	293	8.71	12.21
Thailand	1,022	1,385	19,718	30,228	19.30	21.82
East Timor	10	7	41	27	4.15	4.08
Vietnam	372	544	5,309	9,743	14.28	17.90

Source: *FAOSTAT, 2015.*

Cassava root yields vary widely between countries and within the country, depending on climatic and soil conditions, the varieties planted and crop management. Average cassava yields in Asia have also increased significantly from about 16 t/ha in 2003 to 21 t/ha in 2013 (FAOSTAT, 2015). Much of this improvement reflects the expansion of cassava production into new areas where soils are still relatively fertile. This expansion has been supported by the adoption of new higher-yielding varieties as well as that of more effective agronomic practices, especially the widespread use of better balanced fertilizers.

Closing the Yield Gap in Smallholder Cassava Production

Average cassava yields in Asia are high compared with those in Latin America or Africa. However, the average yields in Southeast Asian countries are much lower than their biological potential yield under optimum growing conditions without supplemental irrigation. Cock *et al*. (1979) calculated that the maximum physiological yield of cassava is about 30 t/ha of dry roots, equivalent to 75-100 t/ha of fresh roots depending on their DM content. Biotic and abiotic constraints – such as varietal constraints, soil related constraints, crop management constraints, climatic constraints and disease and pest constraints limit cassava yields in Southeast Asia. That is why the difference between the average smallholder farmers' yield and the achievable yield on small-holder farms, the so-called "yield gap", is still quite high. The average maximum achievable yield of cassava in Asia was recently estimated at about 46 t/ha by Howeler, 2014b (unpublished). The comparative advantage of cassava is that it will still grow reasonably well under sub-optimal conditions. With high-yielding varieties and good agricultural practices many farmers can expect to obtain cassava yields of around 35 t/ha (75% of maximum achievable yield).

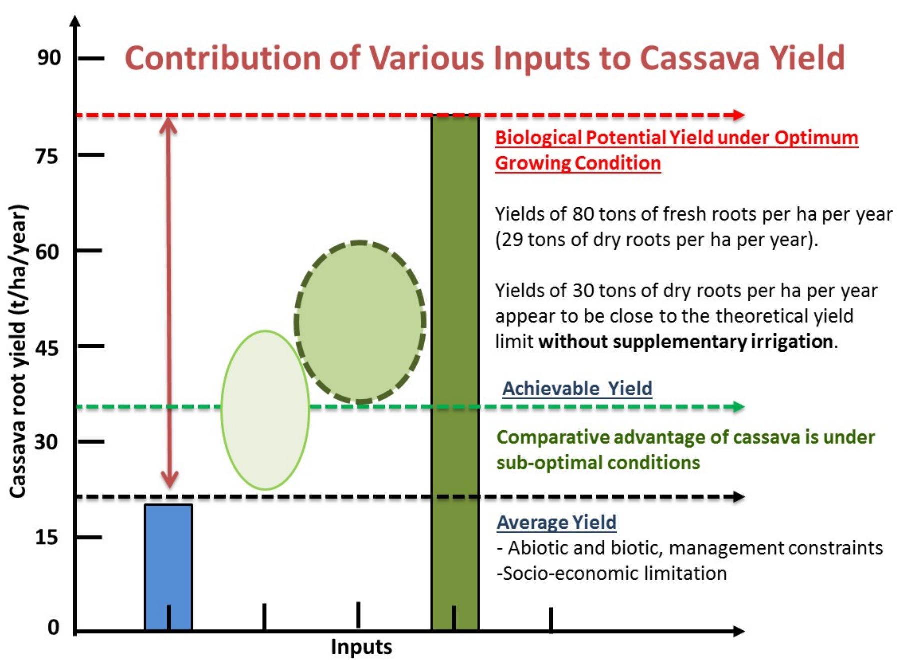

Figure 2. Contribution of various inputs to cassava yields.

Production constraints such as abiotic and biotic constraints, as well as socio-economic limitations, such as lack of access to markets, access to inputs, lack of financial credit, poor infrastructure and inadequate farmer knowledge, limit the average national yields. In addition, the political constraints may contribute to the yield gap. Among the various production constraints, the soil related constraints are estimated to be the most important constraints in Asia (Henry and Gottret, 1996; Howeler, 2014b unpublished).

Production Uncertainties and Constraints for Sustainable Cassava Production

Many farmers see cassava as an easy crop, which needs little inputs or special care. Few farmers understand how cassava should be grown in a sustainable manner to maximize yield and income. Cassava stems are the common planting material for commercial cassava production. To grow healthy plants and obtain high yields, it is important to start with the selection and preparation of good quality planting material from high-yielding varieties and use good agronomic practices.

Lack of suitable high-yielding cassava varieties

During the past four decades, cassava breeders from national programs and CIAT scientists have been developing at least 45 improved varieties in the Southeast Asian region. Many cassava growing areas are already planted with these new varieties. Farmers usually grow well-known and popular cassava varieties, but which may not be the best varieties for their location. One of the main constraints in cassava production is the lack of suitable high-yielding varieties for specific agro-ecological conditions. Smallholder farmers often plant low-yielding varieties and do not use appropriate agronomic techniques. Both on-station and on-farm cassava varietal trials and evaluations can provide possible recommendations concerning the most suitability new varieties for particular locations.

Results from Myanmar and Laos suggest that the best adopted varieties will vary from one place to another even within the country depending upon the agro-ecological conditions (**Tables 2** and **3**).

Table 2. Cassava fresh root yields (t/ha) in variety trials conducted in three locations in Myanmar in 2010/11.

Cassava variety	Tatkone	Nyaung U	Naungmon
KM-98-1	73.3	30.9	38.4
Rayong 72	61.9	32.8	31.1
KU 50	46.2	17.7	42.5
SC 5	41.7	14.6	48.9
HL 23	35.6	17.4	n/a
NARC 61	34.8	27.9	37.5
Nep	33.3	10.9	42.0
Local variety B	31.3	14.1	26.0
Local variety A	31.2	10.8	26.0
SC 205	26.6	n/a	n/a
Rayong 90	10.0	25.6	27.9

At Tatkone Agricultural Research Center, located in the middle part of Myanmar, KM 98-1 from Vietnam and Rayong 72 from Thailand produced the highest yields; Rayong 72 from Thailand gave the highest yield at Nyaung U Agricultural Research Center in the central dry zone, while the highest yields at Naungmon Agricultural Research Center in the northern Shan State of Myanmar were obtained with the Chinese variety SC 5.

Table 3. Cassava fresh root yields (t/ha) and starch content (%) obtained in on-farm variety trials conducted in three locations in Lao PDR in 2010/11.

	Xieng Khouang Phaxay district (1,200 masl)		Vientiane Xaythany district (300 masl)		Luang Prabang Luang Prabang district (700 masl)	
Variety	Yield (t/ha)	Starch (%)	Yield (t/ha)	Starch (%)	Yield (t/ha)	Starch (%)
Rayong 72	38	29	12	23	38	26
Rayong 60	35	26	11	22	na	na
KU 50	31	30	14	26	39	27
Nep	29	29	10	26	20	26
Local	27	22	9	18	19	22
SC 205	24	23	na	na	39	26
Rayong 90	24	27	na	na	35	25

Rayong 72 produced the highest yield while KU50 had the highest starch content in Xieng Khouang Province in the northeastern part of Laos; KU 50 produced the highest yield in Vientiane Municipality in the central part of Laos, while in Luang Prabang Province of north-central Laos, KU 50 and SC 205 from China produced the same high yields, but the starch content of KU 50 was slightly higher than that of SC205. In general the Thai cassava varieties such as KU 50 and Rayong 72 were the best adapted varieties in many parts of Laos, except in the higher elevation areas which are at more than 1,200 masl.

Shortage of high-quality planting materials

Another main constraint of cassava production is the shortage of healthy and good-quality planting material. Only about 5 to 15 stem cuttings can be obtained from cassava plants. This can only produce 5-15 new plants in the next generation. This multiplication rate is much lower than that of most other food crops. The rate of multiplication also depends on the variety and the growing conditions. If the planting area has been affected by pests and diseases, these may be transmitted to the next generation through infected planting material, resulting in poor growth and low yields. Therefore, the following important things must be considered to obtain healthy and high-quality planting material:

- Cut stems from mother plants that do not show disease and/or pest symptoms
- Cut stems from plants growing in fertile or well-fertilized soils
- Cut stems from mother plants that have produced high root yields
- Cut stakes from the lower or middle part of the stems

Inappropriate land preparation, planting time, methods and spacing

Farmers commonly plant cassava at the beginning of the rainy season, which in most Southeast Asian countries is in April or May, but in Indonesia, this ranges from October to December. Some farmers may also plant towards the end of the rainy season, which in most countries is in September/October, or even in November.

There is a range of cultivation practices currently applied by the farmers, but most of them simply learn about the different methods from each other. For land preparation, many farmers in Thailand, southern Vietnam and Cambodia are now using 4-wheel tractors, while many farmers in Myanmar and northern Vietnam still use cattle and buffalos. When the land is flat or slightly undulating, most farmers plant on the flat (without ridging), but in areas with heavy rainfall and poorly drained soils farmers may also plant on top of ridges. Most farmers in Thailand and Cambodia plant cassava on top of ridges while in Vietnam many farmers plant cassava on the flat. In Thailand, many farmers plant cassava on ridges, in hilly areas mostly up-and-down slope, or they plant on the flat in flat or slightly undulating terrain. Some farmers use contour ridges on gently sloping land. Most farmers in Myanmar plant cassava on hand-made mounds (Aye, 2012).

In Southeast Asia, three planting methods are used, i.e. horizontal, vertical and slanted (inclined). In northern Vietnam and southern China farmers use the horizontal method, while most farmers in Cambodia, Thailand and southern Vietnam use the vertical or inclined method. Farmers plant cassava using different spacing methods (Aye, 2012). The distance between rows varies from 50 to 150 cm. Many farmers in intensive growing areas use 60 to 80 cm between plants within the row.

Inadequate soil fertility maintenance and erosion control

Maintenance of soil fertility and nutrient management in cassava production systems is not well understood at the farmer's level in smallholder farming systems. Soil erosion and decline in soil fertility is common in areas where the crop is not managed appropriately.

In Southeast Asia, most farmers use their own farmyard manure as a source of organic fertilizers. However, urea, and compound fertilizers (mainly 15-15-15 formulated in terms of N, P_2O_5 and K_2O) are also commonly used for cassava. Organic fertilizer (mostly animal manure) is either broadcast and incorporated before planting or applied on the soil surface around each plant shortly after planting. Urea and compound fertilizers should be applied at the time of planting or one month after planting. Depending on the farmers' preferences farmers would sometimes mix urea and various P and K fertilizers. Regarding to soil fertility management, hundreds of fertilizer (short-term and long-term) trials conducted in Asia indicated that the response to particular nutrients may change over time, depending initially on the original fertility of the soil (for example: P deficient soils in northern Laos and K deficient soils in Kampong Cham province of Cambodia). After several years of continuous cassava production, however, the main response is likely to be to K, followed by N and with minor responses to application of P.

Management of soil fertility is of critical importance in sustainable cassava production, especially since the crop has traditionally been grown on less fertile soils, and usually with little or no fertilizer application (Howeler *et al.,* 2013). Continuous cultivation of cassava on inherently fertile soils in the uplands of Southeast Asia, without application of any fertilizers (organic and inorganic), is likely to result in decreasing yields and soil nutrient depletion (Ung Sopheap *et al*., 2012; Howeler and Aye, 2014).

Long-term NPK trials conducted at Khon Kaen Field Crops Research Center in Thailand and at Hung Loc Agricultural Research Center in southern Vietnam show that cassava root yields can be maintained by application of balanced NPK fertilizers even after 25-35 years of continuous cassava planting on the same land. Balanced application of N, P, K mineral fertilizers may increase root yields by 50 to 100% in many areas and even more in very poor soils. The root starch content also increases with the application of N, P and K, but most markedly with the application of K. Application of 100 kg N, 50 kg P_2O_5 and 100 kg K_2O per hectare, plus reincorporation of plant tops or compost, achieved yields of up to 40 t/ha (Howeler, 2014) of fresh roots in many places without declining soil fertility.

In Southeast Asia, many farmers grow cassava on gently sloping to steep lands in the upland areas. Soil erosion is also a major constraint in maintaining cassava yields, especially in northern Vietnam, northern Laos and Yunnan province of China. However, to recommend that farmers do not plant cassava on sloping lands is unrealistic when more profitable alternatives do not exist. General principles of farmers' friendly and cost-effective erosion control practices, such as adequate fertilization, closer plant spacing, intercropping, and contour hedgerows, should be encouraged. Intercropping with short-duration crops, like peanut, will generally result in reduced soil loss by erosion (Aye and Howeler, 2012). Previous research also showed that planting contour hedgerows of vetiver grass (*Vetiveria zizanoides)*, *Tephrosia candida* or *Paspalum atratum* is usually the most effective in reducing erosion by slowing down the run-off, trapping eroded sediments and supplying *in-situ* mulch to cover the bare soil between cassava plants (Howeler, 2014a).

Emerging cassava pests and diseases of cassava

Unlike in other parts of the world, cassava in Southeast Asia has been largely free of pest and disease problems, although this situation is changing quite rapidly. Many farmers consider that pests and diseases are not serious problems for cassava production. But cassava production in Thailand declined by between 20 and 30% in 2009/10 due to infestations by the pink cassava mealybug (*Phenacoccus manihoti*). This species of cassava mealybug has also caused major problems in Cambodia. The biological control of the cassava mealybug through the mass release of the parasitoid wasp *Anagyrus lopezi* has been rolled out in parts of the Southeast Asian region, although the spread and continuous efficacy of control may need to be confirmed. A number of other pests, including other mealybug species, mites and whiteflies, as well as a number of diseases caused by phytoplasma, bacteria, and fungi in the region are a concern. Several of these pests and diseases, if unchecked, appear likely to cause major declines in production and thus declines in the livelihoods of many poor farmers. Perhaps the most worrying of these is the cassava witches' broom (CWB) disease. This disease, caused by a phytoplasma, has recently been observed in many cassava growing areas in Southeast Asia, including Vietnam, Cambodia, Lao PDR and Thailand.

Lack of systematic planning and technical assistance to the cassava sector

Cassava production, processing and marketing in many parts of Southeast Asia is done with little planning or technical assistance. Cassava fresh roots and/or dry chips are often in oversupply causing large post-harvest losses due to delayed transportation and marketing. Another major problem is logistics, i.e. inadequate roads and sea port facilities. Many countries rely on export markets. In Thailand, there are only two big ports that have efficient facilities to ship cassava to China.

Unstable prices of cassava products

In Southeast Asia, cassava products are increasingly gaining access to foreign markets. Nevertheless, smallholder farmers are encountering a number of constraints including price fluctuations and market access. Cassava markets are not so stable because of the volatility of prices of cassava products set by cassava factories and traders. At the time of the main harvesting season, the price of cassava products tend to be low, about 2-3 times lower than in the off-season. These prices are the farm-gate prices that the farmers receive from the middlemen, local collectors, and outside collectors. These prices are not the same at all locations in each country. When farmers have access to transportation, they can also take the roots directly to drying floors or starch factories. In only a few countries the root price is based on the starch content, which encourages farmers to plant varieties with high starch contents.

Low investments in research and extension systems

In most countries in Southeast Asia there has been a natural focus on rice production in both research and extension systems, especially in the Mekong Region. Many rice demonstrations and stations are located in optimal locations and encourage the use of high input levels. On the other hand, cassava has been an ideal crop for resource-poor farmers, which has made its production an important activity for local livelihood development. However, it has attracted limited government investment and continues to face concerns over sustainability. This lack of support is a serious constraint for the development of sustainable cassava cropping systems, where appropriate agronomic practices as well as stress tolerances in the development of new varieties are both becoming very important. The investment in cassava research and extension systems should be improved to ensure sustainable cassava production by smallholder farmers. The transfer-of-technology (TOT) approach is used by many national extension programs, but involving farmers directly in the testing of new varieties and technologies, called farmer-participatory research (FPR) trials, is often more effective in identifying technologies that are suitable for the farmers' particular situation. This approach may be more effective in achieving adoption of location-specific technologies; it is an effective way to increase farmers' knowledge, yields and income, and is very essential for improving sustainable cassava production systems in the region.

CONCLUSIONS

Cassava production is an attractive option for smallholders, many of whom have relatively few other options for raising income and linking effectively to markets. For this reason, governments and development agencies should be increasing their interest in cassava as a potential pathway out of poverty for the many rural poor.

Although cassava can help to improve household incomes, general livelihoods and opportunities of smallholder famers in Southeast Asia, there are serious concerns about yield declines, price fluctuations, market instability, land degradation, and maintaining the overall sustainability of cassava production. However, with improved management, greater production, and higher profitability, resilience can be attained. The increase in demand for feedstock has also seen production move into more fragile landscapes, typically without the adoption of best management practices. This is leading to concerns regarding the environmental impact of the cassava boom in Southeast Asia, particularly in Vietnam. Governments of Thailand and Vietnam are seeking to maintain or reduce the current production area, with production increases to meet the growing demand to be derived from yield gains. To maintain the attractiveness of cassava as a feedstock for a range of processing industries, cassava production must be highly cost effective and more environmentally friendly so as to allay concerns about land degradation.

Applied research and development continues to be undertaken by CIAT and partners in a number of projects in Lao PDR, Cambodia and Myanmar. The main focus of the work on cassava production are on the evaluation of germplasm to ensure that the most appropriate varieties are identified for each location, that information is available for the next improved varieties to be selected and that improved management options appropriate for each location can be identified, including soil fertility management, intercropping, crop rotations, management of planting and weeding, and more. In addition, there is work related to on-farm utilization of cassava, value adding by farmers and utilization of processing wastes to help both industry and smallholders.

Farmer Participatory Research and Extension (FPR&E) methodologies are used in these activities, which are undertaken in collaboration with provincial and district agriculture staff so as to increase the chances for local innovation and adoption. Due attention is also focused on the best way to manage other issues, such as socio-economic, ethnic and political situations, which have to be considered to ensure both appropriateness and adoption. There is an urgent need for more in-depth studies leading to research and development regarding cassava production, aimed at improved cassava production and the sustainability of the cassava sector for smallholder farmers in Southeast Asia. Links between farmers and cassava markets, credit systems, and other technology related aspects of cassava production all need to be improved. Steps are necessary to train more agriculture practitioners, cassava researchers, extensionists and progressive farmers in major cassava growing areas in the Southeast Asian countries.

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THE CHINESE CASSAVA AGRO-TECHNOLOGY RESEARCH SYSTEM (CCARS)

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ABSTRACT

In southern China cassava is mainly used for industrial processing to produce starch and biofuel; it is also a potential staple food crop. Recently, demand for cassava-based starch and bioenergy products have been increasing due to their economic benefits as compared to those of other crops. However, what is the impact of these industrial-processing products on poor rural people? Meanwhile, the increasing demand for feedstock for the production of bioenergy and industrial starch, as well as global concerns about environmental pollution, are leading policy makers to look more deeply into this emerging market as a potential contributor to rural poverty reduction. In view of these issues, the Chinese Ministry of Agriculture broke the boundaries between administrative divisions, departments and disciplines and established the Chinese Cassava Agro-technology Research System (CCARS), aiming to study the economics of rural cassava planting and processing, and to assess its impact on poverty by fully integrating and extensive use of the resources coming from the Chinese central government and from local government administrations, from research, teaching, extension, commercial enterprises, farmers' organizations and other social forces. In this review, we describe the mission, structure and responsibilities of CCARS, and show CCARS' contributions to smallholders, researchers and commercial enterprises, suggesting that the setting up of the CCARS system has greatly benefitted the further development of the whole cassava value chain in China.

Key words: Cassava, CCARS, China.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a species native to tropical America, initially cultivated by the indigenous peoples of Latin American and later introduced into the African and Asian continents (Ferreira *et al*., 2008). Currently, it is the sixth food crop in the world and its large starchy roots and high-protein leaves provide a

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basic and inexpensive dietary component for 800 million people, many of whom live under the poverty line in many tropical and sub-tropical countries of Africa, Asia and Latin America. Resilient to drought and various diseases, and tolerant of low-soil fertility enable the crop to grow well under a wide range of climatic conditions, where few other crops could survive without costly external inputs (Ceballos *et al*., 2010). Cassava is also called "the King of Starch" and "Underground Granary". The high starch content (20-40%) makes cassava a desirable source of energy, both for human consumption and for industrial biofuel applications (Prochnik *et al*., 2012). Cassava can be harvested at any time between 6 and 24 months after planting, making it also very useful as a food security crop. However, cassava faces several limitations, such as the crop's heterozygous genetic makeup, which makes it time-consuming to breed efficiently, and the parental lines used to generate new segregating progenies, makes it difficult to identify the parents with good breeding values (Ceballos *et al*., 2004). Cassava also has a complex biological phenomenon named postharvest physiological deterioration (PPD). Estimated losses reach up to 8%, 10% and 29% in Asia, Latin America and Caribbean, and in Africa, respectively (FAO, 2000). In addition, cassava mosaic disease (CMD), caused by different species of cassava mosaic geminiviruses, is the most important disease of cassava in Africa and on the Indian sub-continent (Herrera-Campo *et al*., 2011).

MISSION, STRUCTURE AND RESPONSIBILITIES OF CCARS

In southern China cassava is not a staple food, but it mainly provides the raw material to produce starch, biofuel and animal feed (Gu *et al*., 2013). Recently, cassava-derived bio-energy production has been increasing due to its economic benefits compared to other crops. However, what is the impact of bio-fuel production on poor rural people, and the trade-off between food security and fuel production? Meanwhile, the increasing demand for feedstock to produce bioenergy as well as global concerns about environmental pollution are leading policy makers to look more deeply into this emerging market as a potential contributor to rural poverty reduction.

In order to cope with the challenges described above, both in China and in the world, the Ministry of Agriculture (MOA) of China has established the Chinese Cassava Agro-technology Research System (CCARS). The mission of CCARS is to organize and coordinate the development of the whole Chinese cassava industry, and implement the industrial plans regarding cassava sciences and technologies, arrange and coordinate cassava research at laboratories, and technological demonstrations and technology transfer mechanisms in experimental stations.

CCARS comprises ten Functional Labs (FLs) and ten Integrated Experimental Stations (IESs). A chief scientist (CS) and his/her office were set up in CCARS to lead and manage the activities of CCARS. Each FL is comprised of a principal investigator (PI) and his/her team; in like manner, each IES has a head and his/her team. Every year, the Ministry of Agriculture has provided financial support of 0.3 million RMB to the chief scientist, 0.7 million RMB to the principle investigator of each Functional Lab, and 0.5 million RMB to the leaders of the Integrated Experimental Stations. It means that the Ministry of Agriculture has provided inputs of 12.30 million RMB (about 2 million US $) to CCARS every year. So far, CCARS has operated about ten years. The ten Functional Labs include Genetic Resource Evaluation, Molecular Assisted Breeding, Transgenic Breeding, Seedling Breeding, Management of Pest Control, Management of Disease Control, Soil and Fertilizers, Cultivation Management, Post-harvest Treatment and Processing, and New Product Development and Utilization. According to the various regions of the cassava industry and the characteristics of product marketing in China, ten Integrated Experimental Stations were established in Guilin, Beihai, Wuming and Wuzhou of Guangxi Province, Guangzhou in Guangdong Province, Baisha in Hainan Province, Baoshan in Yunnan Province, Sanming in Fujian Province, Nanchang in Jiangxi Province, and Changsha in Hunan Province, to carry out the experiments, demonstrations and extensions of cassava integrated technologies, and to provide the training courses to cassava smallholders and technicians in villages, towns and counties.

To use CCARS as a platform, workshops involved in developmental strategies and international or intranational collaboration in cassava industrial technologies will be organized every year, as well as the collaborations and exchanges in cassava production technologies at home and abroad. The Tropical Crops Genetic Resources Institute (TCGRI) of the Chinese Academy of Tropical Agricultural Sciences (CATAS), a public welfare research institution under the Chinese MOA, is the host institution of the Chief Scientist of CCARS. TCGRI has several cassava research platforms including the National Cassava Germplasm Bank, Key Laboratory of the MOA for Germplasm Resources Conservation and Utilization of Cassava, the National Potato Professional Technical Processing Center, the MOA's Tropical Crop Seed and Seedling Quality Supervision and Testing Center (Danzhou), etc. These important platforms would support the activities of CCARS' R&D. The actual problems and technical requirements coming from cassava smallholders will be investigated and collected into the database of CCARS. Through the establishment of CCARS, different cassava researchers in different institutions would be effectively organized and cooperate together to improve the efficiency of cassava breeding according to the missions of CCARS and avoid research duplication and unproductive competition.

CONTRIBUTIONS OF CCARS

Since the establishment of CCARS, the following benefits for the cassava industry, for smallholders, researchers and commercial enterprises have been obtained:

1. Contributions to Smallholders

1) Increasing the speed of release and extension of new cultivars. After 30 years of cooperation with the International Center for Tropical Agriculture (CIAT) in the areas of cassava germplasm transfer, training courses and the implementation of cooperative projects, CATAS has set up the National Cassava Germplasm Bank (NCGB), which will be a backup bank of CIAT cassava germplasm in Asia, as well as the National Base for Cassava Crossbreeding (NBCC). Both cassava platforms have been helpful to cassava breeding in CCARS. NCGB is conserving more than 500 cassava core germplasm accessions and NBCC has provided many advanced hybrid parents to cassava breeders. As a result of the establishment of NCGB and NBCC, CATAS has released 13 new cassava cultivars with high yield and high starch content to the smallholders in China, such as SC5 and SC8 (**Figure 1**). These advanced cultivars were also extended to other Southeast Asian countries (**Figure 2**), including SC5 and SC13 for starch industries (Ye, 2009; Ye *et al*., 2014).

Figure 1. Development and release of the high-yield and high-starch cultivars SC5and SC8 by CATAS.

Figure 2. New cassava cultivars, such as SC 5 (on left) and SC 13 (on right), have also been provided to other countries in Southeast Asia.

2) Development of effective cassava production technologies. Through the development of improved cassava cultivation technologies by integrating crop rotation, intercropping, under-sowing, plastic mulching and returning stems to the field, CCARS has provided many benefits to cassava smallholders (**Figure 3**).

Figure 3. Developing a package of effective cassava production technologies for smallholders.

In addition, CCARS also developed a Farmer Participatory Research (FPR) methodology, an effective way to enhance the transfer and extension of agricultural technologies, to increase the capacities of technological demonstrations and extensions, and of monitoring and evaluation. Through their participation in FPR training courses, many smallholders have selected better cultivars, improved their cassava production practices, including pest and disease control (Huang *et al*., 2006). Following the FPR methodology, cassava's nutrient diagnostics for using chemical fertilizers was developed; for instance, to produce cassava yields of 30 t/ha of fresh roots you will need to apply about 100 kg N, 20 kg P_2O_5 and 120 kg K_2O/ha, i.e. to apply the three macro nutrients in the ratio of $N:P_2O_5:K_2O$ of 5:1:6. With the extension of new cassava cultivars and advanced cultivation technologies to smallholders in China, the yields of fresh tuberous roots have increased 38.9%, as well as an increase of 2.71% in dry matter content, and 2.08% in starch content (CATAS, 2009).

3) Accelerating cassava mechanization for planting and harvesting In cassava production, cutting stems and planting them in the field, or harvesting tuberous roots and moving them from the field, are the most labor-intensive operations. Most of the planting and harvesting operations are done by manual methods using tools such as hoes. By hand, one hectare cassava planting can be done by 12 people in one day, but using a planting machine, one hectare of cassava can be planted by three people in an hour. Similarly, one person can harvest 400 kg tuberous roots per day. However, using a machine, a person can harvest 800-1000 kg in one hour.

2. Contributions to Researchers

1) Increasing the cooperative capacities in different teams. In order to investigate the effect of the interaction between genotypes and environments on the physico-chemical traits of cassava roots and starches, professor Gu Bi's team and professor Chen Songbi's team worked together under the same CCARS platform to assess fourteen quantitative characteristics (paste clarity, pasting temperature, viscosity etc.) in seven South China cassava genotypes released by NCGB, grown in eight locations in China. The results indicate that the examined traits could be significantly affected by the factors of genotypes and environments, and the different contributions of genotypes and environments to total variation were determined. A most important economic trait, dry matter content, ranging from 18.3 to 31.9% in seven genotypes, was negatively correlated to rainfall in cassava growing environments, but insignificantly correlated to temperature. Principal component analyses demonstrated that SC8 is the best genotype suited for industrial applications and all cassava genotypes responded differently in various environmental climatic conditions for the examined traits (Gu *et al*., 2013). This result also revealed that SC8 could be used as a good hybrid parent in the crossbreeding program.

2) Improving the capacities to solve complicated problems. Cassava has several limitations, such as low seed set, high genetic load and a heterozygous genetic makeup. It will take a long time to breed a new superior cultivar. In order to indicate the mysterious regulated network, CATAS organized many groups in CCARS to implement cassava genome sequencing. It took more than 50 researchers and a 5-year team cooperation to present the draft genome sequence of a wild ancestor and a domesticated variety of cassava, and to identify 1,584 and 1,678 gene models specific to the wild and domesticated varieties, respectively. It showed the mechanism of cassava's high heterozygosity and discovered millions of single-nucleotide variations, and also analyzed the genes involved in photosynthesis, starch accumulation and abiotic stresses (Wang *et al*., 2014). This cassava genome sequencing data will be helpful in the verification of the functions of proteins in the biological network of leaf photosynthesis and starch accumulation in tuberous roots (Li *et al*., 2010). All these data will also provide a guide for the researchers who work on cassava genetic transformation and molecular-assisted breeding.

3. Contributions to Commercial Enterprises

1) Increasing information sharing regarding cassava processing and marketing of cassava-based products. Cassava can be processed to various products for diverse uses, such as cassava chips, starch, animal feed, bio-ethanol and cassava-based foods. In southern China, the main actors of the cassava value chain are farmers (both small-scale and large-scale), traders and processors. There are about 200 cassava processing factories in China, of which more than 60% are located in Guangxi Province. Most cassava producers are self-employed, and they tend to specialize in a single product, cassava roots, which results in strong competition. Since the establishment of CCARS, cassava producers can share much useful information regarding cassava cultivars, cultivation practices, processing and cassava-based products by consulting the CCARS website in order to improve their product quality against the strong competition based on their own advantages.

2) Improving the cassava value chain in China. In cassava production, all factors, including cultivar, cultivation methods, processing and markets will have different responsibilities in improving the cassava value chain. Using CCARS as a platform, all factors for improving the cassava value chain would be systematically arranged together to efficiently display their responsibilities. Finally, the cassava value chain has improved in the aspects of cassava processing based on the following implementations: 1. the cassava processing procedures were updated to increase starch extraction by more than 25% and decrease energy consumption by more than 20%; 2. Various cassava-based modified starch products were developed for special purposes; 3. Wastes from cassava ethanol and starch factories were used to be a matrix for growing edible mushrooms, and to make organic fertilizer and alternative animal feedstuff.

CONCLUSIONS

The establishment of CCARS in China has brought great benefits to cassava smallholders, researchers and commercial enterprises. It clearly defined the functions of government, researchers, smallholders, processors and markets in the cassava value chain, systemically arranged the responsibilities of different actors in cassava production, and increased their collaborative opportunities against the competition. It is an advanced platform to improve the cassava value chain, and this successful experience in China could be helpful to other countries as well.

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RECENT CHANGES IN THE CASSAVA SECTOR IN VIETNAM

Nguyen Van Bo[1] *and the Vietnam Cassava Research and Development Network*

The cassava production and processing industry in Vietnam has experienced enormous changes in the last decade. During the past 20 years the area planted to cassava has nearly doubled, from about 278,000 ha in 1993 to 544,000 hectares in 2013, while at the same time, with the adoption of high-yield and high-starch varieties, the average yield has also doubled from 9 to about 18 t/ha. The vast majority of cassava in Vietnam is produced by smallholder farmers, for whom it constitutes one of the more important sources of income, especially in poorer communities.

Cassava processing was a very minor business in Vietnam just 20 years ago, whereas now there are more than 80 large cassava starch-processing factories throughout the country, with many more smaller factories. In Tay Ninh Province, which is the largest producer of cassava and has the highest average yield, there are more than 80 starch factories, both large and small. The export of dried cassava chips and of processed starch has grown from a minor industry and now constitutes one of the larger export sectors. Much of the export of cassava products, particularly dried chips, goes to China, with smaller amounts, mainly of starch, to Singapore and elsewhere. In 2010 export income from cassava grew faster than any other export, with a final value of more than US$800 million, making cassava one of the top agricultural export commodities.

A new area of processing is ethanol for use as fuel. The country's four ethanol-producing plants have a capacity of 320 million liters per year, with another 300 million liters of capacity expected to come on line soon from three plants under construction in Phu Tho, Quang Ngai and Binh Phuoc Provinces. At the current production levels of cassava, these ethanol plants could consume as much as one-third of total production and half of current exports of chips, much of which is currently used for bio-ethanol production in China.

While the industry is in good health, there are risks. High-yielding and high-starch varieties have been adopted by most farmers in Vietnam, but about three-quarters of all cassava grown is one variety, namely KM 94. Currently this variety performs well; however, there are always concerns when one variety dominates to such an extent. There are several promising recently released varieties that should be good alternatives to KM 94, but a more systematic approach to breeding and varietal distribution is needed. Cassava production has been largely pest and disease free for many years, but this is changing. The cassava mealybug, *Phenacoccus manihoti*, has caused major problems in Thailand and Cambodia, although as yet has not been a major problem in Vietnam. By contrast, there are a number of diseases that are causing concerns. A timely response to all cassava pest and diseases, in terms of cultural measures of control and breeding for resistance, is now needed. Another threat to cassava production is the low sustainability of many cassava production systems in terms of management of soil fertility and prevention of soil degradation from erosion. The challenge is to work with farmers to identify which are the most appropriate site-specific management systems.

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CASSAVA CONSERVATION AND SUSTAINABLE DEVELOPMENT IN VIETNAM

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ABSTRACT

The project entitled "Vietnam Cassava Conservation and Sustainable Development" has been very successful, as indicated by the results of trials and demonstrations conducted in Tay Ninh, Dak Lak, Phu Yen and Dong Nai provinces, where farmers using the improved technologies and practices boosted cassava yields from 8.5 t/ha to 36 t/ha - a more than four fold increase.

During the period from 1975 to 2015 cassava has become the third most important food crop in Vietnam, after rice and maize. In 2013 the cassava area in Vietnam reached 544,300 ha, with a production of 9.74 million tonnes, and an average yield of 17.9 t/ha. Within Asia, Vietnam is now the third largest cassava producer, after Thailand and Indonesia. Between 1975 and 2000, cassava yields in the country ranged from 6 to 8 t/ha, and the crop was grown mainly for human food and animal feeding. This changed markedly with the introduction by CIAT in 1988 of some high-yielding breeding lines and varieties from Thailand. Two varieties, Rayong 60 and KU 50, were selected for release in 1993 and 1995 and were named KM60 and KM94, respectively. During the 1990s and the first decade of the 21st Century, Vietnam produced several new cassava varieties, initially mainly selections from sexual seed from Thailand and CIAT, such as KM95-3, SM937-26, KM98-1, KM98-7, but our breeders also made crosses that resulted in the release of the latest new varieties: KM140, KM98-5, KM419 and others. The breeding and adoption of new varieties as well as the development and adoption of more sustainable production practices resulted in a complete transformation of cassava, from a poor man's food crop to a highly profitable industrial crop.

More recently, new advances in cassava cultivation techniques have focused on key demonstration sites in the provinces of Tay Ninh, Dak Lak and Phu Yen using mainly KM419 as a very promising short-duration cassava variety with a fresh root yield of about 35-55 t/ha (28% higher than KM94) and a starch content of about 28-31%. This and other new varieties, together with new advances in cassava cultivation techniques, have yielded spectacular results in trials organized in those three provinces.

The Vietnam National Cassava Program (VNCP) has introduced various methodologies, named "6M" and "10T", as well as Farmer Participatory Research (FPR), as collaborative experiences that helped to bring advanced technologies into production for millions of poor farmers. This included the selection of high-yielding varieties and the testing and selection by farmers of locally appropriate technologies. Cassava in Vietnam has great potential but also faces big challenges. At the national level, cassava has become one of the main export crops, which has provided for millions of smallholders an opportunity to increase their yields and improve their standard of living.

Key words: Cassava, production, utilization, cultivation techniques, achievements, lessons and challenges, conservation, sustainable development, Vietnam.

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OVERVIEW OF CASSAVA PRODUCTION AND UTILIZATION IN VIETNAM

Current Cassava Production in the World and in Vietnam

Cassava (*Manihot esculenta* Crantz) has become one of the most important crops in the world, used as food, feed and fuel (**Table 1**). In terms of production, cassava currently ranks 5th, far behind maize, rice, wheat, and potato**.** But, in many tropical countries, especially in Africa, it is the most, or second most, important food crop. Cassava is not only a crop used for food, but also for animal feed, starch processing and in many countries it is currently the main raw material for biofuel processing, including in Vietnam (Nguyen Van Bo *et al.,* 2013). Compared with 1980, the cassava growing area in the world in 2011 had increased 44%, more than any other food crop (Howeler, R.H. 2014).

Table 1. Production, area and yield of major food crops of the world and Vietnam in 2013.

	World			Vietnam		
Food Crops	Production (million t)	Area (million ha)	Yield (t/ha)	Production (million t)	Area (million ha)	Yield (t/ha)
Maize	1,016.74	184.19	5.52	5.19	1.17	4.43
Rice	745.71	164.72	4.52	44.03	7.90	5.57
Wheat	713.18	218.46	3.26	-	-	-
Potato	368.09	19.46	18.91	0.31	0.02	13.57
Cassava	**276.72**	**20.73**	**13.34**	**9.74**	**0.54**	**17.89**
Barley	144.75	49.78	2.90	-	-	-
Sweet Potato	110.74	8.24	13.43	1.36	0.13	10.03
Sorghum	61.38	42.12	1.45	-	-	-
Yam	60.19	5.05	11.91	-	-	-
Millet	29.87	32.91	0.90	-	-	-
Oat	23.82	9.75	2.44	-	-	-
Taro	9.97	1.29	7,67	-	-	-

Source: *FAOSTAT, 2014, cited by Hoang Long et al., 2014*

In 2013, 57.09% of cassava was planted in Africa, 31.98% in Asia and 10.93% in Latin America (**Table 2**) (FAOSTAT, 2014). The table shows that the ten countries in the world with the highest cassava production are Nigeria, Thailand, Indonesia, Brazil, Democratic Republic of Congo, Angola, Ghana, Mozambique, Vietnam and Cambodia. Vietnam accounts for about 3.5% of world cassava production.

Thailand is the biggest exporter of cassava products in the world; its market share is 77.6%; the next largest cassava exporters are Vietnam and Indonesia with market shares of 9.7% and 2.4%, respectively (**Table 2**). In 2014 China imported 1.91 million tonnes of cassava starch, a 34% increase over the 1.42 million tonnes it imported in 2013. Of this, 1.58 million tonnes were imported from Thailand, compared with 1.124 million tonnes in 2013, and 0.297 million tonnes were imported from Vietnam, compared with 0.278 million tonnes in 2013 (Jin Shu Ren, 2014).

Table 2. Cassava in the World, Africa, Asia, Americas and in the ten countries with highest cassava production in 2013.

Cassava in 2013	% Global production	Production (million tons)	Area ('000 ha)	Yield (ton/ha)	Export (% in the world cassava trade)
WORLD	**100.00**	**276.7**	**20,732.2**	**13.3**	**100.00**
Africa	**57.09**	**157.9**	**14,177.3**	**11.1**	-
Asia	**31.88**	**88.2**	**4,181.7**	**21.1**	**99.71**
Americas	**10.93**	**30.3**	**2,351.7**	**12.9**	-
Nigeria	19.51	54.0	3.850.0	14.0	-
Thailand	10.92	30.2	1,385.1	21.8	77.56
Indonesia	8.65	23.9	1,065.7	22.5	2.42
Brazil	7.67	21.2	1,525.4	13.9	-
D.R. Congo	5.96	16.5	2,200.0	7.5	-
Angola	5.93	16.4	1,167.9	14.0	-
Ghana	5.26	14.5	870.0	16.7	-
Mozambique	3.61	10.0	780.0	12.8	-
Vietnam	3.52	9.7	544.3	17.9	9.73
Cambodia	2.89	8.0	350.0	22.9	-

Source: *FAOSTAT, 2014, cited by Hoàng Long et al., 2014.*

Within Asia, Vietnam is the third largest producer of cassava, after Thailand and Indonesia. In 2013 about 4.18 million hectares or 20.17% of the whole cassava area in the world was produced in Asia, where the major producing countries are Thailand, Indonesia, Vietnam, Cambodia, India and China. Average yields in Asia were 21.1 t/ha in 2013, much higher than in the Americas and almost double those in Africa. India has by far the highest cassava yield in the world, at about 35 t/ha (FAOSTAT, 2015; Hoang Kim *et al*., 2014a).

An Overview of the Historical Development of Cassava in Vietnam from 1975 to 2015

Between 1975 and 2000, cassava was grown in all regions of the country, except in the Mekong and Red River deltas. Cassava yields in the country ranged from 6 to 8 t/ha, and the crop was grown mainly for human food and animal feeding. In the period 1981-1990, the commonly grown cassava varieties were Gon, Xanh Vinh Phu and H34, which were well adapted to local conditions but had low productivity. The Hung Loc Agricultural Research Center (HARC) belonging to the Institute of Agricultural Science in South Vietnam (IAS) released the higher yielding varieties HL20, HL23 and HL24, which were grown on 70,000-80,000 ha, mainly in the South (Hoang Kim *et al.,* 1990).

This situation changed markedly with the introduction by CIAT in 1988 of some high-yielding breeding lines and varieties from Thailand. Two varieties, Rayong 60 and KU 50, were selected for release in 1992 and 1995, and named KM60 and KM94, respectively (Trần Ngọc Quyền *et al*., 1995, Trịnh Thị Phương Loan *et al*., 1999; Hoang Kim *et al.,* 2001).

During the late 1990s and the first decade of the 21st Century, Vietnam produced several new cassava varieties, initially mainly selections from sexual seed from Thailand and CIAT, such as KM95-3 and SM937-26 (Trần Ngọc Quyền *et al*., 1995), KM98-1 (Hoang Kim *et al.,* 1999), KM98-7 (Trịnh Thị Phương Loan *et al.,* 2008), KM21-12

(Nguyen Trong Hien *et al.,* 2012a); 2012b), but also made crosses that resulted in the release of several new varieties: KM140 (Tran Cong Khanh *et al.,* 2007), KM98-5 (Tran Cong Khanh *et al.*, 2009), and KM419 (Hoang Kim *et al.,* 2014b; Tran Ngoc Ngoan *et al*., 2015).

The Vietnam Cassava Program, supported by the Ministry of Agriculture and Rural Development (MARD), in close cooperation with CIAT's Nippon Foundation Cassava Project and with VEDAN and other cassava processing factories, promoted the rapid multiplication and wide distribution of high-yielding and high-starch varieties, and the adoption of sustainable cassava production practices, especially in the Southeast, Central Coast, Central Highlands and Northern mountains and uplands. Ten million stakes of the new varieties, mainly KM94, KM98-5 and KM140, were distributed to various provinces in this project (Hoang Kim *et al.,* 2001; Hoang Kim, 2003; Hoang Kim *et al.,* 2006a; 2006b; Howeler, 2004; 2008; 2010; Tran Ngoc Ngoan and Howeler, 2007; Tran Ngoc Ngoan, 2008).

The high yield and high starch content of KM94 made it a very popular variety, especially for processing into dry chips and starch. Within the following ten years, KM94 spread throughout the country. It currently occupies about 420,000 ha or about 75.5% of the cassava growing area; this is followed by KM140, KM98-5, KM98-1, SM937-26, KM98-7, HL23 and Xanh Vinh Phu, which occupy 5.40%, 4.50%, 3,24%, 2.70%, 1.44%, 1.08%, 2.70%, and 3.40% of the total area, respectively (Hoang Kim *et al.,* 2010a).

Cassava yields and production in several provinces have doubled in a short time, stimulated by the construction of new large-scale cassava processing factories. New high-yielding cassava varieties and more sustainable production practices have increased the economic efficiency of cassava production. Many farmers have become rich by growing cassava.

Vietnam has become a distinctive model for Asia and the world in the application of selected technologies, such as the planting of high-yielding varieties and the widespread adoption of sustainable cassava production practices. Cassava production and yield have significantly increased in recent years. In 2013 production was 9.74 million tonnes and the yield reached 17.90 t/ha, a nealy five fold increase in production and a doubling of yields compared to 2000, when cassava production was 1.98 million tonnes and the yield was only 8.35 t/ ha (Nguyen Van Bo *et al.,* 2013); Hoang Kim *et al.,* 2014a; Nguyen Huu Hy, 2015) (**Table 3**).

Table 3. Cassava area, yield and production in the World, Africa, Asia, Americas and in Vietnam (1975-2013).

Cassava	Item	1975	1980	1990	2000	2010	2013
WORLD	Area (1,000 ha)	12,839	13,601	15,210	16,957	19,549	20,732
	Yield (t/ha)	8.59	9.12	10.01	10.38	12.43	13.34
	Production (million t)	110.39	124.13	152.37	176.14	243.05	276.72
Africa	Area (1,000 ha)	7,139	7,054	8,598	11,013	12,993	14,177
	Yield (t/ha)	6.50	6.85	8,17	8,66	10.34	11.14
	Production (million t)	46.47	48.34	70.31	95.40	134.40	157.98
Asia	Area (1,000 ha)	2,962	3,887	3,852	3,404	3,877	4,181
	Yield (t/ha)	10.70	11.81	12.92	14.52	19.32	21.09
	Production (million t)	31.72	45.94	49.78	49.45	74.95	88.22
Americas	Area (1,000 ha)	2,724	2,645	2,739	2,522	2,655	2,351
	Yield (t/ha)	11.76	11.69	11.71	12.32	12.59	12.86
	Production (million t)	32.06	29.69	32.08	31.08	33.45	30,25
Vietnam	Area (1,000 ha)	158	442	256	237	498	544
	Yield (t/ha)	7.42	7.50	8.86	8.35	17.26	17.90
	Production (million t)	1.17	3.32	2.27	1.98	8.59	9.74

Source: *FAOSTAT, 2014, cited by Hoang Kim et al., 2014a.*

In Vietnam cassava has become the third most important food crop, after rice and maize. In 2013 the cassava area in Vietnam reached 544,300 ha, with a production of 9.74 million tonnes, and a yield of 17.9 t/ha (**Table 4**).

Table 4. Area, yield and production of the four major food crops in Vietnam (1975-2013).

Crops	Item	1975	1980	1990	2000	2010	2013
Rice	Area (1,000 ha)	4,855.90	5,600.00	6,042.80	7,666.30	7,489.40	7,902.80
	Yield (t/ha)	2.11	2.07	3.18	4.24	5.34	5.57
	Production (million t)	10.29	11.64	19.22	32.52	40.00	44.03
Maize	Area (1,000 ha)	267.10	389.60	431.80	730.20	1,126.39	1,170.32
	Yield (t/ha)	1.05	1.10	1.55	2.74	4.08	4.43
	Production (million t)	0,28	0.42	0.67	2.00	4.60	5.19
Cassava	**Area (1,000 ha)**	**158.80**	**442.90**	**256.80**	**237.60**	**498.00**	**544.30**
	Yield (t/ha)	**7.42**	**7.50**	**8.86**	**8.35**	**17.26**	**17.90**
	Production (million t)	**1.17**	**3.32**	**2.27**	**1.98**	**8.59**	**9.74**
Sweet Potato	Area (1,000 ha)	205.30	450.00	321.10	254.30	150.80	135.90
	Yield (t/ha)	4.47	5.37	6.00	6.33	8.74	10.00
	Production (million t)	0.91	2.41	1.92	1.61	1.31	1.36

Source: *FAOSTAT, 2014, cited by Hoang Kim et al., 2014a.*

Current Production of Cassava in Vietnam

In Vietnam cassava is grown in all regions of the country, except in the Mekong and Red River deltas, which are predominantly used for production of rice. Cassava is an important source of income for many poor farmers thanks to its easy cultivation, low soil fertility requirements, low investment costs, and good adaptation to various bio-physical and farmers' socio-economic conditions. Cassava is widely grown from the far north to the far south of the country, on more than half a million ha and with a production of almost 10 million tonnes (**Table 4**). This is described in detail in various reviews of the status of cassava in Vietnam (Pham Van Bien and Hoang Kim, 1992; 1998; Pham Van Bien *et al.,* 1996 and 2007; Hoang Kim *et al.,* 2003 and 2010a; and Nguyen Van Bo *et al.,* 2013. **Table 5** shows the evolution of cassava production in the various regions of Vietnam from 1995 to 2013.

Table 5. Cassava production (1,000 tonnes) in various regions of Vietnam 1995-2013.

Ecological region	1995	2000	2005	2010	2011	2012	2013
Red River Delta	79.0	87.9	92.4	108.8	268.2	127.8	87.9
Northern Region	606.3	678.5	986.8	1,260.1	1,448.9	1,491.5	1,500.5
North Central Coast & South Central Coast	602.1	645.9	1.855.9	2,607.6	2,977.9	2,972.2	3,017.9
Central Highlands	283.7	351.5	1.446.6	2,179.5	2,582.2	2,525.9	2,526.4
South Eastern	560.8	154.3	2.270.5	2,283.3	2,536.5	2,339.4	2,433.8
Mekong River Delta	79.6	68.2	64.0	82.3	61.8	278.6	175.7
Total	**2,211.5**	**1,986.3**	**6.716.2**	**8.521.6**	**9,875.5**	**9,735.4**	**9,742.2**

Source: *GSO, 2014, cited by Hoàng Long et al., 2014.*

1) *North Central Coast and South Central Coast*: Cassava production is about 3,017,900 tonnes of fresh roots (30.97% of total production). The provinces of greatest production are Binh Thuan, Nghe An, Quang Ngai and Phu Yen.
2) *Central Highland Region*: In 2013 cassava production was about 2,526,400 tonnes of fresh roots (25.93% of total production). Cassava is mostly planted in Gia Lai, Kon Tum, Dak Lak and Dak Nong provinces.
3) *Southeastern region*: Cassava production is about 2,433,800 tonnes of fresh roots (24.98% of total production); most planted in Tay Ninh, Binh Phuoc, Dong Nai, Ba Ria – Vung Tau and Binh Duong provinces.
4) *Northern provinces*: Cassava production is about 1,500,500 tonnes of fresh roots (15.40% of total production); most cultivated in Son La, Yen Bai and Hoa Binh provinces.

Current Utilization of Cassava in Vietnam

Cassava dried chips and starch are one of ten key export products of Vietnam. Vietnam currently has 13 bio-ethanol factories with a capacity of 1067.7 million liters of bio-ethanol per year; 66 industrial starch processing factories, and more than 2000 manual cassava starch processing units. The statistics also shows that of the 9.7 million tonnes of fresh cassava roots produced, 30% serves the domestic demand for food, animal feed, starch, pharmaceuticals, biofuel and industrial alcohol, while 70% is exported. The amount of exported cassava products from Vietnam ranks No. 2 in the world, behind Thailand, and most is destined to Asian countries such as China, South Korea, Malaysia, Indonesia, India, Myanmar and Japan. According to the "Report of Economic Views" of Vietnam, from 2011 to 2014, the planted area of cassava has remained stable at about 0.55 million ha. In 2014, Vietnam exported about 3.4 million tonnes of cassava products, about 90% of which were exported to China (Hoang Kim *et al.,* 2014a).

According to the General Department of Customs of Vietnam, in 2013 the export of cassava and cassava products reached 3.1 million tonnes with a value of US$ 1.1 billion, 25.7% down in volume and 18.6% in value compared with 2012. Vietnam's cassava yield of 17.9 t/ha currently stands at around No.10 among high yielding countries.

NEW ADVANCES IN CASSAVA CULTIVATION TECHNIQUES IN VIETNAM

New advances in cassava cultivation techniques were tested, demonstrated and put into practice in the project entitled "Vietnam Cassava Conservation and Sustainable Development", which focused on key study areas in the provinces of Tay Ninh, Dak Lak, Phu Yen and Dong Nai. Farmers using the improved technologies and practices boosted cassava yields from 8.5 t/ha to 36 t/ha – a more than four-fold increase.

The objectives of the cassava cultivation techniques program are: The productivity of cassava can be increased by the use of the most appropriate varieties as well as by using the most improved methods of production, including **10 techniques (10T) for intensification of cassava** (in Vietnamese they all start with a T):

1. The use of the best planting materials (stakes) of the most appropriate varieties
2. The optimum time of planting and harvesting, for maximum yield and economic returns
3. The appropriate applications of NPK fertilizer combined with animal manure to improve soil fertility and increase yields
4. The optimum plant spacing suitable for the varieties used and for the particular soil
5. The use of integrated pest and disease management (IPDM) to prevent pests and diseases
6. The improvement of the cassava production system by intercropping cassava with groundnut and other legumenous crops; by alley cropping and crop rotations
7. The application of herbicides and plastic mulch for weed control
8. The appropriate method for land preparation and planting, to reduce soil erosion
9. The development of efficient water management systems for cassava
10. Training: from FPR to 10 T; VietGAP for cassava; combining cassava production and utilization.

1) The use of the best planting material (stakes) of the most appropriate varieties

The objectives of the cassava breeding program are to select and release new varieties with a high-yield capacity of 35-40 t/ha, a starch content of 27-30%, a growth period of 8-16 months depending on the optimum time of planting and harvest, erect stems, short internodes, limited branching, compact canopy, uniform root size, white root flesh and being suitable for industrial processing.

As a result, many new cassava varieties have been released (**Figure 1**), among which is KM419. This variety was recently identified and released (Hoang Kim *et al.,* 2014a; Tran Ngoc Ngoan *et al.,* 2015). KM419 is a short-duration variety with a fresh root yield of 35-55 t/ha and a starch content of about 28-31%. It is currently grown on 90,000 hectares of which 30,000 hectares in Tay Ninh **(Table 6).** Cassava yields of many farmers in Tay Ninh province reached 36-50 t/ha, more than 400% higher than before (FAO, 2013b; Nguyen Van Bo *et al.,* 2013; Nguyen Minh Cuong, 2014; Hoang Kim *et al.*. 2014a).

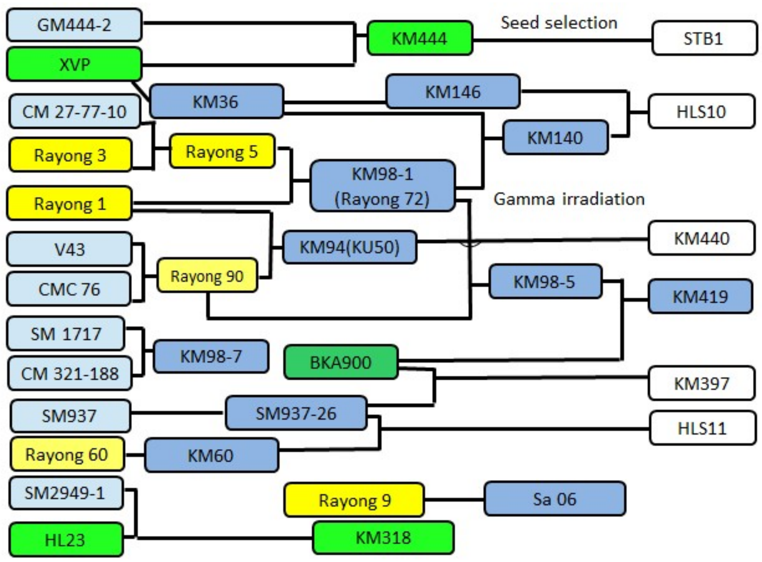

Figure 1. Pedigree of cassava varieties released in Vietnam.

Table 6. Area, yield and production of cassava in Tay Ninh province from 2000 to 2013.

Year	Area ('000 ha)	Yield (t/ha)	Production ('000 tonnes)	The most common varieties
2000	8.0	12.0	9.6	KM94[1)], SM937-26, KM98-1 [2)]
2001	25.4	21.2	538.7	KM94, SM937-26, KM98-1
2002	31.7	21.5	682.3	KM94, KM98-1, SM937-26
2003	35.6	22.5	800.1	KM94, KM98-1, KM140
2004	38.6	23.3	898.7	KM94, KM140, KM98-5
2005	43.3	24.7	1,071.8	KM94, KM140, KM98-5,
2006	45.1	24.8	1,120.7	KM94, KM98-5, KM140
2007	44.5	25.3	1,125.9	KM94, KM98-5, KM140 [3)]
2008	47.8	26.2	1,248.6	KM94, KM98-5, KM419
2009	46.0	26.8	1,236.1	KM94, KM98-5[4)], KM419
2010	40.1	28.6	1,150.7	KM94, KM98-5, KM419
2011	45.7	29.0	1,325.9	KM94, KM419, KM98-5
2012	45.4	30.0	1,317.6	KM419, KM94, KM98-5
2013	45.9	30.0	1,377.0	KM419, KM94, KM98-5

***Source**: GSO, 2014, cited by Nguyen Van Bo et al., 2013; Hoang Kim et al., 2014.*

The key study areas have now expanded to the provinces of Dak Lak and Phu Yen. The adoption of new varieties and new advances in cassava cultivation techniques, cassava conservation and sustainable development have yielded spectacular results in trials organized there. (**Figure 2, Tables 7, 8, 9 and 10**) (Nguyen Thi Truc Mai *et al.,* 2014a and 2015; Nguyen Bach Mai *et al.* 2014b; Tran Ngoc Ngoan *et al.,* 2014 and 2015).

Figure 2. The adoption of new varieties and improved cassava cultivation techniques, has yielded spectacular results in trials organized in Phu Yen in 2015.
Source: *Vietnam Agriculture;* *http://nongnghiep.vn/4-giong-san-moi-post153736.html*

Table 7. Results of a National Standard Yield Trial conducted in sandy grey soil in Dong Xuan district and in red soil in Song Hinh district of Phu Yen province.

Soil type	Cultivar	Yield		Fresh root yield (t/ha)	Starch content (%)	Dry matter content (%)	HI (%)
		Dry chips (t/ha)	Starch (t/ha)				
Sandy grey soil (Dong Xuan)	KM419	13.80a	9.54a	34.90a	27.35a	39.54ab	63.9a
	KM440	12.64ab	8.36ab	31.50ab	27.40a	40.12ab	59.8a
	KM414	10.97ac	7.08bc	27.84bc	26.08b	39.40ab	63.7a
	KM397	10.73bc	7.03bc	26.60bc	26.17b	40.33ab	61.4a
	KM325	9.01c	6.31c	24.18c	26.10b	37.30b	60.7a
	KM98-5	11.20ab	7.47bc	28.01bc	26.80ab	39.98ab	61.3a
	KM94	11.53b	6.80bc	25.64c	26.80ab	44.96a	46.8b
	CV%	11.32	9.35	9.27	3.18	4.50	6.35
Red soil (Song Hinh)	KM419	22.90a	15.16a	53.63a	28.27a	42.70a	64.5a
	KM440	19.95ab	14.44a	50.45ab	28.64a	39.56b	62.7a
	KM444	19.21ab	13.53ab	48.67bc	27.82ab	39.48b	60.5a
	KM414	17.70bcd	12.14b	46.38c	26.18c	38.17c	59.7b
	KM397	18.62abc	12.98b	45.36c	28.63a	41.06a	62.7a
	KM325	13.53de	9.86cd	37.44d	26.35c	36.16c	57.6b
	KM98-5	15.68bcd	10.45bc	38.53d	27.14b	40.72ab	60.8a
	KM94	13.11de	9.08d	32.35e	28.08a	40.54b	56.5b
	CV%	10.35	9.89	8.78	3.54	7.35	5.54

Source*: Nguyen Thi Truc Mai et al., 2014a; 2015.*

Table 8. Yield (t/ha) and economic efficiency of KM419 grown on one hectare each of 12 farmers in Dak Lak province.

No	Farmer	Fresh root yield (t/ha)	Price of fresh roots (VND/kg)	Gross income (million VND/ha)	Production costs (million VND/ha)	Net income (million VND/ha)	Rate of return
1	Hoang Van Huy	36.00	1,700	61.20	37.12	24.07	0.65
2	Ngo Duy Hung	40.50	1,700	68.85	37.12	31.72	0.85
3	Nguyen Van Binh	40.00	1,920	76.80	37.12	39.67	1.07
4	Vu Huu Cong	37.50	1,700	63.75	37.12	26.62	0.72
5	Phung Thi Loan	36.00	1,700	61.20	37.12	24.07	0.65
6	Ho A Si	45.00	1,750	78.75	37.12	41.62	1.12
7	Y Xa Eban	20.00	1,950	39.00	37.12	1.87	0.05
8	Y DHuu Kpor	25.00	1,950	48.75	37.12	11.62	0.31
9	Do Thi Lan	25.00	1,950	48.75	37.12	11.62	0.31
10	Le Van Tam	23.00	1,950	44.85	37.12	7.72	0.21
11	Y Pi MLo	46.50	1,950	90.67	37.12	53.55	1.44
12	Dang Van Thao	45.00	1,950	87.75	37.12	50.62	1.36
	Average	38.83	1,804	70.05	37.12	32.93	0.89

Source: *Nguyen Bach Mai et al.,2014b.*

Table 9. Results of a National Standard Yield Trial conducted in yellow red rocky soil in Krong Bong district and in red yellow soil in Eakar distrct of Dak Lak province.

Soil type	Cultivar	Yield		Fresh root yield (t/ha)	Starch content (%)	Dry matter content (%)	HI (%)
		Dry chips (t/ha)	Starch (t/ha)				
Yellow red rocky soil (Krong Bong)	KM419	19.22a	12.81a	44.50a	28.79	43.2	57.4
	KM440	15.73ac	10.64ab	37.83ab	28.13	41.6	49.4
	KM444	16.23ac	10.47ac	38.19ab	27.43	42.5	52.8
	KM414	17.08ab	11.57a	40.38ab	28.67	42.3	52.1
	KM98-5	15.14ac	10.26ac	36.32ab	28.27	41.7	49.4
	KM140	12.74bc	8.67bc	31.14bc	27.86	40.9	47.0
	KM94	10.49c	6.85c	24.18c	28.37	43.4	48.2
	CV %	16.80	12.96	11.34			
Red yellow soil (Eakar)	KM419	17.3a	12.14a	39.7ab	30.6	43.69	63.4
	KM440	13.6abc	9.03cd	31.8c	28.4	42.84	62.4
	KM444	14.9ab	9.83ab	34.5ab	28.5	43.43	60.0
	KM414	16.2ab	11.06bc	37.5ab	29.5	43.26	61.5
	KM98-5	13.2abc	8.66de	30.4c	28.5	43.42	62.5
	KM140	11.9bc	7.86de	27.9cd	28.2	42.90	61.7
	KM94	9.7c	6.47e	22.8d	28.4	42.83	58.9
	CV %	13.02	14.00	11.21			
	LSD0.05	4.52	2.80	6.89			

Note: In the same column, the average values did not differ significantly according to Duncan test at the 0.05 level. ***Source:*** *Nguyen Bach Mai et al., 2014b.*

Table 10. Yield of KM419 grown on National Regional Trials in Tay Ninh, Phu Yen and Ninh Thuan provinces.

No	Cultivar	Tay Ninh	Phu Yen	Ninh Thuan	**Average**	Yield compared with KM94 (%)
1	KM419 (SVN5)					
	-Area (ha)	15.2	96.9	18.0		
	-Yield (t/ha)	44.1	41.2	41.8	**41.6**	129.6
2	KM94					
	-Yield (t/ha)	32.4	32.2	29.5	**32.1**	100.0

Source: *Tran Ngoc Ngoan et al., 2015.*

2) The optimum time of planting and harvesting for maximum yield and economic efficiency

The best time of planting and harvesting of cassava in Vietnam is variable, depending on local climatic conditions and cropping patterns. Generally, in the Southeastern, Central Highland and South Central Coastal regions, farmers plant cassava in the main season at the beginning of the rainy season (May-June), and in the sub-season at the end of the rainy season (November-January) (Hoang Kim *et al.,* 2003).

Results of experiments on date of planting conducted on a red soil at Hung Loc Center in Dong Nai province show that the highest yields and economic efficiency were obtained when cassava was planted on May 15 for the main season at the beginning of the rainy season; when planted later, cassava yields declined (Nguyen Huu Hy *et al.,* 2007a; Nguyen Huu Hy, 2015).

Results of an experiment on time of harvest conducted in Dong Xuan district of Phu Yên province in the South Coastal region show that the best harvesting time for KM98-5 was at about 9 or 10 months after planting, i.e. from March to April, when cassava produced the highest root and starch yield (**Table 11)** (Nguyen Thi Truc Mai *et al.,* 2014a).

Table 11. Effect of harvesting time on fresh root yield, starch content and starch yield of variety KM98-5 in Dong Xuan district of Phu Yen province.

Havesting time[1)]	Months after planting	Data from experiments			Data of starch content (%) from factory		
		Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)	La Hai	Xuan Phuoc	Dong Xuan
December	6	24.4	27.0	6.59	26.6	27.0	26.5
January	7	27.9	28.3	7.90	28.0	27.7	27.3
February	8	29.3	28.5	8.36	28.9	28.9	28.8
March	9	32.9	28.8	9.48	28.6	28.6	28.6
April	10	34.0	28.1	9.56	28.8	27.3	27.5
May	11	35.4	26.7	9.45	25.4	25.8	25.9

[1)] Planting time was on May 21-22.

Source: *Nguyen Thi Truc Mai et al.,2014a.*

Table 12 shows the results of research conducted in Song Hinh district of Phu Yên province on time of planting and age at harvest for three cassava varieties (Nguyen Thi Truc Mai *et al.,* 2015). These results indicate that:

i) Cassava can be harvested any time, but the roots are usually harvested between 6 and 16 months. Some early-maturing varieties can be harvested at 6–8 months after planting (MAP), but most industrial varieties are harvested between 7 and 16 MAP.

ii) The best planting period was between November and January. The less- appropriate planting time was about late May. The best harvesting time was from November to April.

iii) The appropriate harvesting time for KM419, KM440 and KM444 can vary from 8 to 10 months after planting and may be as long as 16 months when planted in the main season; it can help starch factories to operate for at least 6 months; and for 9-10 months when the crop is planted in the sub-season.

Table 12. Effect of date of planting and time of harvest on fresh root yield, starch content and starch yield of three varieties in Song Hinh district of Phu Yen province.

Variety	Season	Planting time	Harvest time	Months after planting	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)
KM419	the end of the rainy season (Nov-January)	1/2014	11/2014	11	41.50	27.5	11.41
		1/2014	12/2014	12	43.89	27.8	12.20
		1/2014	1/2015	13	45.27	28.6	12.94
		1/2014	2/2015	14	49.65	28.8	14.30
		1/2014	3/2015	15	53.26	30.7	16.35
		1/2014	4/2015	16	56.36	29.8	16.79
KM419	beginning of the rainy season (May-June),	5/2014	11/2014	6	32.35	25.4	8.21
		5/2014	12/2014	7	34.70	26.8	9.30
		5/2014	1/2015	8	37.54	27.9	10.47
		5/2014	2/2015	9	40.40	28.3	11.43
		5/2014	3/2015	10	42.27	28.9	12.22
		5/2014	4/2015	11	45.36	28.4	12.88
KM440	beginning of the rainy season (May-June),	5/2014	11/2014	6	28.70	26.2	7.52
		5/2014	12/2014	7	30.90	27.1	8.37
		5/2014	1/2015	8	38.80	27.3	10.59
		5/2014	2/2015	9	41.30	27.5	11.35
		5/2014	3/2015	10	44.40	28.5	12.65
		5/2014	4/2015	11	46.80	29.7	13.89
KM444	beginning of the rainy season (May-June),	5/2014	11/2014	6	33.26	23.5	7.81
		5/2014	12/2014	7	35.72	24.6	8.78
		5/2014	1/2015	8	36.90	25.8	9.52
		5/2014	2/2015	9	38.20	27.5	10.50
		5/2014	3/2015	10	41.56	27.7	11.52
		5/2014	4/2015	11	42.30	27.8	11.75

Note: KM419, KM440 and KM444 were planted at a spacing of 1.00x0.80 m, or a population of about 12,500 plants per hectare; 100 kg N + 80 kg P_2O_5 + 120 kg K_2O + 10 t/ha farmyard manure were applied.
Source: *Nguyen Thi Truc Mai et al., 2015.*

3) Appropriate application of NPK fertilizer combined with animal manure to improve soil fertility and increase yield

The long-term experiment on NPK fertilizer to cassava at Hung Loc Agriculture Research Center in Dongnai province, clearly shows that cassava yields slowly declined when no fertilizers were applied, and were very low after 21 years of continuous cropping; yields were even lower when N and P had been applied but K had been omitted. (Howeler, 2014; Howeler and Aye, 2014; Nguyen Huu Hy, 2015).

Other experiments on the effect of NPK fertilizers and farmyard manure (FYM) application on cassava yields and economic efficiency were conducted on red soil of Song Hinh and on grey soil of Dong Xuan districts in Phu Yen province of the South Central Coastal region in 2014/15. The results show that the application of fertilizers at the rate of 100 kg N + 80 kg P_2O_5 + 150 kg K_2O + 1,000 kg of the organic fertilizer with micronutrients/ha, or 100 kg N + 80 kg P_2O_5 + 150 kg K_2O + 10 tonnes of manure/ha gave the highest yields and economic efficiency of KM419 in comparison with the control rate of 100 kg N + 60 kg P_2O_5 + 120 kg K_2O or the other NPK rates (**Tables 13** and **14**). This indicates that farmers should apply organic manures combined with adequate and well-balanced chemical fertilizers to maintain their soil's fertility and increase cassava yields and economic efficiency.

Table 13. Effect of the application of NPK fertilizers[1)], FYM[2)] and HCVS[3)] on fresh root yield, starch yield, dry chip yield and economic efficiency of cassava, KM419, in red soil of Song Hinh district in Phu Yen province.

No	Treatments[1)]	Fresh root yield (t/ha)	Starch yield (t/ha)	Dry chip yield (t/ha)	Fertilizer costs (million VND/ha)	Increased costs (million VND/ha)	Net income (million VND/ha)
1	$N_{100}P_{60}K_{60}$	27.3d	7.75d	11.24d	4.66	-1.70	- 16.32
2	$N_{100}P_{80}K_{120}$ (check)	37.5c	10.68c	15.52c	6.36	0	0
3	$N_{100}P_{80}K_{0}$ +10 t FYM/ha	31.1d	8.70d	12.75d	8.96	2.60	-10.24
4	$N_{100}P_{80}K_{90}$ +10 t FYM/ha	45.8b	13.14b	18.92b	10.76	4.40	13.28
5	$N_{100}P_{80}K_{120}$ +10 t FYM/ha	50.6a	14.47a	20.95a	11.36	5.00	20.96
6	$N_{100}P_{80}K_{150}$ + 10 t FYM/ha	54.9a	15.87a	22.89a	11.96	5.60	27.84
7	$N_{100}P_{80}K_{0}$ + 1 t HCVS/ha	29.4d	8.20d	12.11d	7.96	1.60	12.96
8	$N_{100}P_{80}K_{90}$ + 1 t HCVS/ha	39.2c	11.21bc	16.18bc	9.76	3.40	2.72
9	$N_{100}P_{80}K_{120}$ + 1 t HCVS/ha	44.5b	12.77b	18.51b	10.36	4.00	11.20
10	$N_{100}P_{80}K_{150}$ + 1 t HCVS/ha	51.6a	14.86a	21.31a	10.96	4.60	22.56
	CV%	8.72	9.14	10.65			

Note: In the same column, the average value of the characters did not differ statistically significant according to Duncan test at the 0.05 level.

1) Fertilizer rates are in kg/ha of N, P_2O_5, and K_2O, applied as urea, single superphosphate and potassium chloride.

1 US$ = 21,500 VND in 2014/15; Price of cassava fresh root: 1600VND/kg, fertilizers KCl 10.000đ/kg

2) FYM = farm-yard manure (cattle manure)

3) HCVS = organic fertilizer with micronutrients

***Source**: Nguyen Thi Truc Mai et al., 2015.*

Table 14. Effect of the application of NPK fertilizers and FYM[1)] on fresh root yield, starch yield, dry chip yield and economic efficiency of cassava variety KM419 in grey soil of Dong Xuan district in Phu Yen province.

No	Treatments[1)]	Fresh root yield (t/ha)	Starch yield (t/ha)	Dry chip yield (t/ha)	Fertilizer costs (million VND/ha)	Increased costs (million VND/ha)	Net income (million VND/ha)
1	$N_{100}P_{60}K_{60}$	27.6e	7.72	11.04	4.66	-1.70	-10.23
2	$N_{100}P_{80}K_{120}$ (check)	33.8d	9.46	13.52	6.36	0	0
3	$N_{100}P_{80}K_{0}$ +10 t FYM/ha	29.6e	8.28	11.84	8.96	2.60	-6.93
4	$N_{100}P_{80}K_{90}$ +10 t FYM/ha	35.9cd	10.05	14.36	10.76	4.40	3.46
5	$N_{100}P_{80}K_{120}$ +10 t FYM/ha	41.6b	11.64	16.64	11.36	5.00	12.87
6	$N_{100}P_{80}K_{150}$ +10 t FYM/ha	44.9ab	12.57	17.96	11.96	5.60	18.31
7	$N_{100}P_{80}K_{0}$ + 1 t HCVS/ha	28.7e	8.03	11.48	7.96	1.60	-8.41
8	$N_{100}P_{80}K_{90}$ + 1 t HCVS/ha	37.9c	10.61	15.16	9.76	3.40	6.76
9	$N_{100}P_{80}K_{120}$ + 1 t HCVS/ha	42.7b	11.95	17.08	10.36	4.00	14.68
10	$N_{100}P_{80}K_{150}$ + 1 t HCVS/ha	45.8a	12.82	18.32	10.96	4.60	19.80
	CV%	8.60	10.14	12.59			

Note: In the same column, the average value of the characters did not differ statistically significant according to Duncan test at the 0.05 level.

[1)] Fertilizer rates are in kg/ha of N, P_2O_5 and K_2O, applied as urea, single superphosphate and potassium chloride.

1 UD$ = 21,500 VND in 2014/15;Price of cassava fresh root: 1650VND/kg, fertilizers KCl 10.000đ/kg

[2)] FYM = farm-yard manure (cattle manure) [3)] HCVS = organic fertilizer with micronutrients

***Source**: Nguyen Thi Truc Mai et al., 2015.*

Research in North Vietnam during the period 1995-2007 has shown that application of 15 t/ha of pig manure increased cassava yields from 3 to 13 t/ha, while application of only 80 kg/ha of both N and K increased yields to 16 t/ha. However, the application of both chemical fertilizers and rather small amounts (5 t/ha) of manure further increased yields to 18 t/ha, indicating that the combination of chemical fertilizers plus manure was the most effective in increasing yields and produced the highest net income. In this case, the chemical fertilizer supplied most of the macro-nutrients – N, P, and K – while the manure contributed small amounts of secondary and micro-nutrients and supplied organic matter, which further increased yields and will improve the soil's structure (Nguyen The Dang *et al.,* 2007; Nguyen The Dang and Dinh Ngoc Lan, 1998).

4) The optimum plant spacing suitable for the new cassava varieties and for various soils

The best plant spacing of cassava will vary according to the branching habit of the variety, the fertility of the soil, climatic conditions, and whether the crop is grown in monoculture or in association with intercrops.

On red soil of the Southeast region, the plant spacing of 0.9 m x 0.8 m (equivalent to a density of 13,800 plants/ha) gave the highest fresh root yield (37.63 t/ha) (Nguyen Huu Hy*,* 2015).

Research conducted at two different locations in Phu Yen province (**Table 15**) shows that the highest yield of a short, semi-branched variety, KM419, was obtained at a spacing of 1.0 m x 0.7 m, or a population of about 14,500 plants per hectare in both grey soil (34.5 t/ha) and red soil (47.7 t/ha). Most farmers prefer to plant at a spacing of 1.0 m x 0.7 m for maximum productivity, and to facilitate weeding by hand or for intercropping cassava with peanuts (Nguyen Thi Truc Mai *et al.,* 2015).

Table 15. Effect of planting density on the fresh roots yield, starch yield and dry chips yield of KM419 in Dong Xuan and Song Hinh districts of Phu Yen province.

	Fresh root yield (t/ha)		Starch yield (t/ha)		Dry chip yield (t/ha)	
Plant spacing and density	Dong Xuan	Song Hinh	Dong Xuan	Song Hinh	Dong Xuan	Song Hinh
0.8 m x 0.8 m (15.600 plants/ha)	33.8a	42.4a	9.5a	11.95ab	13.5a	17.46ab
1.0 m x 1.2 m (8.300 plants/ha)	29.5b	39.8b	8.3c	11.11ab	11.9b	16.40ab
1.0 m x 1.0 m (10.000 plants/ha)	31.6ab	37.6b	8.8bc	10.60b	12.8ab	15.49b
1.0 m x 0.8 m (12.500 plants/ha)	33.4a	45.2a	9.3ab	12.79a	13.5a	18.62ab
1.0 m x 0.7 m (14.000 plants/ha)	34.5a	47.7a	9.8a	13.45a	13.9a	19.65a
CV%	7.17	8.64	6.21	8.98	4.77	9.17

Note: In the same column, the average value of the characters did not differ statistically significant according to Duncan test at the 0.05 level.
Source*: Nguyen Thi Truc Mai et al., 2015).*

5) The use of integrated pest and disease management (IPDM) to prevent pests and diseases

Following the experience of CIAT, pests and diseases of cassava can best be controlled using the following Integrated Pest and Disease Management (IPDM) practices (Howeler, 2014; Howeler and Aye, 2014):

- Plant cassava varieties with tolerance or resistance to the most important diseases and pests
- Use high-quality planting material cut from mother plants that are free of pest and disease symptoms
- As an extra precaution, treat the stakes with a mixture of fungicides and insecticides before planting
- Apply adequate amounts of fertilizers or manures to stimulate vigorous growth, which enhances resistance or tolerance
- Do not apply insecticides to the crop as these may kill the natural biological control agents that will keep some major pests and diseases under control. Pesticides should only be used as short-term localized applications in “hot spots” where the pest is first observed, and only when the pest is in its early stage of development. Pesticides can be used to control soil-borne pests, such as termites, as this will not affect the natural enemies of foliar pests
- To reduce soil-borne diseases, mainly root rots, rotate cassava with other crops, especially cereals or grasses
- Monitor the crop regularly and pull out plants with symptoms of disease or pest problems. Burn infected plant residues after harvest

- Prevent the movement of diseased or pest-infested planting material from infested to non-infested fields
- Do not purchase planting material from unknown sources, as pests and diseases may be a risk.

6) The improvement of cassava production systems by intercropping cassava with groundnut or other legume crops; alley cropping and crop rotations.

Generally, groundnut and mungbean are used as intercrops with cassava. Besides these, maize, blackbean, soybean, winged bean, sorghum, cashew nut, fruit trees and vegetables are also intercropped with cassava, but to a lesser extent (Nguyen Huu Hy, 2015; Nguyen Thanh Phuong, 2012; Nguyen Thi Thien Phuong, 2012; Howeler and Aye , 2014; Howeler, 2010; 2008; 2004; Howeler and Thai Phien, 2000; Nguyen Huu Hy *et al.,* 2007a; 2007b; 2000; 2002; 1996; 1995; Nguyen The Dang, 2007; Buresova *et al.,* 1987). Although we can show the good effect of alley cropping and crop rotations, or of intercropping cassava with groundnut or other legume crops for soil fertility improvement and soil conservation, most farmers are concerned only with the economic aspects of the intercropping systems.

7) The application of herbicides and plastic mulch for weed control

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 be reduced by adequate and early application of fertilizers to speed up canopy closure, or by intercropping, or by planting towards the end of the rainy season when weed growth is less vigorous. During four years, from 2007 to 2010, Hung Loc Center tested several herbicides for cassava. Herbicide treatments with Dual Gold 960EC at a dose of 2.5 l/ha, or treatments of soil cover with plastic film resulted in the highest root yields (Nguyen Huu Hy, 2015).

8) The appropriate method for land preparation and planting to reduce soil erosion

Best methods of land preparation are tested and implemented by agroecological zones. Farmers learn with hands-on guidance of experienced Tay Ninh farmers, and with videos and reference books (Howeler, 2014; Howeler and Aye, 2014).

9) The development of water management systems for cassava

In Vietnam, cassava is mostly grown on hillsides or on steep slopes without any conditions to obtain water for irrigation during the dry season, so the growth depends entirely on rain and fresh root yields are therefore not as high as in India, or in some other countries. In some irrigated cassava demonstrations in Tay Ninh and Dak Lak provinces, root yields could be as high as 75 t/ha. Therefore, if we can produce cassava under irrigation in the dry season, the income from cassava cultivation might be higher. The problem is the water source for irrigation. Based on the experience of experts of the Vietnam Irrigation Institute, some small to medium-scale ponds can be dug to store water. These ponds can be made with special concrete or HDPE floors, to harvest rainwater for irrigation in the dry season. This is a new direction, so more research is needed to increase cassava yields, especially in mountainous areas to counter the effects of climate change (Nguyen Bach Mai *et al.,* 2014b).

10) Training and development: Sustainable management of cassava, from FPR trials to 10 T, VietGAP for cassava, including cassava production and utilization

Cassava in Vietnam is now a very promising crop for both export and domestic use. VNCP agreed to emphasize the following five topics (Hoang Kim *et al*., 2010a):

1. Determination of an appropriate strategy for cassava research and development in cooperation with processing factories to establish areas with a stable source of raw materials, including the use of cassava for bio-ethanol production.
2. Selection and dissemination of high-yielding varieties with high starch contents and high resistance/tolerance to mealybugs and other pests and diseases. Selection of partially inbred lines derived from materials from CIAT and applying mutation breeding. Selection and development of varieties with high root yield, short duration and with improved quality and nutritional value of cassava roots.
3. Research on integrated cultivation techniques and transfer of appropriate cultivation techniques to farmers to increase the productivity and economic efficiency of cassava production in different eco-regions.
4. Research on the development of cassava processing technologies. Use of cassava leaves and roots in animal feed and food processing. Proper management of cassava starch and ethanol factory effluent, and by-products transformation into animal feed and fertilizers.
5. Development of local and export markets for cassava products.

To develop a sustainable cassava production and utilization sector requires focus on specific strategies that are lasting and comprehensive. These are: i) Education: cassava specialists and technician training, agricultural extension staff to transfer technical advances for farmers to access knowledge immediately and apply these to improve production. ii) Develop policies to develop the overall cassava sector. iii) Research and transfer of cassava production machinery to increase economic efficiency iv) Processing and value addition of the waste materials, such as cassava leaves, stems, stumps, peels, processing residues and sewage sludge, in order to make products with higher value while minimizing environmental pollution.

Currently, among cassava education specialists in Vietnam (1990-2013) there are ten with Ph.D and 15 "Master cassava specialists", as well as hundreds of technicians and thousands of good farmers, who have been trained in sustainable development of cassava. There have been some very successful demonstrations of the application of technical advances in growing, harvesting, processing and utilization of waste with high economic efficiency in Dak Lak, Phu Yen, Dong Nai and Thua Thien-Hue provinces. For example: residues after processing is used for animal feed, stems after processing are being used as material for growing edible mushrooms. Cassava leaves are being used as animal feed (Nguyen Thi Cach *et al*., 2007) and for rearing silkworm; this helps farmers get higher incomes (Nguyen Bach Mai *et al.,* 2014b); Nguyen Huu Hy, 2015. Cassava peels and sewage sludge are being used as a valuable material for processing into organic fertilizer (Nguyen Bach Mai *et al*., 2014b).

CONCLUSIONS

Cassava in Vietnam has been an amazing success story. Vietnam is now a major exporter of agricultural products with a total export value of 25 billion USD per year. With more than half a million hectares of cassava, the export value of cassava products is 800-950 million USD per year. CIAT has made significant contributions in achieving these results by helping to improve the cassava sub-sector of Vietnam. Millions of farmers have benefited from significant increases in yields and profits. Varieties with some genetic background from CIAT, obtained through crossing and many cycles of selection, now cover about 90% of the total cassava area of Vietnam. Cassava in Vietnam is indeed an amazing success story (Bùi Bá Bổng, 2012)!

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RECENT DEVELOPMENTS IN CASSAVA PRODUCTION AND UTILIZATION IN CAMBODIA

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ABSTRACT

Cambodia is an agrarian country with more than one-third of the gross domestic product coming from agriculture, and crop production is the major contributor. Within this sector, the five most important crops in terms of planted area, in this order are: rice, maize, cassava, soybean and mungbean. In Cambodia, cassava is used as food and feed. While cassava roots can be consumed directly after boiling and/or after processing into many foods and food additives, cassava leaves can be used as silage and as nutritious feed for cattle and poultry. There has been a significant change over the last ten years, in both production and yield in the cassava sector in Cambodia. In 2000, the crop was cultivated at slightly above 16,000 ha, but in 2010 a more than tenfold increase in area planted was recorded with up to 206,000 hectares cultivated with cassava. Similarly, a marked increase in yield of more than 120% within this period was also observed. In 2000, the cassava yield was reported to be 9.08 tonnes per hectare, but in 2010 the yield went up to 20.06 tonnes per hectare. Due to a significant increase in both planted area and yield, cassava was ranked second after rice in 2010 in terms of production, while it was ranked fifth after rice, maize, soybean and mungbean in 2000. The driver for this rapid increase in both planted area and yield of cassava could be manifold, but a significant increase in demand for cassava starch in the international markets is regarded as the main factor. This is obvious as a major change in planted area has been principally observed since 2006 in the major cassava production areas of Battambang, as well as in Kampong Cham and Kratie Provinces, which border Thailand and Vietnam, respectively. Studies conducted in these provinces have revealed that there has also been a growing demand by the local markets for starch. Roughly 80% of cassava production in the country is unofficially exported to both Thailand and Vietnam. Demand for starch in both local and international markets is expected to grow further, which will definitely impact the cassava industry in Cambodia. Strengthening national, regional and international networks on cassava research is important to increase crop productivity and to diminish potential threats from some major emerging pests and diseases.

Key words: Cassava production, expansion, Cambodia.

INTRODUCTION

The Kingdom of Cambodia is located in Southeast Asia in the southwestern corner of Indochina, between latitudes 10° and 15° N and longitudes 102° and 108° E. Cambodia covers an area of 181,035 square km and borders with Lao PDR and Thailand to the north, Thailand and the Gulf of Thailand to the west, and Vietnam to the east and south. Geographically, Cambodia is characterized by a low-lying central plain dominated by the Great Lake Tonle Sap. To the plateau region, the Mekong valley dominates on the east, the

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Dangrek Mountains to the north, and Kravahn (Cardamom) Mountains and Damrei (Elephant) Mountains to the south-west, separating the coastal region from the rest of the country.

Cambodia has a tropical monsoon climate with distinct dry and wet seasons. The dry season is from November to April and the wet season is from May to October. Annual rainfall ranges from 1,250 to 4,000 mm; it is low in the central plain and increases towards the Gulf of Thailand. The mean temperature ranges from 21 to 35 $^{\circ}$C with the hottest month being April and the coolest month December.

With an estimated total population of about 14.7 million (RGC, 2010), approximately 80 percent of Cambodian people live in rural areas and most of them are dependent on agriculture as their main source of income. Cambodia is characterized as a low-income country with more than 30% of the population still living below the international poverty line of one dollar per day. The poverty incidence is found to be higher in the rural areas, where people are more likely to be less educated and their living is solely dependent on farming (RGC, 2010).

Amongst all sectors of the national economy, which includes services and industry, the agriculture sector is the only component that has maintained a reasonable stability over the years, even during the international financial crisis and the economic recession in 2007-2008. It has seen a slow decline in its contribution to the national economy; in 2011 agriculture contributed about one third to the gross domestic product.

AGRICULTURE AND CASSAVA

As an agrarian country, Cambodia relies heavily on agricultural production as its main source for food, nutrition and income. Within the agricultural sector, crop production is the biggest contributor to the national gross domestic product (GDP); up to 50-60% of the GDP is accounted for by the sector. Cambodia has a total land area of about 18.1 million ha. At the present, about 3.5 million ha, or around 19% of the total land area, is cultivated. Rice is the major crop in the country and occupies about 2.8 million ha or about 78.79%, followed by maize 6.02% and cassava 5.81% of the total cropping areas (**Table 1**).

Table 1. Major crop production statistics for Cambodia in 2010.

Rank	Crop	Area (ha)	%
1	Rice	2,795,892	78.79
2	Maize	213,622	6.02
3	Cassava	206,226	5.81
4	Soybean	103,198	2.91
5	Mungbean	69,206	1.95
6	Others	160,387	4.52
	Total	**3,548,531**	**100.00**

Source: *MAFF, 2011.*

Other than rice, maize and cassava, major proportions of agricultural land are also planted to legume crops such as soybean, mungbean and peanut, as well as vegetables, sweet potatoes, sesame and sugarcane.

In Cambodia, cassava (*Manihot esculenta* Crantz) is the third most important crop in terms of area planted, after rice and maize. It is grown mainly by smallholder farmers; the roots are used for food to supplement the rice diet, for feeding their animals, and for extraction of starch. In recent years there has also been a major interest in the use of cassava as a raw material for the production of ethanol.

Traditionally, cassava in Cambodia was only a subsistence crop, grown mainly in the farmer's backyard. However, the situation changed. Over the last ten years the cassava planted area in Cambodia has expanded exponentially, from less than 30,000 ha in 2004 to more than 206,000 ha in 2010 (MAFF, 2012) (**Figure 1**).

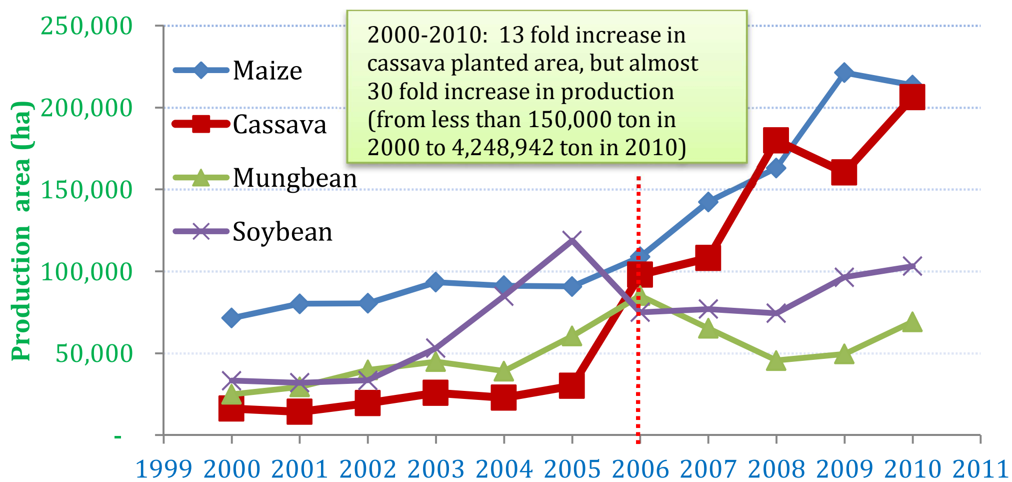

Figure 1. Planted areas of some major crops in Cambodia (2000-2010).

Currently, cassava is cultivated, at both small and large scales, in almost all provinces in the country, with major production areas found in the northeast (Kampong Cham, Kratie), the northwest (Battambang, Banteay Meanchey, Pailin), and in the central regions (Kampong Thom) of the country (**Figure 2**). Currently, the cassava planting area is the largest compared to other major upland crops (maize, soybean and mungbean) in Cambodia (MAFF, 2015) (**Figure 3**).

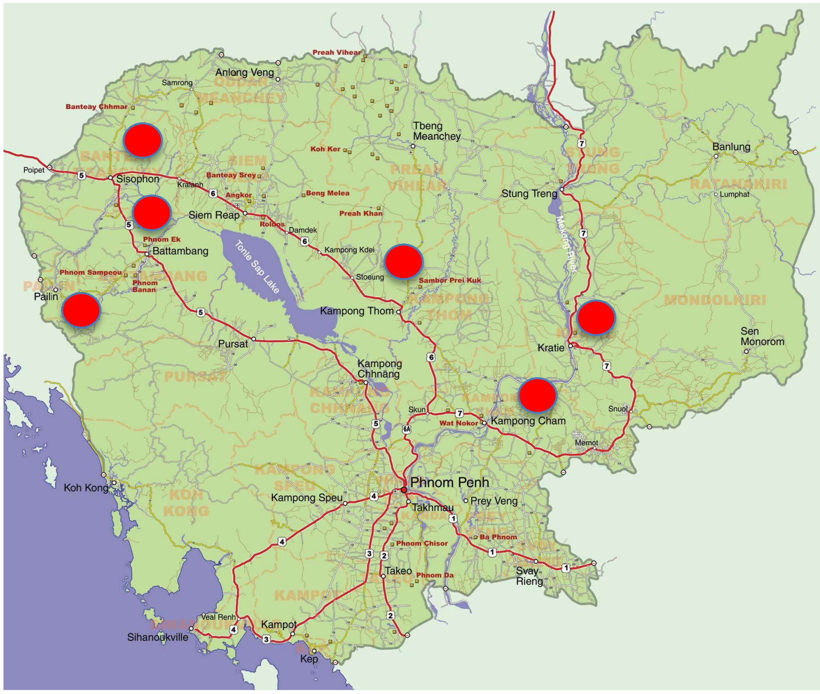

Figure 2. Major cassava producing provinces in Cambodia in 2011.

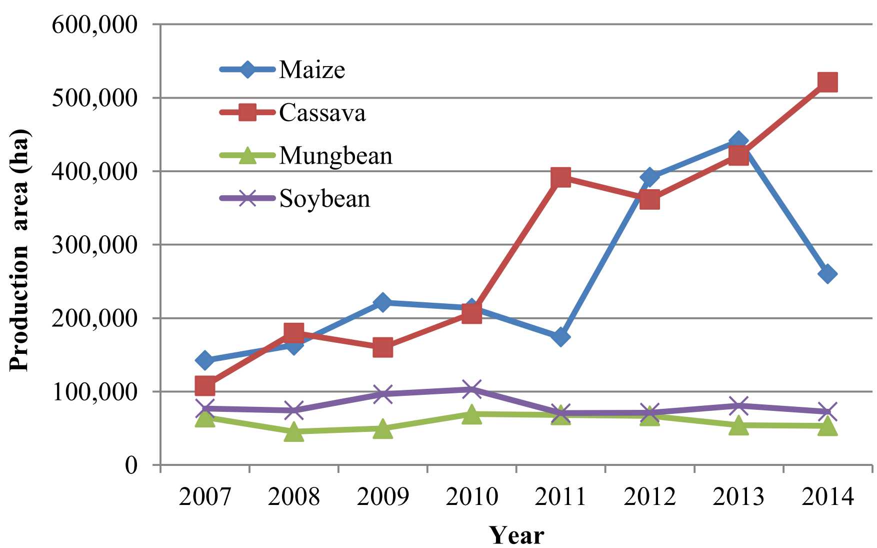

Figure 3. Planted areas of some major crops in Cambodia (2007-2014).

The cultivated area (ha), production (tonnes) and yield (tonne/ha) of cassava in each province of Cambodia in 2014/15 is shown in **Table 3** (MAFF, 2015).

Table 3. Cassava cultivated area, production and yield in the provinces of Cambodia in 2014.

Province	Cultivated Area (ha)	Production (t)	Yield (t/ha)
Bunteay Mean Chey	69,502	1,402,868	20.2
Battambang	124,979	4,303,323	34.4
Kampong Cham	16,492	315,383	19.1
Kampong Chhnang	1,062	6,065	5.7
Kampong Speu	5,088	152,490	30.0
Kampong Thom	37,911	530,379	14.0
Kampot	2,777	13,086	4.7
Kandal	247	1,933	7.8
Koh Kong	185	2,379	12.9
Kratie	67,657	1,428,073	21.1
Mondulkiri	10,628	191,071	18.0
Phnom Penh City	24	240	10.0
Preah Vihear	15,114	181,368	12.0
Prey Veng	1,432	25,776	18.0
Pursat	13,541	406,230	30.0
Ratanakiri	15,574	293,471	18.8
Siem Reap	12,110	183,172	15.1
Preah Sihanouk	246	3,198	13.0
Stueng Treng	14,928	288,360	19.3
Svay Rieng	7,965	140,466	17.6
Takeo	664	5,949	9.0
Otdar Mean Chey	27,760	534,250	19.2
Kep	168	2,423	14.4
Pailin	22,985	473,125	20.6
Tbaung Khmom	52,420	1,058,126	20.2
Total	**521,459**	**11,943,204**	**22.9**

Source: *MAFF, 2015.*

There are several factors contributing to the expansion of cassava from a subsistence crop to a commercial crop, and to being currently the second or third most important crop in the country. Amongst those, a rapid expansion of demand for cassava flour and starch by the international market was probably the prime contributor for this speedy increase in the country's cassava production. Cassava processing in Cambodia has quickly developed in line with the developments of other national industries. There are still few large-scale processing factories. Most of the large processing factories are located in cassava growing provinces such as Kampong Cham, Pailin and Battambang provinces.

Cassava processors (small-, medium- and large-scale) in Kampong Cham and Pailin Provinces are shown in **Tables 4** and **5** (UNDP Cambodia, 2014). Generally, cassava processing factories purchase cassava fresh roots during the main harvest period between November and April. The average maximum amount of fresh roots purchased is about 35-40 tonnes per day and the minimum amount is 10-20 tonnes per day. Some processing factories require very large amounts of fresh cassava roots. The total estimated local requirement of fresh cassava roots may be higher than 400,000 tonnes per year. The total cassava planting area in Cambodia was 512,459 ha and the total production was 11,943,204 tonnes in 2014 (MAFF, 2015).

Table 4. Current situation of cassava starch processing (small-, medium- and large-scale processors) in Kampong Cham Province.

Kampong Cham province					
Name	Location of factories	Month starting processing	End of operation	Processing capacity (tons/hour)	Year started
Hong Leng	Angkor Chey village, Tralap commune, Tbaung Khnum district	Nov	May	4 to 5	2011
Heng Huot	Cheung Khang village, Mong Riev commune, Tbaung Khnum district	NA	NA	NA	NA
Seang Phong	Lar village, Kaung Kang commune, Ponhea Krek district	Oct	May	30 to 40	2005
Sun Ath	Tuok Chey village, Kandaul Chrum commune, Ponhea Krek district	Oct	May	30 to 40	2007
TTY	Chi Pes village, Memot commune, Memot district	Oct	May	30 to 40	2000
Song Heng	Kien Raung village, Vihea Luong commune, Suong district	Nov	May	5 to 6	1998

Cassava processing produces large amounts of wastes, including solid and liquid waste; these are high in organic matter constituents and cyanide. Solid wastes are mainly derived from cassava chip processing. If properly managed, this can be utilized in many ways. Liquid (water) waste, on the other hand, has the potential to pollute ground water or lakes, rivers or streams into which it flows. Cassava processing can also produce an unpleasant smell and unattractive picture. Due to all these problems, cassava processing has always had a reputation of a major environmental pollutant.

Table 5. Current situation of cassava chipping and drying (small-, medium- and large-scale processors) in Pailin Province.

No	Factory/Company name	Storage capacity (t)	Location	Contact person
1	C.T Mithapheap Co, LTD	7,000	Kngork village	Huon Vanny
2	PB & CK Development Co, LTD	50,000	Toek Chenh	H.E Chea Kea
3	Chamroeun Chey	10,000	Ou Andaung	Sa Chamroeun
4	Chinese Company	10,000	Chamkar Café	Chinese
5	Heng Sopheap	6,000	Pang Roloem	Heng Sopheap
6	Chanthan Pailin	3,000	Suosdey	Chan Than
7	Thitina sabsphon	10,000	Ou Russey krom	Le (Thai)
8	Pailin Rungroeung	400	Toek Phos	Sony
9	Pin horn import& Export	500	Leav	Bin horn
10	LeanVirakvoravath	300	Tuol kpos	Virakvoravath
11	Yung Minea	100	Thnal Totoeng	Yung Minea
12	Yung Enterprise	100	Suon Ampovkoeut	Virakvoravath
13	Hin Sarorn	30	Suon Ampovlech	Hin Sarorn
14	Sok Eng 1	2,000	Ou tavao	Sok Eng
15	Pov Rous	50	Pang Roloem	Pov Rous
16	Koeun Police	30	Ou Russey krom	Koeun
17	Sok Eng 2	1,000	Pech Kiri	Sok Eng
18	Rous Khom	100	Toek Phos	Rous Khom
19	Seng Hang	100	Thnal Totoeng	Seng Hang
20	Seng Mengsun	100	Thnal Kaeng	Seng Mengsun
21	Heang lev	6,000	Veal	Heang lev
22	Leang Heng	200	Veal	Leang Heng
23	Che Ly	100	Pang Roloem	Che Ly
24	Chhok long Thib	200	Ou Roel	Chhok long Thib
25	Kim Pros	50	Kon Phom	Kim Pros
26	Chhoeng Ye 2	1,000	Phnom Spung	Chhoeng Ye
27	Nita Kasephal	100	Stoeng Trang	Keo Sokleap
27	Silo Café	1,000	Pang Roloem	Oeu Sothearom
28	Intertrade CO, LTD	300	Pang Roloem	Chang (Thai)
29	Khmer Viniyok Kasekam	1,000	Klong	Ork Samphors

Agricultural Policy

Agricultural Policy, which is known as the Agriculture Sector Strategic Development Plan (ASDP) 2009-2013, is a responsive agricultural policy to address all the major issues that exist within rural Cambodia. According to this policy, the main objectives of the ASDP are to increase agricultural production in order to stimulate the national economy and to contribute to the poverty reduction program (RGC, 2010). Five strategic objectives have been identified such as:

1. Ensure food security through increasing agricultural productivity and diversification
2. Expand markets for agricultural produce
3. Institutional and legislative development framework
4. Fisheries reform
5. Forestry reform

However, despite the recognition of agriculture as a priority for poverty reduction and economic growth, and despite the important contribution that agriculture makes to the national GDP, the recurrent allocation of the national budget to the agricultural sector remains low compared to other sectors (Ngo Sothath and Chan Sophal, 2010).

Constraints and Opportunities

The Cambodian cassava industry is almost exclusively dependent on the markets of neighboring Thailand and Vietnam that act as cassava trade-brokers between Cambodian and the international and/or Chinese markets. Therefore, any fluctuation in cassava demand in the Chinese markets can have a strong influence on the country that produces cassava through these two border markets. The reasons for a lack of direct trade between the Cambodian cassava industries with the international trade dealers, including the Chinese market, can be several but poor standard quality products, the complexity of exportation procedures, and a lack of knowledge by the local processors and exporters of these procedures can be the central ones.

Within the last few years, cassava production in Cambodia has been expanding so fast that it is impossible for both policy and technical support to adequately address these issues. This situation is critical and may lead to massive devastation in the industry if adequate interventions from both institutions are not realized.

Cassava has a poor reputation is terms of leading to soil degradation without soil conservation practices. Many farmers do not apply adequate and well-balanced fertilizers on the cassava crop. If such low-input practices are continued for an extended period, soil fertility will decline and future crop yields will also decrease. Cassava production in Cambodia is unsustainable under current existing farmers' practices (Ung Sopheap *et al*., 2012)

Insect pests (mainly mealybugs) and diseases (mainly witches' broom) are becoming significant threats to cassava production in the country. Without adequate technical support from research institutions as well as proper quarantine regulation in plant protection these can significantly affect the sustainability of both crop production and the starch industry in the country. Furthermore, it will have a great impact on the livelihoods of many poor cassava farmers.

Cassava processing is low-tech and less competitive because of poor drying and storage facilities and lack of quality control systems. Due to high energy cost in Cambodia, the processing plants encounter problems to produce final products with competitive prices with neighboring countries (UNDP Cambodia, 2014). However, there are considerable opportunities to increase the productivity, profitability, and sustainability through better production and processing systems in Cambodia.

Future Challenges

1. Enhance a wider recognition of cassava as a crop of economic potential to poverty reduction, economic prosperity and environmental sustainability by policy makers, technical personnel and the public. It is hoped that by getting interventions from policy makers, the sustainability of this crop's production can be maximized for the improvement of farmers' livelihoods. To achieve this strategy, several activities are proposed. Those are:
   - To develop a national cassava policy
   - To develop a national cassava network by the conducting of national cassava workshops
   - To build public awareness about cassava's contribution to poverty reduction in the country.

2. Strengthen a national network on cassava research and extension. The activities follow:
   - Develop/introduce the best and most adapted high-yielding varieties
   - Test for the most appropriate fertilizer application for different agro-ecosystems in the country.
   - Test for the best option of cassava-based integrated farming systems for different socio-economic situations
   - Develop effective and sustainable cassava production management systems.

3. Prepare for the outbreak of emerging pests and diseases problems.
   - Develop a farmer participatory monitoring system to closely watch the presence of newly emerged pests and diseases.
   - Develop most effective control systems, including varietal, biological, chemical, and cultural practices.

4. Build human resources in cassava production and processing.
   - Farmers: cassava production practices, production of healthy planting materials, cassava breeding and varietal testing, insect identification, pest and disease management, nutrient management, soil-erosion control, rural processing of cassava products
   - Processors: cassava starch standards and factory sanitary requirements according to potential importing markets, appropriate waste management systems, processing cassava products.

5. Enhance the development of competitive cassava processing industry, small, medium and large, in the country
   - Encourage public and private investment in the production and processing of cassava

- Develop sustainable and ecologically friendly waste management systems.

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THE CHANGING ROLE OF CASSAVA IN RURAL POVERTY ALLEVIATION IN LAO PDR

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ABSTRACT

Cassava has long been an important crop for food security in Lao villages, especially during times of rice deficiency. It is also a major component in many traditional livestock feeding systems. The recent introduction of high-yielding, high starch content varieties and improved cassava production practices, combined with improved feed processing and utilization technologies has enabled intensification of household livestock production. Sales of livestock by smallholders have improved cash income and opportunities for purchasing staple foods. While traditional household uses of cassava and increased smallholder livestock production are still important for food security, especially in remote upland areas, the recent establishment of cassava-processing industries in Lao PDR, which is driven by strong regional and global demands for cassava-based products, has resulted in new opportunities for income generation through sales of cassava as feedstock for various agro-industries.

Between 2005 and 2009, four modern dry starch-processing industries were established in central and southern Lao PDR that began buying and processing fresh roots. Fresh roots are also dried by smallholder cassava growers or by small- to medium-scale commercial enterprises. Dried cassava chips are exported to neighboring countries or used domestically by feed mills.

A recent survey of cassava-processing industries revealed that several different models for cassava producer-processor linkages are currently being practiced and adapted to local socio-economic conditions. All of the surveyed starch industries indicated shortages of feedstock because of inadequate root production, for various reasons. Improved varieties introduced from neighboring countries are planted in production areas, but no systematic testing to determine best-adapted varieties for specific locations has been undertaken. Most factory managers indicated that soil fertility in their production areas was high, so there is currently no need to use fertilizers in early years after forest clearing. Some factory managers and extension staff expressed concern about long-term productivity. Linkages between factories and public sector agricultural extension services have, so far, been limited and enterprises have largely been responsible for the extension of new technologies.

Improved public-private sector partnerships in applied research and extension can help to increase sustainable cassava production and profitability, benefiting both cassava growers and processors, resulting in improved livelihoods for rural people.

Key words: Cassava production, processing, research, extension, Lao PDR.

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Recent History and Current Situation of Cassava in Lao PDR

Lao PDR is a landlocked nation bordered in the north by China, in the east by Vietnam, in the south by Cambodia and in the west by Thailand and Myanmar. The Mekong river runs through the north-western part of Lao PDR and then along much of the border with Thailand. Most of the country is mountainous, with only about 10% of flat land, which is located mainly in the Plain of Jars in the northeast province of Xieng Khouang and in the southern provinces. The population of about 6.5 million people consists of many ethnic groups, but is dominated by the Lao Loum or lowland Lao.

Traditionally, cassava (*Manihot esculenta* Crantz) has been grown as a backyard crop. The roots are used as an important human food, especially in times of rice shortage, and as an energy source for feeding livestock, like cattle, buffaloes, pigs and poultry, while young leaves are sometimes cooked as a vegetable. Leaves and young stems are also fed to cattle and pigs, either after wilting or in the form of silage. Pigs are generally left to roam freely and often dig out the cassava roots, while cattle may forage on the leaves of cassava plants in the field, especially during the dry season when there is little grass to eat. Raising and selling cattle and pigs was the main source of cash income for many farmers.

As recently as 1988, there was no commercial market for cassava. In 1979 the Tha Ngone Feedmill was established just north of Vientiane and around 1985 they tried to make contracts with farmers to produce cassava as the raw material to produce pig and poultry feed. An Australian aid project did some research on varieties, and various cultural practices using mainly local varieties as well as Rayong 3, introduced from Thailand. In 1989 there were about 100 ha of cassava planted under contract in the Vientiane area, but farmers soon lost interest due to the low price paid for their roots. This project was discontinued.

With cooperation of the Thai Department of Agriculture, in 2001 eight of the most promising Thai cassava varieties were introduced, including two for human consumption, which were planted, together with two local varieties, in replicated trials at the Namsuang Livestock Research Center near Vientiane as well as in the Houay Khot Research Station near Luang Prabang. These and many trials that followed clearly indicated that the best Thai varieties, mainly KU50 and Rayong 90, could nearly double the yields of the local eating varieties. In the following years, these trials were extended to the Naphok Agriculture Research Center northeast of Vientiane and to the Northern Agriculture and Forestry College in Luang Prabang. In 2002 these varieties were also planted in seven on-farm trials in Luang Prabang and Xieng Khouang provinces. In the following years additional varieties were introduced from Vietnam and China and added to the cassava germplasm collection in Naphok Center. In 2004, the Nippon Foundation Cassava Project, working in close collaboration with CIAT's PRDU[4] project, established more on-farm trials in Xieng Khouang and Oudomxay provinces, and in collaboration with NAFRI other on-farm trials in Luang Prabang. In 2004/05, there were 18 on-farm trials and four on-station trials, including an NPK fertilizer trial at the Cattle Bank station in Xieng Khouang province. From 2004 to 2012, as part of the Nippon Foundation's Farmer Participatory

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[4] Participatory Research and Development for the Uplands

Research (FPR) Project, some on-station experiments were continued, mainly at the Naphok Center and at the Agriculture College in Luang Prabang, but the project was mainly focused on FPR trials in different villages in Xieng Khouang, Luang Prabang and Oudomxay provinces in order to enhance the widespread adoption of higher yielding varieties and more sustainable production practices.

Currently, cassava remains an important food security crop and a good energy and protein source for on-farm animal feeding, but more and more farmers are now growing cassava not as a subsistence crop but as a cash crop, for sale to traders or to nearby starch or animal feed factories. With the introduction of new higher yielding cassava varieties and improved management practices the cassava area and yields have markedly increased, as shown in **Figure 1.** Cassava production increased more than seven fold from 2009 to 2013 (FAO, 2015).

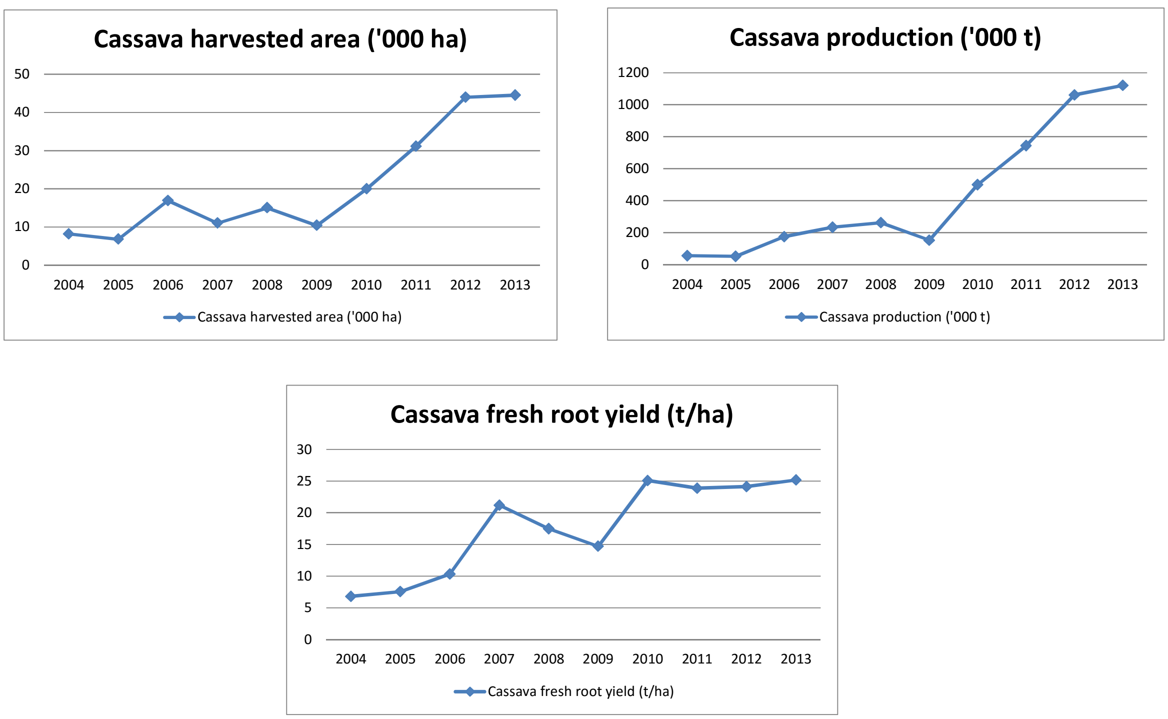

Figure 1. Cassava harvested area, production and yield in Lao PDR from 2004 to 2013.
***Source**: FAO, 2015.*

In 2011 about 26% of cassava roots produced was used for food, 12% for feed , 10% was waste (mainly peels) and 52% (380,000 tonnes) was for "other uses", which is mostly processing into starch and dry chips (FAO, 2015). Thus, it is clear that cassava in Lao PDR is now mostly a cash crop, produced and sold to improve the farm family's income, but it also continues to be an important emergency food as well as an on-farm livestock feed, mainly for pigs. A survey of 779 cassava growing households, conducted in

2007, gives details of the traditional production practices and usage in Lao PDR (Thiphavong Boupha *et al.,* 2010).

Traditional Use of Cassava as Food and Feed

In spite of its increasing use for processing, cassava remains an important food, mainly for farm families living in isolated areas of Lao PDR. These families plant mostly local varieties that may produce low yields but do have good taste as well as other attributes such as easy to peel or requiring little cooking time. In these areas it may be difficult to buy other foods and if their rice crop fails or is insufficient they may rely mainly on cassava to carry them through to the next rice harvest. Because cassava is drought tolerant and can grow reasonably well in low fertility soils it is a good food security crop that will not be affected by poor soils or weather conditions. Also, cassava does not have a specific harvesting time and can be left in the ground until needed. And if the roots are not needed as food, they can be boiled and fed to the pigs or cattle, or they can be chipped and dried to be fed to poultry. In addition, the young leaves and shoots can be cooked and when mixed with some spices can make a high protein and delicious vegetable. When farmers have to work all day in far-away fields they often harvest some cassava plants, bake the roots in hot ashes of a fire and cook the young leaves as a vegetable for lunch.

Use of Cassava for Intensification of Livestock Production

For many farmers in Laos the sale of livestock is their main source of cash income. They may raise pigs, but the free roaming local breeds may take three years to scavenger enough food to reach market weight. Similarly, cattle that have to graze on far-away grasslands may take years to reach maturity and may lose a lot of weight during each dry season when there is little green grass to eat. CIAT scientists in the Forages and Livestock for Small-holder (FLSP) project have worked hand-in-hand with NAFRI scientists to help upland livestock producers use better grass and legume species that can be grown near the house for cut-and carry feed production for cattle and pigs that are kept in stalls or are tethered near the house. This saves labor and greatly improves the daily weight gain of the animals (Connell *et al*., 2010). However, they realized that additional feeding of cassava roots and leaves, either boiled, dried or ensiled, can markedly further increase the daily weight gain and improve the efficiency of livestock production. Thus, the early research on cassava was mainly focused on using cassava for the intensification of livestock production. This research focused on identifying higher yielding cassava varieties and improved cultural practices. This research was conducted initially at NAFRI's Namsuang Livestock Research Center and later at their Naphok Agriculture Research Center, as well as at the Northern Agriculture and Forestry College in Luang Prabang (**Table 1**). The latter experiments were conducted by some of the students of the college in collaboration with several groups of three students from Zamorano University in Honduras, who spent a year working at the college.

Table 1. Results of a standard cassava variety trial conducted at the Northern Agriculture and Forestry College in Luang Prabang province of Lao PDR in 2009/10.

No.	Cassava variety	Origin	Root yield (t/ha)	Starch content (%)	Starch yield (t/ha)
1	SC205	China	35.8	23.5	8.4
2	KU 50	Thailand	34.1	26.9	9.2
3	SC5	China	33.1	22.1	7.3
4	KM140	Vietnam	32.8	23.8	7.8
5	Rayong 72	Thailand	30.4	26.1	7.9
6	Vinh Phu	Vietnam	28.8	24.7	7.1
7	Rayong 90	Thailand	27.3	29.3	8.0
8	OMR 36-31-1	China	24.0	21.7	5.2
9	Local Luang Prabang	Laos	19.0	22.5	4.3
10	Nep	Vietnam	15.3	27.8	4.3

But the Nippon Foundation Cassava Project, in collaboration with provincial or district extension offices, also conducted many on-farm and farmer participatory trials, mainly in the northern provinces of Xieng Khouang, Oudomxay and Luang Prabang. They also organized many training courses for extensionists and farmers of these provinces to learn about more intensive cassava production technologies as well as the use of dried or ensiled cassava roots and leaves for on-farm animal feeding. The participants learned and practiced using a simple hand-operated slicing machine to slice cassava roots for easy sun-drying, and another type of hand-operated chopping machine to chop young cassava stems and leaves for easy drying or to make root and leaf silage. These dried or ensiled products could be stored for long periods, mainly for use during the dry season when other feeds were less available. They also trained researchers and extension personnel in the use of Farmer Participatory Research and Extension (FPR&E) methods to enhance the adoption by farmers of new cassava varieties and production practices.

In addition, CIAT introduced sexual seed of varieties growing at high elevations in Latin America in order to select new varieties with better adaptation to year-round low temperatures for some high elevation areas in the mountains of Laos. CIAT scientists worked closely with local researchers and extensionists, mainly in Houa Phan province, conducting field trials to identify the best adapted germplasm for those high elevation conditions. Furthermore, they conducted some on-station experiments at the Cattle Bank station near Phonsavanh city of Xieng Khouang province to determine the response of newly introduced as well as local varieties to the application of different levels of N, P and K fertilizers, and to determine the most effective way to reduce soil erosion by the use of contour hedgerows and other soil conservation practices. They found that in these very poor soils, the yields of both varieties could be more than doubled with the application of 50 kg of P_2O_5 and 50-100 kg of K_2O/ha (Aye *et al.,* 2010), and that the planting of contour hedgerows of *Paspalum atratum* grass and the application of chemical fertilizers were both very effective in reducing soil loss by erosion when cassava is grown on slopes.

These on-station and on-farm FPR trials were initially conducted in the northern provinces of Oudomxay, Luang Prabang and Xieng Khouang, but later expanded to areas near the capital Vientiane and the southern provinces of, Saravan and Champasak, where the new cassava starch factories were established (**Figure 2**).

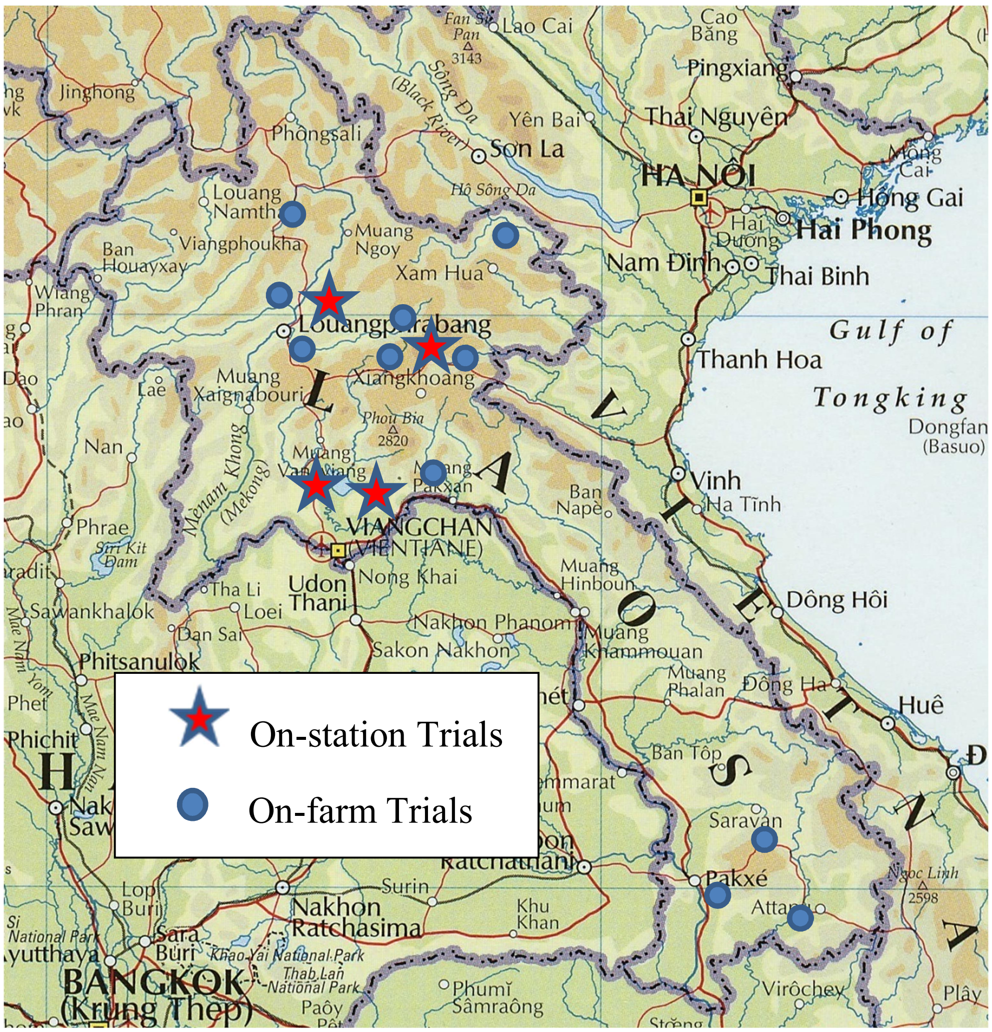

Figure 2. Location of NAFRI/CIAT cassava research sites in Lao PDR.

Recent Development in Cassava Markets and New Opportunities for Cash Cropping

With the adoption of new varieties and better production practices cassava yields have started to increase and the cassava growing area to expand. In addition, both local and international markets opened up for various cassava products, providing new opportunities for farmers to sell their cassava roots. This in turn provided the incentives to further increase the area, to start planting higher yielding varieties, which tend to be bitter and unsuitable for human consumption, and to intensify their crop management practices, leading to higher yields. This is a typical example of how cassava can serve as an engine for rural development, where increased yields and production lead to an upward spiral of small investments in processing plants, which in turn increase demand and root prices, which further lead to more and larger markets for a diversity of cassava products (Fahrney *et al.,* 2010). **Table 2** shows how the previous uses of cassava for food and feed have grown to multiple uses and potential new markets in Lao PDR.

Table 2. Current and future multiple uses and markets for cassava in Lao PDR.

On-farm use	V*	Household consumption of cassava roots for food security
	V	On-farm feeding of cassava roots and leaves for livestock
	V	On-farm processing, feed formulation for intensified village livestock production
Local processing	V	Sale of fresh roots to nearby starch and feed processing factories
	V	Chipping and drying of roots for sale to distant factories or for off-season processing
		Household- or village-scale wet starch extraction enterprises
		Household processing of starch-based foods (noodles, sweets) for local sale
Large commercial markets	V	Medium- and large-scale dry starch extraction enterprises
		Commercial starch-based food processing enterprises
		Non-food starch consuming industries (paper, textiles, adhesives, pharmaceuticals, etc
	V	Commercial animal feed mills
		Bio-ethanol distilleries (planned)
		Chemical modification of starches (MSG, sweeteners, bioplastics)
		"Bio-refineries" for synthesis of multiple complex products (petroleum replacement)

*rows marked with "V" are current uses; others are planned or potential future uses.

During the past ten years four dry starch factories were established, two north of Vientiane capital and two in the southern provinces of Saravan and Champasak. There are plans to construct more starch factories. There are also four commercial animal feed mills, two located north of Vientiane and one near Luang Prabang; these are using dry cassava chips as an important ingredient. The largest feed mill is CP Laos, a subsidiary of CP Thailand, which is the largest producer of animal feed in Asia. It took over the facilities of Tha Ngone Feed Mill and started operation in 2009. This mill currently buys 4000 tonnes of dried chips per year, but has plans to double capacity. About 60% of feed is used by the company on their breeder farm to supply piglets to contract farmers for fattening. They buy dry cassava chips from farmers and traders without contracts or extention support.

Three smaller feed mills are state enterprises, piloted through development assistance cooperation, but these will eventually be privatized. In addition, there are four major areas where private traders buy dry cassava chips, either to sell to the feed mills or for export across the border to China, Vietnam or Thailand. These are located in Luang Namtha in northwest Laos for export to China, in Xieng Khouang and Bolikhamxay for export to Vietnam, and in Champasak and Saravan provinces for export to Thailand and China (via Danang in Vietnam), respectively. The location of these three different cassava processing enterprises is shown in **Figure 3**.

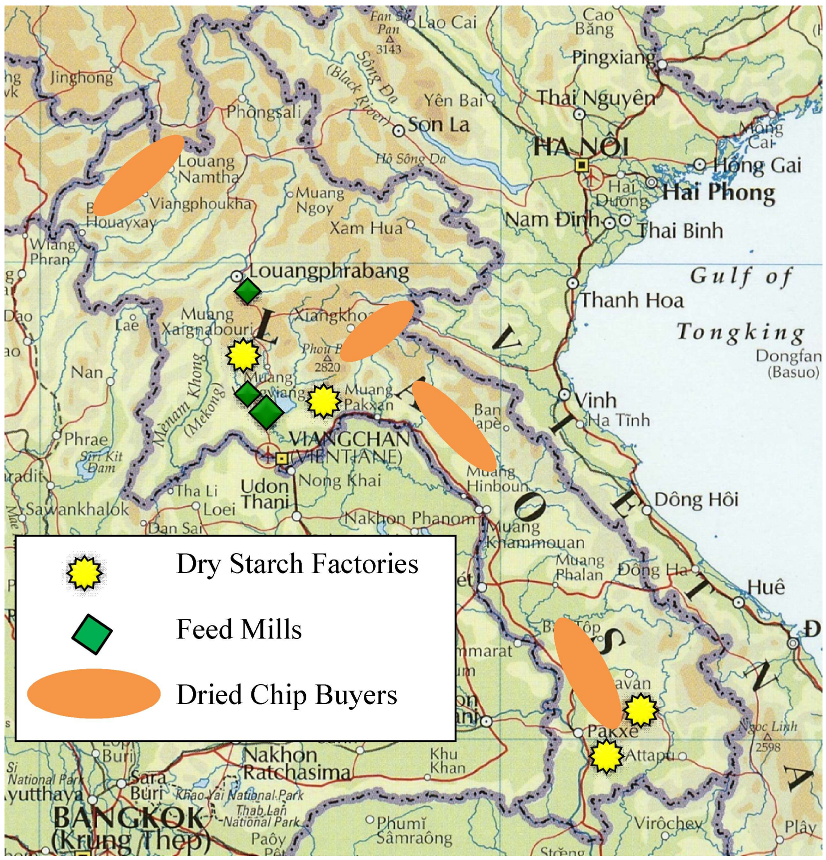

Figure 3. Locations of cassava processing industries in Lao PDR.

The recent establishment of these three different markets for cassava roots have had a marked impact on farmers' decisions about which crops to grow and where. **Figure 1** clearly shows the huge increases in cassava area, yields and total production, starting in 2005, but greatly accellerating since 2009. These new markets have also affected where cassava is grown as indicated by the large new areas of cassava in Bolikhamxay, Saravan, Vientiane capital and Xieng Khouang, as shown in **Table 3.**

Table 3. Major cassava production areas in Lao PDR in 2011.

Province	Harvested area (ha)	Production (tonnes)	Yield (t/ha)
Saravan	2,795	97,350	34.83
Bolikhamxay	2,790	68,220	24.45
Vientiane municipality	2,435	110,775	45.49
Xieng Khouang	2,360	23,565	9.99
Champasak	1,710	49,360	28.87
Vientiane province	1,425	36,280	25.46

***Source**: Department of Agricultural Statistics, 2011.*

Survey of Dry Starch Factories in Lao PDR in 2011

In November, 2011, NAFRI and CIAT interviewed the managers of three of the four dry starch factories and government extensionists to learn about the feedstock production base, factory operation, planting practices, opportunities and constraints. The three factories are: 1. Hu Phu Company, located in Lao Ngam district of Saravan province, which started operations in 2005 and has a current capacity of 100 tonnes dry starch per day; 2. Lao Indochina Group, located in Pak Ngeum district of Vientiane Municipality, which started in 2007 and has a current capacity of 320 tonnes dry starch per day; and 3. KPN, located in Phathoumphon district of Champasak province, which started operations in 2009 and has a current capacity of 90 tonnes dry starch per day.

The results of the survey of these cassava starch factories can be summarized as follows:

- All cassava starch factories reported operating below capacity because of difficulties obtaining enough roots
- All factories received land concessions for multiplying planting materials and for extending their processing season through having their own plantations, but most cassava is produced by small-holders under contract with factories
- Contract lengths vary from two to five years, depending on investment costs for land clearing, preparation and fencing. Planting materials are provided by the companies in the first year
- Credit for fertilizers is not included in contracts with starch factories, so contracted farmers do not apply chemical fertilizers. Factory managers believe that it is not necessary to use fertilizers on recently cleared land (if ever)
- Two factories sold cassava processing residues (outer skins and fibrous residues) for export to organic fertilizer manufacturers in Vietnam
- One factory manager said that not using chemical fertilizers results in stronger plants that resist mealybug infestation
- There is some side-selling by contracted farmers to freelance traders who buy dried cassava chips for export to Thailand and Vietnam
- Companies and freelance traders near starch factories also contract with farmers to buy chips for export. Some of these companies provide credit for fertilizers and planting material of improved varieties

- One factory manager reported that villagers encroached on their concession land to plant crops other than cassava. The concession is in an area of high fertility and abundant rainfall, so farmers preferred to grow higher value crops
- Factories provide extension through company staff, with only limited linkages with government extension offices. Government extension officers near factories expressed lack of knowledge about cassava production practices, but they also expressed interest in training and willingness to work with factories and smallholders to increase cassava production
- Some extensionists worried that cassava "destroys soils" and they were concerned about the long-term productivity of the land
- Factories are experimenting with different models for engaging smallholder farmers in cassava production. The two prevailing models are "2+3" and "1+4"
- In the "2+3" model:
  - Farmers supply land and labor (2)
  - Companies supply land preparation (fencing), technologies (planting material/varieties), and markets (3)
- In the "1+4" model:
  - Farmers supply land (rented to factories) (1)
  - Companies supply labor (to prepare land, plant, maintain, harvest), land preparation, technologies (varieties), and market for harvested cassava (owned by the factory) (4)
  - Farmers may be employed (daily wages) on company labor teams that work on several farms, or, if they provide labor on their own farm they will be paid extra for the cassava sold to the company
- One company has 5-year rental contracts; then returns the land to farmers. That company hopes that farmers will have knowledge, experience and suitable land to continue growing cassava to supply the factory in year six and beyond.

Lao Cassava Research for Development Network

The recent establishment of cassava processing enterprises is providing Lao farmers with new livelihood opportunities. Smallholder cassava farmers and processors depend on each other and both will benefit from increased and more sustainable production. Therefore, a new partnership is required to mobilize key stakeholders (cassava farmers, processors, researchers, extensionists, policy makers) to plan, implement and extend results of research aimed at increasing the sustainable production of cassava. The research priorities, to be decided by the Network stakeholders, may include the following topics:

- Soil fertility/fertilizer management for the long-term sustainability of the enterprise
- Intercropping for income generation, erosion control and fertility maintenance
- Manipulation of seasonality (time of planting and harvest)
- Pest and disease management (surveillance, biological control, IPM)
- Processing waste management and its potential use for livestock feeding

CONCLUSIONS

The peoples of Lao PDR have a long history of growing cassava as a subsistence crop, used as food in times of rice shortage, but mainly used to feed livestock for sale as these have been their main source of monetary income. It is only in the last ten years or so that farmers and government officials have seen the value of cassava as an important engine for rural development, as has happened in neighboring countries, particularly Vietnam and Cambodia. With the recent establishment of four starch factories and three commercial animal feed factories that use cassava in their feed rations, as well as many private and commercial traders that will buy dried cassava chips for export and for sale to feed mills, there are many new opportunities for farmers to grow cassava for sale. And with the recent high prices of fresh roots, due to increasing demand for dry chips in China, Vietnam and Thailand, there are additional incentives for farmers to increase their cassava areas and yields. The latter can be achieved by planting high-yielding and high-starch varieties, applying the right amount and balance of fertilizers, having adequate and timely weed control, monitoring and controlling any outbreaks of pests and diseases, and harvesting when roots have their highest starch contents or when prices increase during the off-season. The marked increases in cassava area and yield have resulted in spectacular increases in total root production, much of which is now being processed into value-added products for export as well as local consumption.

Since farmers, processors and the country as a whole are benefitting from this development, it is important to enhance a closer cooperation between government officials (researchers, extensionists and policy makers), farmers and processors. This may take the form of an official Cassava Research for Development Network or by the establishment of national cassava trade or processors associations, which can lobby the government for various issues related to cassava production, processing and trade.

While most of these new developments have benefitted many farmers, lifting many out of poverty, there is a danger that the uncontrolled extension of the cassava planted area, especially on steeply sloping land, and the current non-use of fertilizers, will eventually result in excessive soil erosion and nutrient depletion, resulting in stagnant if not declining yields. To prevent this, it is important to train extensionists and farmers in the proper use of chemical fertilizers, combined with organic manures to increase yields and maintain their soils' fertility. This will also allow for continuous production on the same land, which should be the flattest and closest to their house, in order to prevent the practice of shifting cultivation and reduce the drudgery of long walks to far-away fields. In that case, the steeper slopes can remain under forest vegetation or be planted to fruit trees, rubber or coffee. In this way, cassava can become not only an engine for rural development but also a crop that protect the soil for use by future generations.

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CASSAVA PRODUCTION SYSTEMS IN THE PHILIPPINES: NEW OPPORTUNITIES AND CHALLENGES

Algerico M. Mariscal[1]

In recent years cassava production in the Philippines has witnessed some noticeable improvement in terms of yield and planted area due to available technologies and financial support from the government that recognizes the increasing demand for cassava as food, feed and fuel. The demand for cassava raw material from feed and food processors, starch mills and the energy sector triggered the Department of Agriculture to develop a Cassava Industry Development Roadmap from 2011 to 2016. This roadmap aims to increase average cassava production from the current 9.6 t/ha to 20 t/ha in 2016. This is complemented by a package of interventions in production systems to cater to the current demands for food, feed, fuel and other industrial uses. The production target is from 2.0 million tonnes to 8.0 million tonnes during the five-year program.

In 2011 the government has included cassava, sweet potato and banana as staple crops, aside from rice and maize, due to the need for greater food security and availability. Thus, cassava for the food program is being prioritized as energy food in the Philippines, especially for Muslims in Mindanao. Moreover, the passage of the Biofuel Act of 2007 has mandated all gasoline-based vehicles to operate on at least a 10 percent mixture of ethanol; thus several investors are now putting up ethanol plants using cassava as the raw material.

In terms of available technology, the Philippine Root Crops Research and Training Center (PhilRootcrops), based at the Visayas State University in Baybay City, Leyte, has continuously developed improved cassava varieties to meet the needs of each sector. What remains to be done is to sustain cassava production on a long-term basis via land suitability, proper cultural management, control of pests and diseases, nutrient management and the best cropping systems that are sustainable and profitable for cassava farmers.

Global climate change and its effect on crops is basically the most important challenge that needs to be addressed in cassava production systems.

Key words: Cassava production systems, investment, technology, Philippines.

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POTENTIAL ROLE OF CASSAVA IN UPLAND FARMING SYSTEMS AND IN POVERTY REDUCTION IN MYANMAR

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ABSTRACT

In Myanmar, cassava (*Manihot esculenta* Crantz) is one of the most important crops because it provides food security, feed and income for upland smallholder farmers. Recently, there has been high demand for cassava in domestic and export markets in Southeast Asia. This is a great opportunity for smallholder farmers in Myanmar to produce cassava profitably and sustainably.

Cassava adapts to a wide range of agro-ecological conditions, grows reasonably well in low fertility soils and has tolerance to drought and pests in tropical and subtropical countries. The productivity of cassava is low in traditional cassava cropping systems. The most outstanding reasons for this low productivity are the lack of suitable cassava varieties and appropriate agronomic practices. Three years of on-station and on-farm research efforts have been dedicated to resolve these challenges. Many research questions still remain unanswered. However, it is possible to share the preliminary results of cassava germplasm evaluation and improved agronomic practices for sustainable cassava systems. Nine cassava varieties have been evaluated in four different agro-ecological conditions by the Department of Agricultural Research since 2009. Root yields of introduced cassava varieties were significantly higher than those of existing local varieties in all locations. In the dry zone area, the varieties Rayong 72 from Thailand and KM 98-1 from Vietnam produced higher root yields (62 and 73 t/ha, respectively) and had higher starch contents than the two local varieties (31 t/ha). Planting densities between 10,000 and 18,000 plants/ha were required to produce acceptable yields. Most cassava is grown continuously without any fertilizer or with very low amounts of poorly balanced fertilizers. The time of fertilizer application, methods of fertilizer application and fertilizer types were tested with farmers. Even local varieties with improved agronomic practices yielded twice the amount of fresh roots compared to local varieties with existing farmers' practices. Farmers can reduce the cost of cassava production by using improved varieties and better agronomic practices, and improve their farm management in order to achieve higher yields and better quality cassava. Nowadays, farmers are starting to adopt the planting of high-yielding cassava varieties and use better agronomic practices. Nevertheless, in order to obtain optimum profits for smallholder farmers, developing high-yielding cassava varieties and appropriate agronomic practices should be considered of high priority. However, cassava research in Myanmar has a relatively short history with very limited human resources and links to the private business sector for better market opportunities.

To achieve significant impact in cassava-based farming systems, a cassava research and development network should be established within the country, and greater collaboration with other cassava research and development institutions in the region and beyond should be promoted.

Key words: Cassava potential, upland farming systems, Myanmar.

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INTRODUCTION

Cassava (*Manihot esculenta* Crantz) continues to be one of the most important crops in Myanmar because it provides food security, feed and income for upland smallholder farmers. Recently there has been high demand for cassava in domestic and export markets in Southeast Asia. Cassava in Myanmar has rapidly changed its role from being a food crop to an industrial crop within a decade. There are more than 3 million cassava farmers in the Greater Mekong sub-region, while there are at least 30,000 farmers in Myanmar who are growing cassava. This is a great opportunity for smallholder farmers in Myanmar to produce cassava sustainably for income generation in order to improve their livelihoods.

History and Current Situation of Cassava in Myanmar

Cassava was introduced into Myanmar as a food crop from Malaysia in the middle of the 19th century. The starchy root crop was first grown in the coastal region, i.e. in Tanintharyi and Rakhine States and in the Ayeyarwaddy delta (Than, 1992). It is locally known as "Pilaw Penan", "Capali Ou", "Kalaw". As in other parts of Southeast Asia, cassava is produced mainly by smallholder farmers without any inputs or with little inputs (i.e. no fertilizers or little fertilizers) expect for family labor, and planting traditional varieties. Many farmers in the rural areas consume cassava roots and young shoots and leaves for their home consumption and for animal feeding. In some upland communities cassava has become the main diet, especially during periods of rice shortage. Many farmers also grow cassava not only for use as food and feed but also for sale to local starch factories and/or drinking alcohol distilleries. The role of cassava has changed from being primarily a food crop to being an industrial crop with multiple uses, including being an animal feed, a feedstock for production of cassava starch, sweetener and in processed food, as well as for alcohol production. The crop has now become an important source of income for resource-poor farmers as a "cash crop" or "commercial crop" in Myanmar. Market opportunities in domestic and neighboring countries, such as China and Thailand, are the major driving force for these changes.

Cassava Area, Production and Yield

Nowadays cassava is grown in all parts of the country. The major producing regions and states in Myanmar are the Ayeyarwaddy region and Kachin state, followed by Sagaing region and Shan state. In 1988/89, the total harvested area was 5,602 ha, while the total production was 58,232 tonnes with an average yield of 10.4 t/ha (Than, 1992). Over the past 25 years cassava production has increased nearly eight times because the growing area has proportionally increased in Myanmar. The cassava yield, however, has not shown a significant increase, from an average of 10.4 t/ha in 1988/89 to 11.6 t/ha in 2013/14 (DOA, 2014). The harvested areas, average yield and production of cassava in 1988/89 and in 2013/14 for the regions and states of Myanmar are presented in **Table 1**. Traditionally Ayeyarwaddy was the top cassava producing region with smallholder farming systems. At present, Kachin state has a larger cassava planted area, but the average yield is lower than in the Ayeyarwaddy region.

Cassava adapts to a wide range of agro-ecological conditions, grows reasonably well in low fertility soils and has tolerance to drought and pests in tropical and subtropical countries (Howeler, 2014). That is why the area under cassava has markedly been increasing in Myanmar. Cassava production has also greatly increased during the past ten years due to increased demand for both domestic utilization and export. The impact of cassava production in Myanmar has been immense. The most outstanding reasons for the low yields are the lack of suitable cassava varieties and the use of inappropriate agronomic practices. In contrast, the highest average yield was obtained in Bago region (32.6 t/ha), due to more intensive cultivation, planting high yielding varieties from Thailand and with higher inputs (mainly fertilizers).

Table 1. Cassava harvested area, average yield and production in the various regions and states of Myanmar in 1988/89 and in 2013/14.

	Harvested area (ha)		Average yield (t/ha)		Production (t)	
Region/State	1988/89	2013/14	1988/89	2013/14	1988/89	2013/14
Ayeyarwaddy	3,664	14,547	10.6	16.7	13,787	242,298
Bago	555	1,039	5.7	32.6	3,175	9,599
Chin	7	107	3.0	4.4	21	474
Kachin	174	22,022	7.2	13.1	1,260	289,099
Kayah	NA	NA	NA	NA	NA	NA
Kayin	30	490	12.9	7.3	388	3,598
Magway	NA	NA	NA	NA	NA	NA
Mandalay	NA	NA	NA	4.8	NA	2
Mon	109	336	11.9	15.2	1,303	5,111
Rakhine	60	278	3.9	6.7	233	1,862
Sagaing	30	1,953	15.0	7.1	450	13,831
Shan	0.4	1,482	1.5	20.1	0.6	17,540
Thanintharyi	555	686	10.5	12.7	5,819	8,683
Yangon	416	823	16.3	19.8	6,795	16,273
Total	**5,602**	**43,764**	**10.4**	**11.5**	**58,232**	**608,371**

Source: *Than, 1992 and DOA, 2014.*

Current Cassava Production Systems

Traditionally cassava is a poor man's crop in Myanmar. The average land holding size for a cassava farmer was less than 1 ha (Than, 1992). The rainy season in Myanmar starts in the middle of May and ends in the middle of October. Generally, cassava is planted in the beginning of the monsoon season (May and June). Some farmers also plant cassava in the late-monsoon season (October and November) (Aye, 2012). However, cassava can be planted year-round in many parts of Myanmar if there is sufficient soil moisture. Cassava is normally harvested at 10-11 months after planting and the time of harvesting also depends upon weather conditions and market opportunities.

Most farmers grow cassava as a sole crop, but a few farmers practice intercropping cassava with other crops, such as maize and grain legumes. There is a great opportunity for smallholder farmers to intercrop cassava with other cash crops such as groundnut and common bean (Aye and Howeler, 2012). Before planting, most farmers prepare the land to loosen the soil and incorporate any weeds. Usually the soil is plowed using cattle or buffaloes and weeds are collected manually. Recently, some farmers use hired tractors for land preparation – mainly plowing and disk harrowing – especially when they have larger fields and commercial plantations.

Farmers in the Ayeyarwaddy delta plant cassava on hand-made mounds. The mounds are prepared by hoe, the size is around 90-100 cm wide, 30-50 cm high, and 150-200 cm between the center of mounds. In the mount planting method, the plant population is between 2,500-4,500 per ha, which is considerably lower than the standard population of 10,000 plants per ha. Some farmers plant cassava stakes on top of ridges with various spacing of 90-150 cm x 90-150 cm. A few farmers prefer to plant cassava stakes horizontally in shallow furrows at the same spacing as that used on ridges. Many farmers use the vertical planting method on the mounts or ridges. Farmers usually weed 3-4 times during the cassava growth cycle, while very few farmers use herbicides for weed control. As mentioned earlier, most cassava is planted in Myanmar with little or no fertilizers. But some farmers use locally available fertilizers, such as urea for N fertilizer, triple superphosphate (TSP) for P fertilizer and they may also use compost and farmyard manure. Research has shown that the application of K fertilizer at 90 kg of K_2O/ha significantly increased cassava yield from 12 t/ha to 15 t/ha in Yezin of Myanmar in 1988/89 (Than, 1992). Unfortunately, most farmers do not use K fertilizer for cassava. The productivity of cassava is usually low in traditional cropping systems, and this practice also results in gradual soil fertility depletion, especially that of soil K.

Available Cassava Varieties in Myanmar

Most farmers grow so-called local cassava varieties with various names. Most popular varieties are Hinthada local, Mon local, Shwepyitha and Yoe Sein. These local varieties have been grown for many years, but some are newly introduced by local businessmen and cassava growers; these include varieties with names such as Bangkok, Japan, Malaysia and Singapore (Aye and Oo, 2010). The origin and main features of most cassava varieties in Myanmar are unknown. But Shwepyitha seems to be Rayong 1. Than (1992) indicated that 13 cassava varieties were introduced from the CIAT cassava program in Thailand to Myanmar in 1990. Due to the lack of cassava research and development in Myanmar, unfortunately these varieties have not been maintained. In 2009, CIAT introduced another nine promising cassava varieties from the cassava germplasm collection in Lao PDR (**Table 2**). The germplasm collection is currently maintained by the Department of Agricultural Research (DAR) in Yezin and on several satellite stations.

From 2009 to 2011 CIAT has conducted preliminary cassava variety assessments in different regions of Myanmar, including the Dry Zone. This research was conducted in collaboration with the Department of Agricultural Research (DAR) and local field staff based in the network of research stations. The evaluations of cassava varieties included those suited mainly for direct human consumption, industrial application (feed, starch, biofuel) and for dual purposes. More than 45 improved cassava varieties have been released by national cassava breeding programs and CIAT in the region (Howeler and Aye, 2014). Among these, there may be many promising cassava varieties suitable for Myanmar conditions.

Table 2. The names, origins and features of CIAT-related varieties that were introduced to Myanmar in 2009.

Variety name	Origin	Mean features	Utilization
SC 5	China	High yield	Industrial
SC 205	China	High yield	Industrial
NARC 61	Lao PDR	High yield	Food and feed
KU 50	Thailand	High yield, high starch content	Industrial
Rayong 72	Thailand	High yield, high starch content	Dual purpose
Rayong 90	Thailand	High dry matter content, high yield	Industrial
HL 23	Vietnam	High yield	Dual purpose
KM 98-1	Vietnam	High yield, high starch content	Dual purpose
Nep	Vietnam	High yield, good eating quality	Food

Capacity Building

Nowadays, some farmers are starting to adopt the planting of high-yielding cassava varieties and use better agronomic practices. Nevertheless, in order to obtain optimum profits for smallholder farmers, developing high-yielding cassava varieties and appropriate agronomic practices should be considered. In addition, cassava research in Myanmar has a relatively short history with very limited human resources and links to the private business sector for market opportunities. Therefore, training of trainers (ToT) on "cassava production and on-farm utilization" was conducted for 24 government agricultural research and extension staff at DAR in March 2010.

Preliminary Results of Recent Research

More than 50 farmers participated in on-farm evaluations of cassava varieties, plant spacing, planting methods, and fertilizer application in Hinthada district in Ayeyarwaddy region of lower Myanmar, and in Nyung Oo district in Mandalay region of central Myanmar. Three years of on-station and on-farm research efforts have been dedicated to solve these challenges. Many research questions still remain unanswered. However, it is possible to share the preliminary results of cassava germplasm evaluations and improved agronomic practices for more sustainable cassava production systems.

Nine cassava varieties have been evaluated in four different agro-ecological conditions by the Department of Agriculture Research since 2009. The results of these evaluations at three locations in Myanmar are presented in **Table 3**. The potential root yields of the introduced cassava varieties were found to be significantly higher than those of the two tested local varieties in all locations. In the central part of Myanmar, represented by Tatkone, Rayong 72 from Thailand and KM 98-1 from Vietnam produced very high root yields. i.e. 62 and 73 t/ha, respectively, as compared to only 31 t/ha for the two local varieties. These two introduced varieties also had higher starch contents than the local varieties.

A planting density of between 10,000 and 18,000 plants/ha was required to produce acceptable yields. Most cassava in Myanmar is grown continuously without any fertilizer inputs or with very low amounts of poorly-balanced fertilizers (without K). Therefore, fertilizer types and rates of application were tested with farmers. Even the two local varieties, Hinthada local and Shwepyitha, with the use of improved agronomic practices yielded twice the amount of fresh roots (more than 20 t/ha) compared to local varieties produced with existing farmers' practices (less than 10 t/ha). Fertilizer use in Myanmar is the lowest among ASEAN countries and research and development efforts are required to enable a sustainable and profitable inclusion of balanced fertilizers into the cassava production systems.

Table 3. Cassava fresh root yields (t/ha) in variety trials conducted in three locations in Myanmar in 2010/11.

Cassava variety	Tatkone	Nyaung U	Naungmon
KM-98-1	73	31	38
Rayong 72	62	33	31
KU 50	46	18	43
SC 5	42	15	49
HL 23	36	17	n/a
NARC 61	35	28	38
Nep	33	11	42
Local variety B	31	14	26
Local variety A	31	11	26
SC 205	27	n/a	n/a
Rayong 90	10	26	28

A simple harvesting tool was also introduced to improve the efficiency of labor and time. The result from ten cassava fields indicate that 15-20 mandays are required to harvest one ha of cassava by hand, while with the use of these harvesting tools the harvest of one ha could be achieved in 15-20 manhours (equivalent to 2-3 mandays). Farmers can markedly reduce the cost of cassava production by using improved varieties and agronomic practices, as well as improved farm management to achieve higher yields and better quality cassava roots.

Potential Growth for Cassava in Myanmar

For cassava production, Myanmar has many special advantages. Cassava can grow well within 30° S and 30° N of the equator, which makes Myanmar (9° 58' to 28° 29' N; 92° 10' to 101° 10' E) very suitable for cassava production. These advantages also include abundant rainfall, large areas of fertile lands along the four major river systems (the Ayeyarwady, the Chindwin, the Sittaung and Thanlwin), with water flowing from north to south into the Andaman Sea. Water resources potentially available to Myanmar are estimated to be about 1,576.6 km^3. Myanmar has a total of 12.25 million hectares of arable land and permanent crops, the 25th largest endowment in the world, while being the 38th largest country in the world. Land utilization in Myanmar is presented in **Table 4**. The potential expansion of new agricultural land remains more than 5 million ha. Currently, rice is the single most important crop in Myanmar, and is grown on more than half of its arable land. However cassava production in Myanmar has potential for sustained growth because most of the arable land has low-pH upland soils (Dierolf *et al*., 2001) where cassava can grow better than most other crops.

Table 4. Land utilization in Myanmar in 2012/13.

Land use	Area (million ha)	Percentage
Net sown area	11.97	17.70
Fallow land	0.24	0.36
Cultivable waste land	5.61	8.29
Reserved forests	16.90	24.98
Other forests	16.26	24.02
Others	16.66	24.65
Total	**67.66**	**100.00**

Source: *DAP, 2014.*

Urgent Research Needs in Myanmar

Cassava is a potential crop that can be promoted by the government, as it is relatively easy to grow, even on infertile soils, and has currently good market opportunities. It can be maintained in the field and harvested during food shortages for rural upland communities. Furthermore, the leaves and roots can be used as an important feed source for a range of livestock species (cattle, pigs, chicken, and fish) commonly owned by smallholders. The global market for cassava products has expanded rapidly, with attention recently turning to Myanmar. Even though many upland farmers want to grow cassava for their food and income to improve their livelihoods, the crop has so far received very little attention from government officials of the Ministry of Agriculture and Irrigation. The following aspects need urgent attention:

Varietal improvement

Suitable cassava varieties are still lacking in many parts of Myanmar. The country should introduce various varieties of cassava through international research organizations (such as the CIAT cassava program), including those bred for special nutritional problems such as high ß-carotene varieties to combat vitamin A deficiency, as well as high yielding, high dry matter varieties for the industrial market. Varietal evaluations would need to be conducted to select the best varieties in various locations across the country.

Good agronomic practices

There has been very little research focussed on improving cassava agronomic practices because of a lack of well-trained researchers. Cassava research should continue on plant population density, alternative cropping patterns and systems (including intercropping), various times of planting and harvest, rapid multiplications of quality planting materials, effective weed control, monitoring and observation of potential pests and diseases, and alternative sources and rates of fertilizer application to improve crop nutrition, especially at various representative locations. In Myanmar, cassava can produce a reasonable yield with minimum inputs, but farmers can obtain much higher yields by providing a medium to high level of inputs. Among the above-mentioned agronomic practices, improved crop nutrition is known to be one of the most important components for increasing cassava yields while also maintaining the natural resources.

CONCLUSIONS

Cassava is becoming an important multi-purpose crop, both for food security and income generation of smallholder farmers. Because of high domestic and regional demand for cassava products, cassava production is a great opportunity as a vehicle for rural development and poverty reduction in Myanmar, particularly in remote upland areas. The government and the private sector should invest in both cassava research and extension systems to promote more sustainable cassava production practices by cassava growers, especially smallholder upland farmers. Farmer participatory research and extension (FPR&E) methodologies should be used in national agriculture research and extension systems. These methods are undertaken in collaboration with farmers and local authorities so as to increase the chances for local innovation and adoption. Due attention should also focus on the best ways to manage other issues, such as socio-economic, ethnic and political situations, which have to be considered to ensure both appropriateness and adoption in Myanmar. A development network should be established within the country, and collaboration with other research and development institutions in the region and beyond should be promoted.

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TRANSFORMING THE CASSAVA SUBSECTOR IN NIGERIA

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Cassava production in Nigeria is increasing at three percent every year, but more than 50 percent of cassava production is subsistence farming, and most of the rest is semi-commercial in nature. To fully exploit cassava's immense potential, especially as a replacement for imported raw materials and as an export commodity, a cassava transformation that builds upon previous efforts, increases productivity and commercializes the harvest has been embarked upon under the Agricultural Transformation Program of President Goodluck Jonathan and being implemented by the Honorable Minister of Agriculture, Dr. Akin Adesina. The cassava transformation seeks to create a new generation of cassava farmers, oriented towards commercial production and farming as a business, and to link them up to reliable sources of demand, either processors or a guaranteed minimum price scheme of the government. The overarching strategy of the cassava transformation is to turn the cassava sector in Nigeria into a major player in local and international starch, sweeteners, ethanol, high-quality cassava flour (HQCF) and dried chips industries by adopting improved production and processing technologies, and organizing producers and processors into efficient value-added chains.

Implementation of the value-added chain activities will be driven by the private sector with support from the public sector. A Cassava Market and Trade Development Corporation (CMTDC) will be established as the primary vehicle for implementation of value-added chain activities. Primary activities of the CMTDC will be market development, including advocacy with potential users of cassava-based products and policy-makers, to ensure reliable demand. From the public sector, the federal, state, local governments and NGOs will organize and train farmers in modern production methods and disseminate to them improved varieties and inputs required to grow them.

Experience from around the world has shown that crop campaigns to raise productivity require a close partnership with research and development of enabling technologies. The transformation plan will invest significantly in the development of improved production methods, new varieties, disease and pest diagnostic surveys and the development of novel cassava products. The transformation plan will support the production of high starch content and early varieties for an 8-10-month crop, and varieties with increased nutrition to enhance the health status of consumers, especially children.

The expected impact includes the creation of one million jobs, half on-farm and half off-farm, and realize a US$450 increase in the income of 1.8 million cassava farmers due to the increase in average productivity from 12.5 t/ha to 25 t/ha in target regions of intervention, and the creation of strong supply chains to the industry.

Key words: Value-added chains, novel cassava products, training, Nigeria.

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"HUAY BONG 80" A NEW VARIETY WITH HIGH YIELD AND HIGH STABILITY FOR STARCH CONTENT

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ABSTRACT

Huay Bong 80 (HB80) is a new cassava (*Manihot esculenta* Crantz.) variety developed by researchers from Kasetsart University in cooperation with the Thai Tapioca Development Institute (TTDI). This new variety has been protected by the Thai New Plant Variety Protection Act of B.E. 2542 (AD 1999) from January 4, 2010 to January 3, 2022. This new variety is the progeny from the cross between Rayong 5 and Kasetsart 50. HB80 has high fresh root yield potential and high root starch content. HB80 has a similar yield to Huay Bong 60, but higher than Kasetsart 50 and Rayong 5. Concerning root starch content, HB80 was the best. Results of 93 yield trials conducted from 2001 to 2010, show that HB80 had the best performance in starch content when compared with three check varieties (Kasetsart 50, Huay Bong 60, and Rayong 5). HB80 had the highest starch content in 75 yield trials and the second highest starch content in the remaining 18 trials. Nine years of yield trials demonstrated that the variety HB80 not only has high root yield but also a superior and more stable starch content.

INTRODUCTION

In Thailand, there are only two organizations that conduct cassava breeding activities. One is the Rayong Field Crops Research Center, Department of Agriculture (DOA), Ministry of Agriculture and Cooperation; and the other is the Department of Agronomy, Faculty of Agriculture, Kasetsart University. The names of varieties released by the Rayong Field Crops Research Center start with the letter "R" (for example, R1, R5, R90, R72, R7, R9, and R11). Until now, Kasetsart University has released four cassava varieties, i.e. Sriracha 1 in 1990, Kasetsart 50 (KU50) in 1993, Huay Bong 60 (HB60) in 2003, and Huay Bong 80 (HB80) in 2008.

In 2010, about 1.2 million hectares of cassava were planted in Thailand, producing 22 million tonnes of fresh roots. The average yield was 21 t/ha. The most widely planted variety by Thai growers was KU50, occupying 53% of cassava production land in Thailand in 2010. It was followed by R5 with 23% of the cassava growing area (OAE, 2010). KU50 and R5 are the first two cassava varieties that were selected in collaboration with growers. HB80 is the most recent variety released by the Department of Agronomy, Faculty of Agriculture, Kasetsart University, with research support from the Thai Tapioca Development Institute (TTDI). HB80 has been registered as a new protected variety in order to prevent the export of this variety to other countries and varietal trading by large companies. This varietal protection does not prevent the multiplication and trading among Thai farmers. During the evaluations leading to the release of HB80, we have conducted many trials over the course of nine years. The results of these trials were used to evaluate the stability of performance of

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HB80 compared to other popular varieties in Thailand. A successful variety not only has good average agronomic and quality traits, but is also stable for those traits. We have explored the genotype by environment interaction (GxE) as a measure of differences among varieties in phenotypic stability. If GxE exists, then the ranking of varieties depends on the particular environmental conditions where they are grown. Other than having average high performance for yield and other essential agronomic traits, superior varieties should be stable over a wide range of environmental conditions. In other words, breeders need to select high performance varieties with high stability (low GxE). Differences among varieties for performance across different environments is likely due to differential reactions to abiotic and biotic stress factors, like drought or diseases (Becker and Leon, 1988). In a previous study, the GxE of traits was studied in 15 morphologically and genetically diverse cassava genotypes in six locations over two seasons per location using a mixed model analysis of variance, with genotypes and locations considered to be fixed effects, and season considered to be random effects (Tan and Mak, 1995). The research showed that genotype effects were strongest in controlling root cyanide content, harvest index, and root dry matter content. Environment was the major cause of variation in commercial root number and fresh root yield (Tan and Mak, 1995).

MATERIALS AND METHODS

Data from 93 cassava yield trials, conducted between 2001 and 2010, were used to evaluate the stability of four varieties: Huay Bong 60 (HB60), Huay Bong 80 (HB80), Kasetsart 50 (KU50), and Rayong 5 (R5). The 93 trials were conducted in 23 locations in 11 provinces, i.e. Chachoengsao (two locations), Kanchanaburi (three locations), Buri Ram (one location), Chaiyaphum (four locations), Kalasin (two locations), Chon Buri (one location), Kamphaeng Phet (one location), Nakhon Ratchasima (six locations), Prachin Buri (one location), Suphan Buri (one location), and Uthai Thani (one location). This study focused on four varieties: HB60 and HB80 are the most recent varieties from Kasetsart University and KU50 and R5 are the most popular varieties currently planted by Thai growers. The pedigrees of these four varieties are related to each other, as shown in **Figure 1**. Both R5 and KU50 are the parents of HB60 and HB80. All trials were conducted with a randomized complete block design with four replications and planted at 1×1 m spacing. Fertilizer (15-15-15 N-P_2O_5-K_2O) was applied in all trials at a rate of 312.5 kg/ha. Standard cultural practices were used.

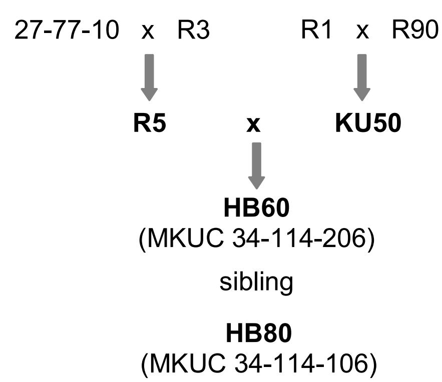

Figure 1. The pedigrees of the varieties R5, KU50, HB60, and HB80.

DATA ANALYSIS

The statistical analyses focused on three traits: fresh root yield (t/ha), dry root yield (t/ha), and starch content (%). Analysis of variance (ANOVA) combined the results of all 93 trials and was carried out using the SAS software. To explore the GxE, the additive main effect and multiplicative interaction, or AMMI, was carried out using the CropStat program from IRRI (IRRI, 2007). The AMMI model analysis combines the additive parameters of ANOVA with multiplicative parameters of Principal Components Analysis (PCA). AMMI analysis can present the result graphically in two kinds of biplots, AMMI1 and AMMI2. The AMMI1 biplot shows the genotype and environmental means and the grand mean on the abscissa, and its IPCA1 (interaction principal component axis) scores for genotypes and environments on the ordinate. For AMMI2 biplot, the IPCA1 is on the abscissa and the IPCA2 is on the ordinate.

The AMMI analysis provides a biplot of main effects and the first principle component scores of interactions (PCA1) of both genotypes and environments (**Figure 2**). The differences among genotypes in terms of direction and magnitude along the X-axis (yield) and Y axis (IPCA1 scores) are important. **Figure 2** shows how to interpret the results from the AMMI1 biplot. The AMMI1 biplot is separated into four quadrants. The lower yielding environments are in quadrants 1 and 4 and the higher yielding environments are in quadrants 2 and 3. The cultivars or environments with high PCA1 scores (negative or positive) indicate large interactions (low stability), while cultivars or environments with low PCA1 scores indicate small interactions (high stability) (Crossa *et al*., 1990). In a biplot where the PCA1 score is on the vertical axis and the mean yield is on the horizontal axis, genotypes that appear near a perpendicular line have similar means and those that fall near a horizontal line have similar interaction patterns.

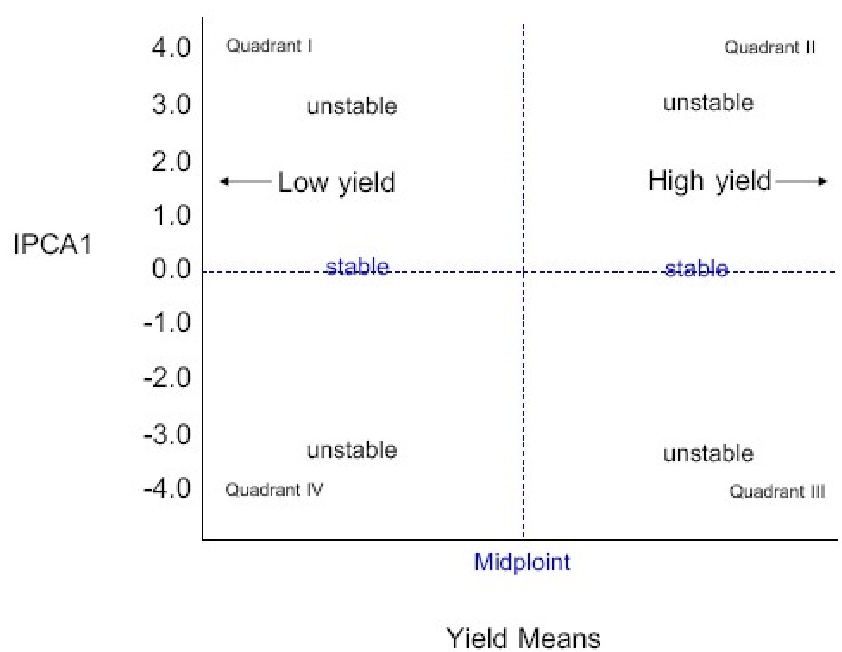

Figure 2. Interpretation of an AMMI1 biplot.

RESULTS AND DISCUSSION

The ANOVA combining 93 trials for three traits (fresh root yield, dry root yield, and starch content) is shown in **Table 1**. The main effects (trial and variety) and their interaction were significant for all three traits. The means comparison of the average root yield (fresh and dry) and starch content was carried out using the Bonferroni method and is shown in **Table 2**. Fresh root yield of HB80 was not different from those of HB60 and KU50 but was higher than that of R5. Dry root yield of HB80 was not different from that of HB60 but was higher than those of KU50 and R5. R5 had the lowest yield. HB80 had the highest starch content, followed by HB60 and then KU50; R5 had the lowest starch content.

Table 1. ANOVA for fresh root yield, dry root yield, and starch content of four Thai cassava varieties combined over 93 yield trials conducted in farmers' fields between 2001 and 2010.

Source of variance	df	Mean Squares		
		Fresh root yield	Dry root yield	Starch content
Trial	92	907.49**	160.17**	170.59**
Replication (Trial)	276	34.91	5.97	3.77
Variety	3	647.69**	116.36**	572.72**
Trial x Variety	276	39.84**	7.31**	6.035**
Error	828	21.09	3.78	2.78

** Significant at $\alpha = 0.01$ level

Table 2. Average root yield and starch content of four Thai cassava varieties in 93 yield trials conducted in farmers' fields between 2001 and 2010.

Variety	Root yield (t/ha)				Starch content (%)	
	Fresh	Sup. (%)	Dry	Sup. (%)	(%)	Sup. (%)
Huay Bong 80	30.26 ab[1/]	109[2/]	11.74 a	112[2/]	27.11 a	112[2/]
Huay Bong 60	30.79 a	111	11.36 a	109	25.38 b	105
Kasetsart 50	29.58 b	107	10.98 b	105	25.05 c	104
Rayong 5	27.75 c	100	10.43 c	100	24.12 d	100

[1/] Within a column, means followed by different letters are different at $\alpha = 0.05$, based on Bonferroni means separation.
[2/] Percent relative to Rayong 5

Trait stability is an important objective in a cassava breeding program. To compare stability among the four varieties (HB80, HB60, KU50 and R5), an AMMI model was used to explore stability for three traits: fresh root yield, dry root yield, and starch content. For fresh root yield (t/ha), HB80, HB60, and KU50 had similar stabilities and these were higher than the stability of R5 (**Figure 3**). For dry root yield (t/ha), HB80 and HB60 had similar stabilities, and these were higher than the stabilities of KU50 and R5. R5 had the lowest stability and average dry root yield (**Figure 4, Table 2**).

Considering the AMMI1 biplot for starch content, HB80 clearly had the highest starch content (**Figure 5**). HB60 had high stability for starch content but the starch yield was lower than that of HB80.

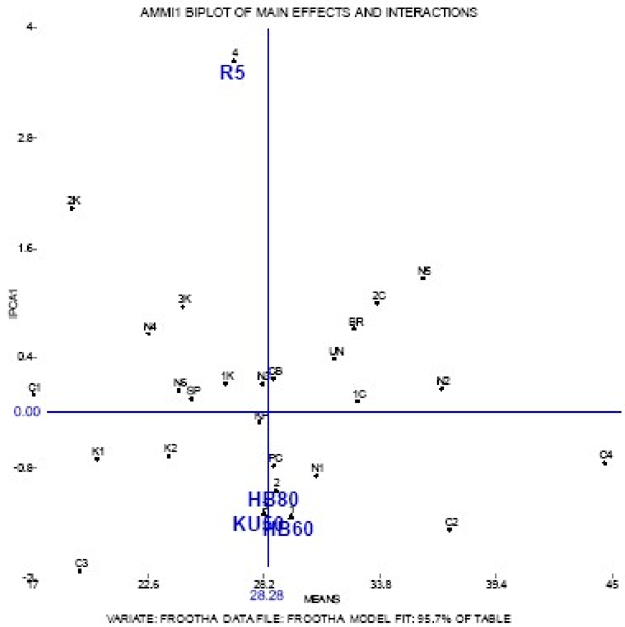

Figure 3. Biplot of the AMMI1 model for fresh root yield (t/ha) of four varieties across 93 environments between 2001 and 2010. Numbers denote varieties (1 = HB60, 2 = HB80, 3 = KU50, and 4 = R5) and letters denote locations.

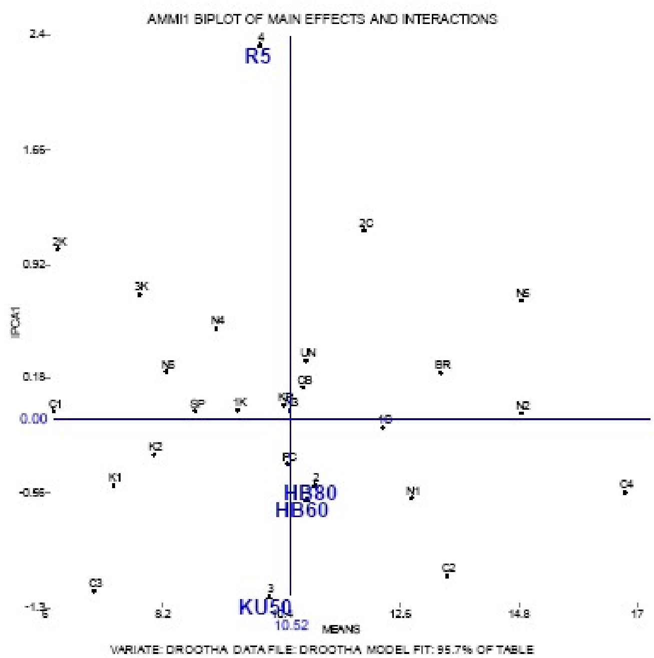

Figure 4. Biplot of the AMMI1 model for dry root yield (t/ha) of 4 varieties across 93 environments between 2001 and 2010. Numbers denote varieties (1 = HB60, 2 = HB80, 3 = KU50, and 4 = R5) and letters denote locations.

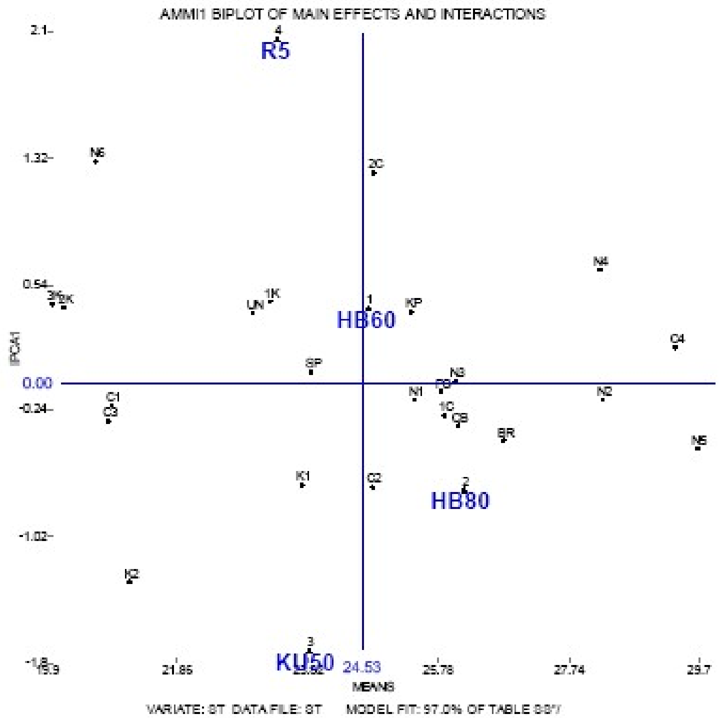

Figure 5. Biplot of the AMMI1 model for starch content (%) of 4 varieties across 93 environments between 2001 and 2010. Numbers denote varieties (1 = HB60, 2 = HB80, 3 = KU50, and 4 = R5) and letters denote locations.

In addition, an AMMI2 biplot was used to examine stability along with the AMMI1 biplot. In the AMMI2 biplot, the first two PCA axes demonstrate the relative magnitude of the GxE for specific genotypes and environments. The further away from the axes center a genotype or environment is, the larger the GxE. The points situated close to the origin with scores close to zero for the IPCA1 and IPCA2 axes represent stable genotypes and environments. The interpretation of the AMMI2 biplot for GxE is based on the magnitude and on the signs of the scores of the genotypes or environments for the interaction axes considered. For starch content stability, HB80 was closest to the origin, indicating that it had the highest stability. High starch quantity and stability is an excellent characteristic of HB80. The strong performance of HB80 is evident from the 93 trial data. When considering only the ranking of the mean starch content of each variety in each trial, regardless of statistical significance, HB80 had the highest starch content in 75 out of 93 trials; it had the second highest starch content in the remaining 18 trials. Stability varies among traits. Based on this study, starch content was more stable than fresh or dry root yield. This suggests that selection for starch content in cassava would be more effective than selection for fresh or dry root yield.

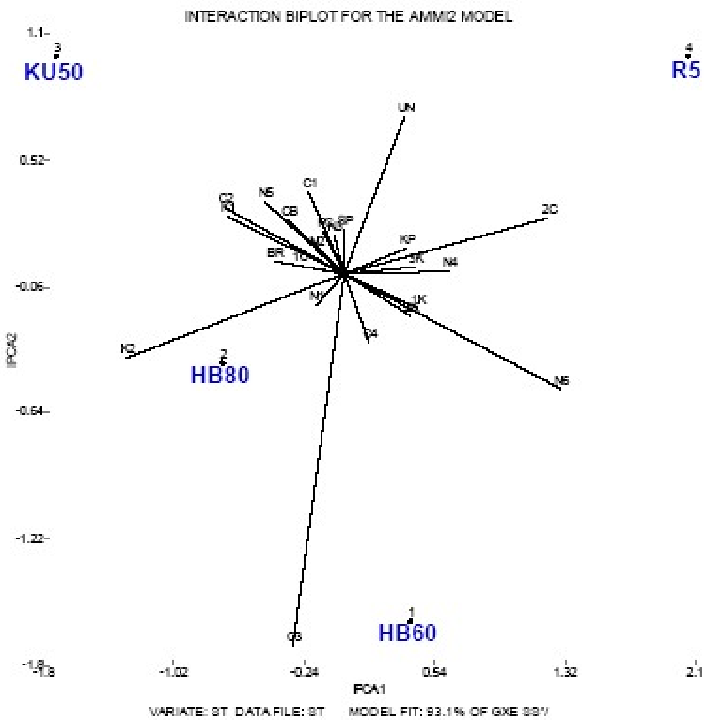

Figure 6. Biplot of the AMMI2 model for starch content (%) of 4 varieties across 93 environments between 2001 and 2010. Numbers denote varieties (1 = HB60, 2 = HB80, 3 = KU50, and 4 = R5) and letters denote locations.

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DEVELOPMENT OF WAXY STARCH CASSAVA VARIETIES IN THAILAND

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ABSTRACT

A cassava mutant for waxy (amylose free) starch was discovered at the International Center for Tropical Agriculture (CIAT) in Colombia in 2007. In order to develop waxy starch varieties suitable for growing and use by the starch industry in Thailand, an agreement between CIAT and the Thai Tapioca Development Institute Foundation (TTDI) was signed in March 2008. The crosses between the waxy line, AM 206-5, and cassava varieties adapted to Thailand were made at CIAT between August 2007 and March 2009. A total of 16,353 F_2 seeds were shipped to TTDI for selection in 2009. These imported seeds were planted in plastic bags and had a germination rate of 71.79% (11,741 plants). One month after sowing, the seedlings were transplanted to the field and 11,559 plants survived. During seedling selection, 2,871 plants were identified as having waxy starch and among those 550 seedling plants were selected as lines with good performance in 2009/10. This waxy starch trait is controlled by a single recessive gene. The 550 selected waxy clones were planted in a single row trial and selected for both high root yield and starch content in 2010/11. A total of 40 waxy clones were selected from this single row trial and are now planted in the preliminary yield trial. It is clear that waxy cassava starch has a higher viscosity and higher paste clarity, which are the properties of waxy starch. It is expected that large-scale production of waxy cassava will be materialized around 2013/14.

INTRODUCTION

Starch consists of amylose and amylopectin. The amylose content of cassava starch ranges from 15 to 25%, depending on cultivars and growth conditions (Angraini *et al*., 2009; Sriroth *et al*., 1999). The average amylose content of analyses made of more than 4,000 cassava genotypes was 20.7% (Sánchez *et al*., 2009). Amylose is a linear chain of α-1,4-linked glucose units with very few, α-1,6-linkages, which causes it to be hydrolyzed more slowly, but giving it a higher density and makes it insoluble. In contrast, amylopectin is composed of hundreds of short α-1,4 glucan chains joined together by α-1,6-linkages, with approximately 5% of the residues having both α-1,4 and α-1,6-linkages (Hoover*,* 2001). Starch is produced to serve as a source of energy in the plant cells. To synthesize starch, starch synthase (SS) catalyzes the elongation of glucan chains through the introduction of α-1,4-glucosidic linkages between the incoming glucose residues of ADP-glucose and the growing glucan chains. Starch synthases identified in higher plants can be categorized into two groups: one is exclusively granule bound (GBSS-types I and II), while the other (SS I, II and III) may be located partially or entirely in the soluble phase. The waxy mutants, which have been identified in many plant species, lack a functional version of the 58-60 kDa *GBSSI* protein (Myers *et al.,* 2000). The role of granule-bound starch synthase I (*GBSSI*) in

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starch synthesis has been well characterized as a result of studies using amylose-free (also called waxy or *wx*) mutants. *GBSSI* has been shown to be responsible for amylose synthesis in plant storage organs (James *et al*., 2003; Tsai, 1974). The amylose-free or "waxy" phenotype was first found in maize and it is among the first genes fully characterized (Hannah, 2000). In maize, this phenotype shows in the endosperm of seeds and is characterized by little or no amylose accumulation due to a mutation that alters or silences the expression of the *GBSSI* gene and thus prevents its function linking ADP-glucose to a pre-existing glucan molecule (Hannah, 2000).

The *GBSSI* gene mutation has been studied widely (Zeeman *et al.*, 2010). For example, the *GBSSI* structural genes were sequenced in maize (Klosgen *et al.*, 1986), rice (Wang *et al.*, 1990; Okagaki, 1992), barley (Rohde *et al.*,1988), wheat (Murai *et al.*, 1999), potato (van der Leij *et al.*, 1991), sweet potato (Kimura *et al.*, 2000), foxtail millet (Fukunaga *et al.,* 2002), and amaranth (Park *et al.*, 2009). The search for the waxy trait in root and tuber crops goes back to the early 1990s. Amylose-free transgenic potato and cassava plants were obtained via the down regulation of *GBSSI* (Visser *et al.*, 1991; Tallberg *et al.*,1998; Raemakers *et al.*, 2005). More recently, Zhao *et al.* (2011) also reported transgenic cassava plants that express hair-pin dsRNA homologous to the cassava's *GBSSI* conserved region under the control of the vascular-specific promoter p54/1.0 from cassava (p54/1.0::GBSSI-RNAi) or the cauliflower mosaic virus (CaMV) 35S (35S::GBSSI-RNAi), which resulted in several waxy starch materials.

Waxy mutations can be found in nature in different plant species (Eriksson 1969; Sakamoto, 1996; Hoshino *et al*., 2010). In cassava there were initially no reports of finding waxy mutants in the germplasm collection at CIAT (Sánchez *et al*., 2009). However, Ceballos *et al.* reported in 2007 the discovery of a spontaneous waxy (amylose-free) starch mutation in cassava in a partially inbred clone, AM 206-5, which had resulted from self-pollination of a large number of cassava genotypes. The AM 206-5 clone was crossed into elite germplasm from the International Center for Tropical Agriculture (CIAT) and from Thailand (Ceballos, 2009). The Thai Tapioca Development Institute (TTDI) and CIAT signed an agreement in 2008 to develop waxy starch cassava varieties that are suitable to grow in Thailand. The objective of this report is to summarize the ongoing project to develop waxy cassava varieties in Thailand during the period 2009-2011.

MATERIALS AND METHODS

The amylose-free cassava lines discussed in this study had been developed during 2004-2007 by Ceballos *et al.* (2007). Briefly, in 2004, seeds from 74 different parental clones had been collected and grown in the field at CIAT, Colombia. Once the plants had reached their maturity stage, they were self-pollinated to produce seeds for the selection in the next growing season. In 2006, 20,000 seeds obtained after self-pollination were planted. In 2007, only one clone (AM206-5) was found to present the amylose–free starch trait. Between August 2007 and March 2009, F_2 lines were produced from crosses among F_1 lines of crosses between waxy starch line, AM 206-5, and Thai commercial varieties at CIAT. 16,348 F_2 seeds were harvested between May and July 2009 and shipped to TTDI, Huay Bong, Nakorn Rachasrima, Thailand, for selection. All seeds obtained from CIAT were germinated in plastic bags filled with mixed soil. A total of 11,719 plants (71.68%) germinated. One month later, the seedlings were transplanted to the field. A spacing of one meter between plants and two meters between rows was used in order to reduce inter-plant competition. A total of 11,559 plants survived the transplanting. First year selection, or seedling plant selection, was done in March-April 2010. The identification of waxy plants was done by spraying cut roots of each plant with a solution of 2% potassium iodide. The plants with brownish stained roots were classified as waxy while those with blue iodine stains were non-waxy. The waxy genotypes were then visually selected for good plant type, high root yield and a high harvest index (H.I.). Stakes were cut from each selected plant, representing each clone or genotype.

Starch samples obtained from the roots of selected waxy clones were analyzed for specific waxy starch characteristics, including paste viscosity, peak viscosity, and breakdown (RVU), paste clarity, paste clarity after storage at 4°C for seven days, and compared with starch from normal cassava plants.

Stakes cut from each selected plant were planted in single rows of 10 plants at a spacing of 1x2 meters (within and between rows, respectively). The local commercial varieties Huay Bong 80 (HB 80) and Kasetsart 50 (KU 50) were planted in each 10th row as check varieties. In the second year, plants were harvested at 12 months after planting (April, 2011). The selection in the second year, or single row trial was based on plant type, root yield and starch content, harvest index and susceptibility to diseases and insect pests, in comparison with the adjacent check varieties. Selected waxy clones were planted in a preliminary yield trial in 2011.

RESULTS AND DISCUSSION

Of the 16,353 F_2 seeds planted in plastic bags in late 2009, only 11,719 healthy seedlings were transplanted to the field. Of these, 11,192 plants survived. During the first year of selection 25.7% of the plants (2,875 out of 11,192) showed the waxy trait. The segregation ratio of waxy phenotype (*wx wx*) in the F_2 from crosses between heterozygous F_1 (*Wxwx*) genotypes, based on field-phenotyping confirmed the expected ratio of 3 normal to 1 waxy plants. From the Chi-square test, this confirms that a single recessive gene controlled the waxy starch trait in cassava, as shown in **Table 1**.

Table 1. Chi-square test of the segregation ratio of waxy genotype (*wx*) in the F_2 from crosses between F_1 (*Wxwx*) heterozygous plants.

Field-based phenotyping				
Genotype	Phenotype	Expected	Observed	X^2 (prob.)
WxWx	Non-Waxy (normal starch)	8,394	8,317	2.825 (<0.01)
Wxwx				
wxwx	waxy	2,798	2,875	

Out of the 2,875 waxy plants, 550 (19.13%) were selected visually for single row selection during the second year of evaluation based on high root yield and good plant type. Each plant was genetically different. These 550 waxy clones were harvested and selected in mid-March 2011 based on good plant type, high root yield, high harvest index and high root starch content compared with check varieties. A total of 40 waxy clones were selected as summarized in **Table 2**. They have been propagated for the third year selection in a preliminary yield trial. In 2013 through 2014, Thai waxy starch cassava is expected to be ready for pilot commercial production.

Starch physicochemical properties of cassava waxy starch identified in this program were different from those of normal starch. The average peak viscosity of waxy starch was 95 RVU, while, that of normal starch from check varieties was 69 RVU. The starch breakdown property of waxy starch was twice that of normal starch. Paste clarity of waxy starch was almost double that of normal starch (**Table 3** and **Figure 1**). Moreover, after storage at 4°C for 7 days, the paste clarity of waxy starch was stable at 88% light transmittance, whereas that of normal starch decreased from 47% light transmittance before storage to 3% after storage (**Figure 2**).

Table 2. Some agronomic traits of a total of 574 waxy clones, 40 selected clones, as well as the check varieties KU 50 and HB 80.

Traits	Mean of waxy clones		Mean of check varieties	
	Total (550 Clones)	Selected (40 clones)	KU 50 (44 rows)	HB 80 (45 rows)
Fresh root yield (kg/plant)	3.85±2.31[a]	7.16±2.07	8.16±2.35	7.19±2.25
Root starch content (%)	19.3±4.09	21.9±2.11	26.1±2.87	27.5±3.06
Harvest index (H.I.)	0.35±0.17	0.49±0.08	0.51±0.08	0.52±0.10

Table 3. Relevant chemical information of waxy and normal cassava clones (lines).

Parameters	Waxy clones*			Check varieties**		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Peak viscosity (RVU)	62	121	**95**	47	88	**69**
Breakdown (RVU)	34	62	**48**	7	66	**24**
Paste clarity (% Light transmittance)	65	95	**87**	27	72	**47**
Paste clarity after storage at 4 °C for 7 days	67	95	**88**	1	24	**3**

* n = 525 ** n = 76

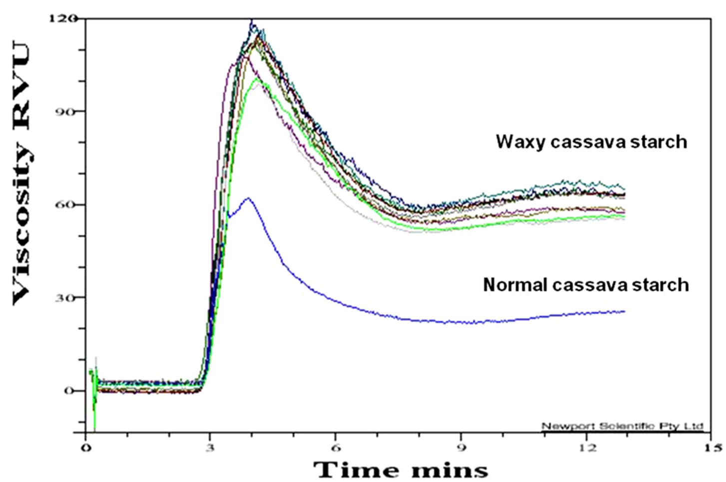

Figure 1. Paste viscosity profile of waxy and normal cassava starches as determined by a Rapid Visco Analyzer, 5% db. Graphical Analysis Results – 04/06/10.

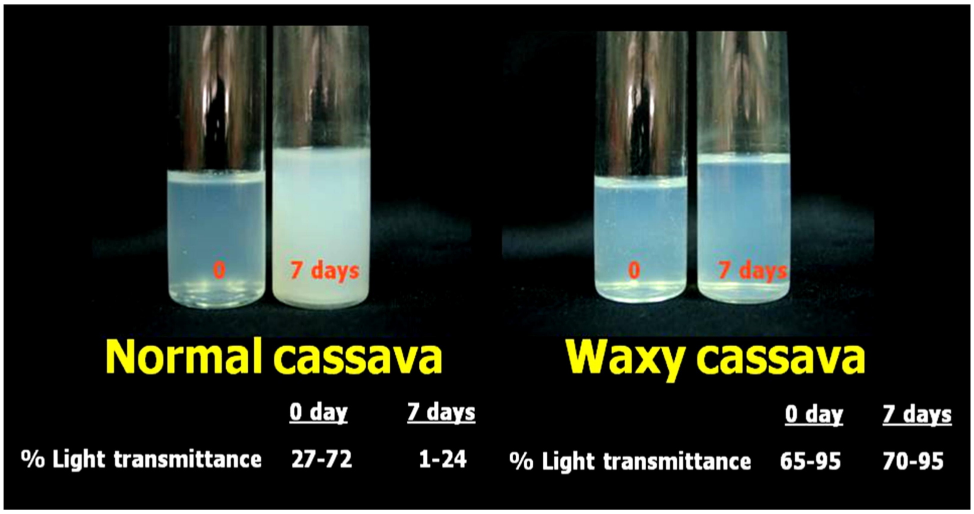

Figure 2. Pastes of waxy and normal cassava starches stored at 4 ℃ for 0 and 7 days.

CONCLUSION

In 2007, CIAT discovered a cassava mutant for waxy starch, line AM 206-5. This is the first spontaneous mutant cassava genotype with waxy starch. There are reports of transgenic waxy cassava lines (Visser *et al*., 1991; Zhao *et al*., 2011). Waxy cassava starch is characterized by a higher viscosity and higher paste clarity, especially after thawing compared with normal cassava starch (Sánchez, *et al*., 2010). Therefore, waxy cassava starch may have good use in many applications, such as in frozen foods.

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EVALUATION OF PROMISING CLONES OF CASSAVA FOR HIGH ROOT YIELD AND ETHANOL CONVERSION IN DIFFERENT LOCATIONS IN INDONESIA

Sholihin[1]

ABSTRACT

The objective of the various trials was to test the performance of promising clones of cassava (*Manihot esculenta* Cranz) for high root yield and ethanol conversion in various locations in Indonesia over several years. The initial evaluations were done during two years (2007/08 and 2009) in Lumajang (East Java), Banyuwangi (East Java), Lampung Selatan (Lampung), Lampung Timur (Lampung) and Lampung Tengah (Lampung). The promising breeding lines used were CMM 99008-3, OMM 9908-4, OMM 9904-70, CMM 99023-12, OMM 9904-111, CMM 99023-4 and MLG 10311, as well as the released varieties Adira 4 and UJ5 used as checks. Fresh root yields were determined at nine months after planting.

The study showed that based on the stability analysis of Eberhart and Russel (1966), CMM 99008-3, OMM 9908-4, OMM 9904-70, CMM 99023-4, UJ5, MLG 10311 and Adira 4 can be considered as stable clones, while CMM 99023-12 and OMM 9904-111 were found to be unstable. The mean of the fresh root yields of OMM 9908-4 over locations and years was the highest (42.2 t/ha), 16% higher than that of UJ5 (=Kasetsart 50); this yield difference is equivalent to Rp 4,460,800/ha or around US $ 496/ha.

OMM 9908-4 was also found to be moderately resistant to red spider mites and to the root rot disease caused by *Fusarium* sp. And the mean ethanol yield of OMM 9908-4 was 10,122 liters/ha. Clone OMM 9908-4 has been released as a new variety, named Litbang UK 2, in 2012. This clone is the result of open pollination of the female parent MLG 10006.

Key words: Cassava, fresh root yield, stability, promising clone, high yield, ethanol, Indonesia.

INTRODUCTION

The use of the best varieties is important in increasing production. Cassava production can be increased by intensification of the area planted or by increasing the planted area. Intensification can be done by using high yielding varieties. In 2007 there were ten released varieties in Indonesia, including UJ5. This variety was introduced from Thailand where it is known as Kasetsart 50 (KU50). It was subsequently selected for its high yield in Lampung, and was officially released as UJ5 in 2000. Yield trials with this variety were mostly conducted in Lampung province. Adira 4 is another released variety. This variety is popular in Java and was officially released in 1987. New varieties, which may be better than either UJ5 or Adira 4, are in the pipeline. If a new variety that is better than UJ5 or Adira 4 is available, farmers will benefit.

In Indonesia, cassava is planted in many different environments. To study the response to these conditions, variety trials should be conducted in some of these environments and during different planting seasons. From these variety trials, important information can be obtained about the yield stability of each genotype. There are several

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ways to analyze the data obtained, one being based on additive models. This technique is used for the analysis of yield stability. This technique is based on the regression of the variety's performance on an environmental index, like that which was proposed and modified by Finlay and Wilkinson (1963), Eberhart and Russell (1966), Perkins and Jink (1968), Freeman and Perkins (1971) and Shukla (1972). The aim of the trial was to evaluate the performance of several promising clones of cassava for high yield and their suitability for ethanol production, in various locations and over two different years.

Red mites are one of the most important cassava pests, especially during the dry season in Java. Farmers in Java do not like UJ3 (= Rayong 60 from Thailand) because this variety is susceptible to red mites. Yield losses of cassava because of mite attacks can reach 73% on susceptible varieties and 15% on resistant varieties (Byrne *et al*., 1982). Indiati (1999) reported that the yield loss of cassava because of mite attacks was 95%. This research was done in a greenhouse with artificial inoculation of mites. In general, farmers handle the mite attacks by planting resistant varieties.

Root rot is one of the diseases affecting cassava. There are two kinds of root rots in cassava: wet root rot and dry root rot, each being caused by different pathogens. Wet root rot is caused by *Phytopthora drechsleri*, *Pythium* spp., *Fusarium* spp. and *Sphaerostilbe repens*, while dry root rot is caused by *Rigidoporus lignosus, Botriodiplodia theobromae,* or *Armillaria mellea* (Makambila, 1994). *Fusarium* spp. is a soil microbe, so it can attack plants from the early growth stages until the harvest and post-harvest. This disease will appear when plants receive a lot of rain during the root growth phase and when soil drainage is poor.

Many industrial products are made from cassava, such as starch, sorbitol, fructose, glucose, crackers, and bio-ethanol. The prospects for using cassava as feedstock for the ethanol industry in Indonesia are good. The important thing in the ethanol industry is the supply of raw materials. Based on the roots' starch content, the conversion efficiency of starch to sugars, the fermentation ratio of sugar to a bioethanol concentration of 7-11%, the distillation efficiency, and the amount of fresh roots needed to produce l liter of bio-ethanol 96% can be calculated. The ethanol industry wants a cassava variety that can produce 1 liter of bioethanol 96% from as low amount of fresh roots as possible.

Currently, there is a company in Indonesia, called MedcoEnergi which produces ethanol from cassava. This company is located in Lampung province on Sumatra Island. The ethanol industry can use fresh roots, dry chips, starch or flour of cassava. Supriyanto (2006) and Broto and Richana (2006) reported that the production of 1 liter of ethanol requires 6 kg of fresh roots. However, Ginting *et al*. (2006) reported that only 4-6 kg of fresh roots are needed to produce 1 liter of ethanol 96%, depending on the cassava variety. Supriyanto (2006) reported that the cost of production of ethanol in Indonesia is Rp 2,790/ liter, assuming that the price of fresh roots is Rp 300/kg, that of α-amylase is Rp 40,000/kg, and gluco-amylase Rp 50,000/kg. The latter two materials are enzymes that are needed in ethanol production.

MATERIALS AND METHODS

The initial yield trials were conducted during two years (2007/08 and 2009) in Lumajang (East Java), Banyuwangi (East Java), Lampung Selatan (Lampung), Lampung Timor (Lampung) and Lampung Tengah (Lampung). The experiments used a randomized complete block design with three replications. The plot size was a 5x5 m and the planting distance was 100x80 cm. The rate of fertilizer application was 93 kg N+ 36 P_2O_5 + 60 K_2O/ha. The clones used were CMM 99008-3, OMM 9908-4, OMM 9904-70, CMM 99023-12, OMM 9904-111, CMM 99023-4 and MLG 10311 as promising clones, as well as Adira 4 and UJ5 as checks of released varieties. The parameter recorded was fresh root yield (t/ha) of nine month old plants. The root yield data were analyzed using MSTAT (Michigan Statistic), version C software (released by Michigan State University) to obtain the combined analysis of variance. The stability analysis used was based on the technique of Eberhart and Russel (1966). This technique uses the coefficient of regression (b_i) and the mean square of the standard deviation (S^2d_i) of the clones. Any clone is considered a stable clone if the coefficient of regression is not significantly different from one, and the mean square of the standart deviation is not significantly different from zero.

Another varietal trial was conducted in Kalimantan Tengah in 2011/12. In this case, ten clones/varieties, i.e. UJ5, UJ3 (also known as “Thai” = Rayong 60 from Thailand), CMM 02048-6, CMM 03001-10, Adira 4, MLG 10311, Malang 4, Malang 6, CMM 03020-2, and Litbang UK 2 (= OMM 9908-4) were planted in an experiment using a randomized complete block design with three replications. The plot size was 5x10 m and the plant spacing was 100x80 cm. Plants were fertilized with 300 kg urea + 150 SP-36 + 150 KCl/ha (135 kg N + 55 P_2O_5 + 90 K_2O/ha). Plants were harvested at ten months after planting.

Several cassava clones were also evaluated for their susceptibility to red mites in the glasshouse of ILETRI in Malang during the dry season of 2011. The experiment used a randomized complete block design with three replications and ten clones. Stem cuttings were planted in 30 cm diameter pots. Each plant was infested with 15 red spider mites at two months after planting. The damage intensity due to the mite attacks was evaluated at seven weeks after infestations using the scoring system shown in **Table 1**.

Table 1. Score of leaf damage due to red spider mites.

Score	Damage intensity
0	No symptoms
1	Initiation of yellowish spots on some of the lower and/or middle leaves
2	Fairly abundant yellowish spots on lower and/or middle leaves
3	Considerable damage: many spots; small necrotic zones and curling of leaves, especially the basal and middle leaves; yellowing and loss of some leaves
4	Severe damage: heavy defoliation in the lower and middle part of the plant; a large number of mites as well as webs can be observed
5	Total defoliation of the plant; shoot reduced in size with large number of webs; death of plant

***Source**: Bellotti and Schoonhoven, 1978.*

The damage intensity of the mite attacks was calculated as follows:

$$I = \sum \frac{nxv}{NxV} x100\,\%$$

where I = the damage intensity of the mite attack
N = number of leaves/plant
V = the highest score (5)
n = number of leaves in each score category
v = category score (from 0 to 5) (**Table 1**)

The level of resistance to red mites was determined based on the standard deviation method that was developed by Doreste *et al.* (1979):

Highly resistant (HR) = $I < (\bar{I} - 2\delta)$
Resistant (R) = $(\bar{I} - 2\delta) < I < (\bar{I} - \delta)$
Moderately resistant (MR) = $(\bar{I} - \delta) < I < (\bar{I} + \delta)$
Susceptible (S) = $I > (\bar{I} + \delta)$

where: $(\bar{I})$ = mean of the damage intensity of the mite attack.

Several cassava clones were also evaluated for their susceptibility to root rot caused by *Fusarium* spp. The following method of evaluation is a modification of the method developed by Onyeka *et al.* (2005). The peel of a clean tuberous root was removed and the peeled root was cut across to produce a slice of 1.5 cm thickness; each root slice was washed with clean water and a shallow hole was made. Then these root cuts were disinfected by submergence in 0.05% solution of NaOCl, followed by washing with sterile water. After that, the root cuts were put in a sterile petri dish, three cuts/petri dish as replications. 0.1 ml of a solution containing 10^6 spores of *Fusarium* spp. per ml was placed in the shallow hole of the root slice. Then all samples were placed at room temperature in the pathology laboratory. The cut roots were scored visually as follows: 1) colonization of the fungal pathogen on the root cuts, 2) change of root color, and 3) physical change (rot) of root cut. The root cuts were evaluated 7-10 days after inoculation as follows:

0 = no symptoms
1 = rot 1-25%
2 = rot 25-50%, and
3 = rot >50%.

Based on the scores, the intensity of the damage was calculated as follows:

$$I = \sum \frac{nxv}{NxV} x100\,\%$$

where I = the damage intensity of root rot
N = the number of samples
V = the highest score (3)
n = number of root cuts in each category score
v = category score (from 0 to 3)

The levels of resistance to root rot were determined based on the standard deviation method developed by Doreste *et al.* (1979), as shown above for red mite damage.

The bioethanol analysis was done in the Microbiology Laboratory of BBTP (Balai Besar Teknologi Pati) in Lampung, Indonesia, from November 2005 to Oktober 2006, using the following method developed by BBTP: The total sugar content of each clone should be analyzed before bioethanol analysis. The results of this analysis were used as basis to determine the amount of grated roots to result in a total sugar content (free sugar plus sugar hydrolyzed from starch) of 15% weight/volume in 1.5 liter of water. The bioethanol analysis was as follows: The tip and base of fresh cassava roots were cut off, followed by peeling and grating. The amount of grated root can be determined to get the total sugar content of 15% weight/volume in 1.5 liter of water. The calculation was based on the total sugar content of each clone taken before the bioethanol analysis. The pH of the solution was adjusted to 6.5. The next step was **liquifaction**, by adding the enzyme α-amilase and heating to a temperature of 90°C during 30 minutes. This was followed by **saccharification**, by adding the enzyme gluco-amylase and keeping the temperature at 55 ºC during 2 hours (mixed mechanically). The next step was **fermentation** by inoculating the slurry with yeast (*S. cerevisiae* Haiken) at a temperature of 32 ºC and mixing during two hours. Those solutions were put in three Erlenmeyer flasks of 500 ml capacity (3 replications), and then fermented at room temperature during 70 hours. This produced ethanol at a concentration of 7-11%. 200 ml solution was then taken for **distillation** until the final solution reached 150 ml; the ethanol concentration was then measured using an alcohol meter.

RESULTS AND DISCUSSION

1. Varietal Evaluations

The root yields of the nine clones in eight different environments over two years are shown in **Table 2**.

For the year 2007/08, in Lumajang in East Java, the root yields at nine months after planting ranged from 33.5 to 48.4 t/ha, with a mean of 39.7 t/ha. The root yield of OMM 9904-111 was the highest, but it was not significantly different from the root yield of the other clones. In Lampung Selatan, the root yields ranged from 23.7 to 39.8 t/ha, with a mean of 32.7 t/ha. The yield of MLG 10311 was the highest, but was similar to that of OMM 9908-4, CMM 99008-3, OMM 9904-70, CMM 99023-4 and UJ5. In Lampung Tengah, the root yields ranged from 27.1 to 50.2 t/ha, with a mean of 39.8 t/ha. The yield of CMM 99023-4 was the highest, but was similar to the yield of MLG 10311 and UJ5. In Lampung Timur, the root yields ranged from 19.5 to 42.7 t/ha, with a mean of 34.1 t/ha. The yield of OMM 9904-70 was the highest, but was similar to the yields of OMM 9908-4, MLG 10311, UJ5, and CMM 99023-12.

Table 2. Fresh root yield of cassava clones/varieties in five locations and two years, 2007/08 and 2009.

No.	Clone/variety	Root yield (t/ha)								
		Lumajang 2007/08	Lampung Selatan 2007/08	Lampung Tengah 2007/08	Lampung Timur 2007/08	Lumajang 2009	Banyu-wangi 2009	Lampung Selatan 2009	Lampung Tengah 2009	**Mean**
1	CMM 99008-3	36.3 a	31.7 abc	33.3 de	25.2 de	46.9 a	29.8 b	30.3 a	23.6 e	**32.2 e**
2	OMM 9908-4	42.1 a	35.7 ab	40.8 bcd	42.6 a	60.4 a	47.3 a	34.1 a	34.8 a	**42.2 a**
3	OMM 9904-70	41.8 a	37.7 a	40.3 bcd	42.7 a	52.8 a	43.8 a	29.7 a	25.4 cd	**39.3 bc**
4	CMM 99023-12	37.0 a	27.6 bc	27.1 e	35.4 abc	55.2 a	52.2 a	35.5 a	24.5 de	**36.8 cd**
5	OMM 9904-111	48.4 a	23.7 c	36.7 cd	19.5 e	48.8 a	46.7 a	24.3 a	26.0 c	**34.3 de**
6	CMM 99023-4	38.4 a	32.5 abc	50.2 a	29.7 cd	54.4 a	31.0 b	30.8 a	17.9 h	**35.6 d**
7	MLG 10311	33.5 a	39.8 a	49.3 ab	41.6 a	53.0 a	47.5 a	36.8 a	21.6 f	**40.4 ab**
8	UJ5	40.7 a	37.7 a	43.1 abc	38.4 ab	45.7 a	30.8 b	34.6 a	19.1 g	**36.3 cd**
9	Adira 4	39.6 a	27.6 bc	37.5 cd	32.1 bcd	48.3 a	43.7 a	32.5 a	29.6 b	**36.4 cd**
	Mean	**39.8**	**32.7**	**39.8**	**34.1**	**51.7**	**41.4**	**32.1**	**24.7**	**37.0**
	C.V. (%)	14.0	14.2	12.5	11.3	11.5	15.0	13.5	9.6	

Note: The numbers in the same column with the same letters are not significantly different at the 5% level.

For the year 2009, in Lumajang, the root yields ranged from 45.7 to 60.4 t/ha, with a mean of 51.7 t/ha. The root yield of OMM 9908-4 was the highest, but it was not significantly different from that of the other clones. In Banyuwangi, also in East Java, the root yields ranged from 29.8 to 52.2 t/ha, with a mean of 41.4 t/ha. The yield of CMM 99023-12 was the highest, but not significantly different from that of OMM 9908-4, OMM 9904-70, OMM 9904-111, MLG 10311, and Adira 4. In Lampung Selatan, root yields ranged from 24.3 to 36.8 t/ha, with a mean of 32.1 t/ha. The root yield of MLG 10311 was the highest, but was not significantly different from that of the other clones. In Lampung Tengah, root yields ranged from 17.9 to 34.8 t/ha, with a mean of 24.7 t/ha. The root yield of OMM 9908-4 was the highest, and significantly higher than that of any of the other clones.

The mean of the fresh root yields of OMM 9908-4 over locations and years was the highest at 42.2 t/ha; it was 16% higher than the mean yield of UJ5, which was 36.3 t/ha. This yield difference would be equivalent to Rp 4,460,800/ha or about US $ 496/ha when US$ 1 = Rp 9000.

The analysis of variance for fresh root yield of the nine clones, planted in eight different environments in two years is shown in **Table 3**.

Table 3. Combined ANOVA for the root yields of nine cassava clones, over five locations and two years.

Source	Degrees of freedom	Mean Square
Environment (E)	7	37.047**
Error (a)	16	47.237
Clones (C)	8	233.371**
C x E	56	91.954**
Error (b)	128	23.807
Coefficient of variation (%)		13.17

** = significantly different at 1%

It can be seen that the effect of clones and environment (locations), and the interaction of clones by environment, were all significant for the fresh root yields of nine month old plants. Although statistically significant, the interaction of genotype with the environment to produce the phenotype is generally low. This phenomenon was also reported by Sholihin (2009; 2011), as well as by Kalkani and Sharma (2010).

The yield of these clones could be higher than the yield achieved in these trials if the clones are planted in better environments than those of these trials. Besides that, the rate of fertilizer application is also important in determining yields. Sholihin *et al.* (2010) reported that Malang 6 produced more than 100 t/ha when it was planted at a plant spacing of 1.25 x 1.25 m and fertilized with 500 kg of the compound fertilizer Phonska (15% N+ 15% P_2O_5+ 15% K_2O) + 300 kg urea + 10 t cow manure/ha. Beside that, the phyisical and chemical characteristics of the soil are also important in determining the yield.

Stability analysis based on regression coefficients and standard deviations

The clones x locations interaction was significant, so an analysis of stability of clones should be made to know the stability and adaptability of these clones. Eberhart and Russel (1966) used the regression coefficient (b_i) between the yield and the environment índex, and the mean square of the standard deviation (S_{di}^2) as the stability criteria. In this methodology, a stable clone or variety has a regression coefficient (b_i) which is not significantly different from one (1), and a mean square of the standard deviation (S_{di}^2), which is not significantly different from zero (0). The mean of the fresh root yield, the regression coefficient (b_i) and the mean square of the standard deviation (S_{di}^2) of the cassava promising clones are shown in **Table 4**.

Table 4. The mean of the fresh root yield, the regression coefficient and the mean square of the standard deviation of nine promising cassava clones.

Clones/Varieties	Mean of fresh root yield (t/ha)	Regression coefficient (b_i)[a)]	Mean square of standard deviation (S_{di}^2)[b)]
1. CMM 99008-3	32.2	0.8 ns	-9.7 ns
2. OMM 9908-4	42.2	0.9 ns	-9.2 ns
3. OMM 9904-70	39.3	0.9 ns	-11.2 ns
4. CMM 99023-12	36.8	1.1 ns	31.1*
5. OMM 9904-111	34.3	1.2 ns	42.1*
6. CMM 99023-4	35.6	1.3 ns	16.9 ns
7. MLG 10311	40.4	1.0 ns	12.4 ns
8. UJ5	36.3	0.8 ns	12.0 ns
9. Adira 4	36.4	0.8 ns	-14.3 ns

Note : a) ns = not significantly different from 1
b) ns = not significantly different from 0
* = significantly different at 5% level

The mean square of the standard deviation (S_{di}^2) of CMM 99023-12 and OMM 9904-111 are significantly different from zero (0), and that of the others are not significantly different. The regression coefficients (b_i) of all the clones/varieties tested are not significantly different from one (1). As such, based on the stability analysis of Eberhart and Russel (1966), CMM 99008-3, OMM 9908-4, OMM 9904-70, CMM 99023-4, MLG 10311, UJ5 and Adira 4 can be considered stable clones, while CMM 99023-12 and OMM 9904-111 are unstable clones.

The results of the varietal evaluation conducted in 2011/12 in Kalimantan, shown in **Table 5**, indicate that clone OMM 9908-4 (Litbang UK 2) produced the highest yield of 89.48 t/ha at 10 months after planting. This yield is higher than the mean yield of 42.22 t/ha obtained with this clone in the multi-location trial conducted in 2007/08 and 2009 (see **Table 2**). The experiment was planted on May 4, 2011. The rainy season in Kalimantan Tengah started when plants were about seven months old, so during the root filling period plants were well supplied with water.

Table 5. Root yield, starch content and starch yield of cassava clones at ten months after planting in Kalimantan Tengah in 2011/12.

No	clone/variety	Fresh root yield (t/ha)	Fresh root starch content (%)	Fresh root starch yield (t/ha)
1	UJ5	55.7 b	21.0 a	11.7 bc
2	UJ3	74.3 ab	19.8 ab	14.7 ab
3	CMM 02048-6	58.3 b	16.3 d	9.5 c
4	CMM 03001-10	75.1 ab	17.7 c	13.3 abc
5	Adira 4	75.9 ab	19.1 b	14.5 ab
6	MLG 10311	80.4 a	18.5 bc	14.9 ab
7	Malang 4	71.2 ab	19.6 b	14.0 ab
8	Malang 6	57.8 b	18.6 bc	10.8 bc
9	CMM 03020-2	59.0 b	19.3 b	11.4 bc
10	Litbang UK 2	89.5 a	18.6 bc	16.6 a
Mean		**69.7**	**18.9**	**13.0**
LSD 5%		20.5	1.3	4.4
CV (%)		17	4	20

Source*: Sholihin, 2013.*

2. Varietal Evaluation for Susceptibility to Red Spider Mites

The results are shown in **Table 6**. It was found that OMM 9908-4 (Litbang UK 2) was moderately resistant to red spider mites and UJ5 was also moderately resistant.

Table 6. Results of the evaluation of cassava clones for their susceptibility to red spider mites.

Clones	Reaction to red spider mite attack	
	Damage intensity(%)	Susceptibility class
OMM 9908-4 (Litbang UK 2)	40.23	Moderately resistant
CMM 99008-3	41.84	Moderately resistant
Adira 4	14.48	Resistant
UJ5	37.73	Moderately resistant
MLG 10311	19.19	Moderately resistant
MLG 10032	33.63	Moderately resistant
MLG 10033	43.53	Moderately resistant
CMM 03069-6	40.96	Moderately resistant
CMM 03008-11	38.00	Moderately resistant

Source*: Sholihin et al., 2011.*

3. Varietal Evaluation for Susceptibility to Root Rot caused by *Fusarium* spp.

The results of the evaluation of promising clones to root rot caused by *Fusarium* spp., shown in **Table 7**, indicate that OMM 9908-4 (Litbang UK 2) and UJ5 were both moderately resistant to this type of root rot, Adira 4 was resistant, while UJ3 was susceptible (Sholihin *et al*., 2011).

Table 7. Results of the evaluation of cassava clones for susceptibility to root rot caused by *Fusarium* spp.

Clones	Reaction to root rot	
	Disease intensity (%)	Susceptibility class
OMM 9908-4 (Litbang UK 2)	14.00	Moderately resistant
UJ5	16.65	Moderately resistant
UJ3	48.90	Susceptible
Adira 4	0	Resistant

***Source**: Sholihin et al., 2011.*

4. Analysis of bioethanol production

To get information on the best clone/variety to be used as raw material for bioethanol production, during 2005-2006 some clones/varieties were analyzed for bioethanol production potential. The result showed that the fermentation ratios of sugar to a bioethanol concentration of 7-11% of the various clones tested were quite varied (**Table 8**). The differences were affected by the starch content of each clone and also by the ease of hydrolyzation by the enzymes to glucose, as well as the fermentation process with yeast to become ethanol. Logically, a high total sugar content of the solution will produce a high glucose concentration resulting in a high bioethanol conversion. Not all sugar available after the saccharification process can be converted to bioethanol.

Table 8. Fermentation ratio, the starch content, total sugar content and the amount of fresh roots needed to produce 1 liter of bioethanol 96% of some cassava clones.

Cassava clones	Fermentation ratio (%)[1)]	Dry root starch content	Fresh root total sugar content[2)]	Amount of fresh roots needed to produce 1 liter bioethanol 96% (kg)
Gebang	76.9 g	82.01 b	38.40 def	5.54 c
Adira 4	85.0 d	80.31 e	40.93 bcd	4.70 g
Iding	90.7 b	80.30 e	32.01h	5.30 d
CMM 99023-12	79.1 f	78.85 g	31.92 h	6.48 a
CMM 9906-12	85.2 d	80.41 d	33.70 gh	5.70 b
OMM 9908-4 = Litbang UK 2	85.4 d	80.48 d	42.38 b	**4.52 h**
CMM 99023-4	88.0 c	80.41 d	36.59 ef	5.08 e
CMM 99008-3	85.4 d	82.13 a	45.28 g	4.23 i
Malang 6	83.4 e	80.46 d	39.12 cde	5.04 e
MLG 10311	92.2 a	80.93bc	41.29 bc	4.29 i
UJ3	91.6 ab	79.57 f	36.22 fg	4.93 f
UJ5	83.1 c	80.24 e	43.47 ab	4.52 h
Coefficient of variation (%)	2.0	1.06	3.24	1.87
Least significant difference at 5 %	1.4	0.01	2.75	0.08

1) Fermentation ratio of sugar to a bioethanol concentration of 7-11%.
2) Total sugar includes free sugar plus hydrolyzed sugar from starch

***Source**: Ginting et al., 2006*

Based on the sugar content after saccharification, the fermentation ratio, and the efficiency of distillation, the amount of fresh roots to produce 1 liter of bioethanol 96% can be calculated. The amount of fresh roots needed to produce 1 liter of ethanol 96% of OMM 9908-4 was equal to that of UJ5 and 3.83% lower than that of Adira 4. The amount of fresh roots (with water content of 50%) to produce 1 liter bioethanol 96% can be calculated. The mean root yield and the potential yield of bioethanol of some of the tested cassave clones are presented in **Table 9**. The mean yield of bioethanol of OMM 9908-4 was 10,122 liters/ha, i.e. 11 and 17% more than those of Adira 4 and UJ5, respectively.

Table 9. The mean fresh root yield and mean yield of bioethanol from three released cassava varieties in Indonesia.

Varieties	Mean fresh root yield (t/ha)[1)]	Mean yield of bioethanol 96% (litres/ha)
Litbang UK 2(OMM 9908-4)	42.2	9,336
Adira 4	36.4	7,745
UJ5	36.3	8,031

[1)] See Table 2. ***Source***: *Sholihin et al., 2011.*

Ginting *et al.* (2006) reported that the conversion ratio of fresh roots to bioethanol 96% correlated positively with the water content of the fresh roots (r = 0.92**), correlated negatively with the dry matter content (r = - 0.93**), total sugar content (r = - 0.90**), the starch content (r = -0.68*) and the amylose content (r = - 0.64*). Thus, the starch content, water content, dry matter content, the total sugar content, and the amylose content are important characteristics in the selection of promising clones for the development of new varieties to be used as raw material for the bio-ethanol industry.

CONCLUSIONS

Litbang UK 2 **(**formerly clone OMM 9908-4) was found to be a very good variety. The mean of the fresh root yield of OMM 9908-4 over five locations and two years was the highest. This clone was also found to be stable, based on the method of Eberhart and Russel (1966). The potential yield of ethanol from OMM 9908-4 may be as high as 14,472 liters/ha. Adira 4 was shown to be more resistant to both red spider mites and *Fusarium* root rots than the other clones tested.

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CASSAVA MOLECULAR BREEDING PROGRAM AT CIAT

L.A. Becerra Lopez-Lavalle[1], H. Ceballos[1] and C. Hershey[1]

Approximately 4,000 years ago, ancient civilizations completed the domestication of the major crop species that form the basis of human survival today. These crop species not only included the major commodity crops − rice, wheat and maize − but also today's orphan crops, cassava, potato and sweet potato. It is critical for the sustainability of the human race that more attention is given to these so-called orphan crops. Currently, more than 1 billion people depend almost exclusively on cassava for survival and yet the 'green revolution' for this crop is still far on the horizon. One very compelling piece of evidence in this regard is that not much gain has been attained in the past two decades through conventional breeding, neither for increasing productivity nor for transferring the much needed crop sustainability traits such as resistance to pest and diseases.

CIAT's cassava molecular genetics team has begun a ten-year research plan focusing on unraveling the genetic processes involved in the selection of superior landraces some 2,000 years ago, which today are much in use by resource-poor farmers in the tropics. Unraveling this mechanism and thus revealing the genes responsible for their domestication and agricultural revolution will be instrumental for future genetic improvements to enhance the productivity and sustainability of cassava. CIAT is today fully committed to integrating the advances in biotechnology, genomic research and molecular marker applications with conventional cassava-breeding practices to create the foundation for molecular cassava breeding, an interdisciplinary science that will revolutionize cassava improvement in the twenty-first century.

Over the past ten years, CIAT has developed genomic resources that together with molecular genetics strategies, such as functional molecular markers, linkage-disequilibrium-based association mapping, functional and comparative genomics, offer the possibility of accelerating molecular breeding for abiotic and biotic stress tolerances in cassava crops. This presentation will give an overview of the current status of molecular cassava genetics.

Key words: Orphan crops, biotechnology, molecular genetics, CIAT.

[1] Cassava program, CIAT, Cali, Colombia.

VALUE-ADDED CASSAVA FOR BIO-INDUSTRIAL DEVELOPMENT USING BIOTECHNOLOGICAL APPROACHES

Zhang Peng[1]

Cassava (*Manihot esculenta* Crantz) accumulates a lot of starch in its storage roots that can be processed into food, feed, modified starches and biofuels. The high-yield potential and robustness against unfavorable environmental conditions make cassava a suitable crop for marginal lands, which will not significantly compete with other food crops. There are several key biological constraints in cassava for bio-industrial development. For example, the postharvest physiological deterioration (PPD) of cassava storage roots is the biggest disadvantage during starch and bio-ethanol processing world-wide; different types of starches from cassava are also in demand by starch companies; stability and high yield under different environmental conditions are also required. Conventional breeding efforts have attempted to address these constraints, but with limited success due to heterozygosity and inbreeding depression in cassava. New biotechnological tools can change this situation by offering various approaches to the challenges of cassava. These new technologies have the potential to make it much more productive, a better source of bio-industrial products and profitable to grow. Here we present our recent research progress, for example, on genetic transformation, modification of starch biosynthesis, prolonged leaf life and delayed PPD of cassava storage roots.

To further extend the application potential of cassava starch, development of novel starches with different amylose/amylopectin ratios has been achieved by the down-regulation of granule-bound starch synthase I (GBSSI) or branching enzymes (BE) expression in cassava. Amylose-free and high-amylose cassava will provide novel feedstock for industrial application. Another successful example of transgene-mediated cassava improvement is to prolong the leaf life in cassava. Cassava sheds its leaves during growth, especially in the tropical dry season. With the production of *SAG12-IPT* transgenic cassava, we have proved that senescence-inducible expression of isopentenyl transferase could extend leaf life, increase drought stress resistance and alter cytokinin metabolism in cassava. Recently, we have also investigated protein expression profiling during the PPD process and several key enzymes have been identified. Since PPD in cassava is associated with wound-induced oxidative burst in its roots, overexpression of enzymes that regulate reactive oxygen species (ROS) is necessary. Transgenic cassava co-expressing ROS-scavenging enzymes *vis-à-vis* superoxide dismutase (MeCu/ZnSOD) and catalase (MeCAT1) or ascorbate peroxidase (MeAPX2) showed improved plant antioxidant defenses and delayed PPD occurrence.

Our ultimate objective is to promote cassava as the major feedstock for bio-industrial applications through the generation of novel germplasms by genetic engineering.

Key words: Value-added cassava, bio-industrial development, biotechnology.

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AN INTEGRATED PLATFORM FOR THE ADVANCEMENT OF MOLECULAR BREEDING OF CASSAVA

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ABSTRACT

Cassava is an important tropical crop in many Asian and African countries, providing food security, income generation for small-scale farmers, and a source of starch for industrial processing. The RIKEN group has developed an integrative, functional-genomics platform for cassava for use by the global cassava research community to advance cassava molecular breeding. This has been done in collaboration with the Agricultural Genetics Institute (AGI), Mahidol University, and the International Center for Tropical Agriculture (CIAT). The platform provides: 1) Full-length cassava cDNA resources (KU 50, MEcu72 and MPer417-003), 2) ESTs using next generation sequencing (NGS) (MECu72, MPer417-003, Huay Bong 60 and Hanatee), 3) an integrative cassava database that meets international standards, 4) a cassava microarray containing more than 30,000 genes, 5) a cassava transformation system, and 6) a cassava breeding system that utilizes heavy-ion beam irradiation for mutagenesis. We hope that the effective use of this platform will allow researchers to advance the molecular breeding of cassava for production of high-yield and high value-added cassava in Asian countries. Details about this collaborative research project are presented in the following report.

Key words: Cassava, functional genomics, heavy-ion beam irradiation, microarray, starch, transformation.

INTRODUCTION

Cassava is an important tropical crop that provides food security and income generation for many small-scale farmers in tropical and subtropical countries (FAO, 2010). Cassava starch (20-30% per fresh root weight) is produced and stored in the

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tuberous roots of cassava and serves as a primary energy source when consumed by people or livestock. Cassava starch also plays a major role as a source of industrial starch and has had significant impact on the starch industry worldwide. It has been used as supplement to foods and animal feed, and also served as a resource for the industrial production of biofuel, bioplastic, amino acids via a saccharification and fermentation process, and as an addition to foods to modify texture. The cassava industry in Thailand alone accounts for more than 60 percent of the global exports of cassava and approximately five million growers in Southeast Asia supply cassava to domestic and foreign cassava processing industries (FAO, 2010). Cassava production in Vietnam has increased four-fold since the year 2000. These data clearly indicate the economic importance of cassava and that its production is greatly increasing.

Cassava is facing a number of production challenges worldwide due to the increased demand which has greatly increased the acreage of cassava plantings, as well as the need for a greater research effort. These challenges include the need for high-yield cassava cultivars, a greater understanding of biotic and abiotic stress tolerance, and molecular studies of postharvest physiology to prevent physiological deterioration (PPD). High starch content, and adaptation to variable growing conditions are especially important for cassava production in Asia, and recent global climate changes have highlighted the importance of studies on the response of cassava to drought and high-salinity stress, and diseases caused by fungi, bacteria, and viruses (Umemura *et al.,* 2011; Utsumi *et al*., 2012a). There are a variety of challenges presented by the need to increase cassava productivity and success has been limited (Ceballos *et al*., 2004). In particular, low breeding efficiency has hampered progress in cassava breeding. Therefore, effective molecular breeding strategies and research tools need to be established for cassava to overcome these obstacles.

In a collaborative project, the following integrated resource platform has been developed for advancing the molecular breeding of cassava. This platform includes: 1) the large-scale collection of full-length, cassava cDNA sequences (KU 50, MEcu72 and MPer417-003) (Sakurai *et al*., 2007; Fernando *et al*., unpublished data); 2) large-scale identification of ESTs using NGS (MEcu72, MPer417-003, Huay Bong 60 and Hanatee) (Fernando *et al*., unpublished data); 3) an integrative cassava database that meets international standards; 4) cassava microarray containing more than 30,000 genes; 5) cassava transformation system for Asian cultivars, and; 6) a cassava breeding system that utilizes heavy ion-beam irradiation for mutagenesis. This platform can be utilized for the molecular breeding of cassava in collaboration with researchers from a variety of countries, such as Africa and other Asian countries. It is hoped that this integrative cassava molecular breeding platform can make a significant contribution to increasing the income of cassava farmers by providing the cultivars needed for the sustainable production of cassava. In the present report, the current status and future perspective of our international collaborative studies (RIKEN, AGI, Mahidol University and CIAT) towards the advancement of cassava molecular breeding are summarized.

CHALLENGES TO OVERCOME

1. Full-length cDNAs and the collection of ESTs using NGS

Full-length cDNAs are essential for the correct annotation of genes, their proper alignment to genomic sequences, and for the functional analysis of genes and their encoded products (Seki *et al.,* 2002a; Iida *et al.,* 2004; Sakurai *et al.,* 2005; Seki and Shinozaki, 2009). The application of full-length cDNA sequences to the improvement of genome annotations and transcriptome analyses has been reported in various plant species, such as *Arabidopsis* (Seki *et al.,* 2002a) and rice (Kikuchi *et al.,* 2003).

RIKEN and CIAT reported the construction of a full-length cDNA library (KU 50 cultivar) of leaves and roots from cassava plants that had been subjected to a variety of conditions, and the large-scale isolation of cassava full-length cDNAs (Sakurai *et al*., 2007). In these studies, the ESTs were assembled into 6,355 contigs and 9,026 singletons that were further grouped into 10,577 scaffolds. A total of 4,621 new cassava sequences and 1,521 sequences with no significant similarity to sequences in plant protein databases were found. The generation of full-length cDNAs have also been provided for other important cassava varieties, such as MEcu72, which exhibits resistance to whitefly (*Aleurotrachelus socialis*), and MPer417-003, which exhibits resistance to whitefly and mealybug (*Phenococcus herreni*), so that the genes involved in the resistance to these pests can be identified (Fernando *et al.,* unpublished data).

In addition to the cDNA resources, a microsatellite marker (SSR) and EST-SSR-based genetic linkage map of cassava has been developed by using an F1 population derived from a cross between Huay Bong 60 (a cultivar with high fresh-root yield, high starch content, and high cyanogen content) and Hanatee (a Thai variety that has low fresh-root yield, low starch content, and low cyanogen content) (Sraphet *et al.,* 2011). The presence of the SSRs in the EST-SSR markers was confirmed by cloning and sequencing of the amplified products of randomly selected primers. The genetic map was also used for the identification of a QTL associated with cyanogen content (Whankaew *et al*., 2011) and first branch height (Boonchanawiwat *et al.,* 2011), as well as QTLs for fresh-root yield and starch content. A high-resolution genetic linkage map is essential for effectively applying the markers linked to traits of interest so that they can be used for marker assisted breeding (MAB). Therefore, a collaborative research project for the development of RNA-SNP markers by RIKEN and Mahidol University is also being considered and discussed.

2. A cassava DNA microarray

DNA microarrays have become a widely used technology for high-throughput analysis of gene expression. They provide an effective approach for studying the transcriptomes of biological systems at different developmental stages, when they are subjected to various environmental conditions, and in mutants and transgenic plants (Chen *et al.,* 2002; Kreps *et al*., 2002; Seki *et al*., 2002b; Seki *et al*., 2004; Matsui *et al*., 2008). Microarrays are also useful for identifying downstream target genes of signaling molecules, such as transcription factors, and for identifying potential *cis*-acting elements by combining expression data with genomic sequence data (Seki *et al*., 2001).

Recently, high-throughput sequencing of transcriptomes (RNA-Seq) has become available due to advances in sequencing technologies. NGS technologies and platforms have made large-scale sequencing of DNA low-cost and thus provided a wealth of new information on genomes and transcriptomes of a variety of crop species. RNA-Seq can be used to detect and identify novel transcripts and isoforms, map exon-intron boundaries, discover sequence variations, and reveal splice variants. DNA microarray technology, however, still has several advantages over RNA-Seq. These advantages include: the generation of smaller data sets that are easier to analyze and do not require the infrastructure needed to manage and analyze RNA-Seq datasets. The advantages of microarrays are expected to gradually decrease, however, and that RNA-Seq will become the predominant tool for gene expression profiling as computing hardware, and the quality and analytical power of RNA-Seq analysis algorithms, improves (Guo *et al*., 2013; Zhao *et al*., 2014).

Yang *et al*. (2011) and Utsumi *et al*. (2012b) developed an Agilent 60-mer cassava oligonucleotide microarray representing approximately 20,000 genes. The oligonucleotide microarray developed by the RIKEN team has been used, in collaboration with Mahidol University, to study the expression profiles of cassava genes during storage-root initiation (Sojikul *et al*., submitted). The RIKEN group has also more recently developed a new Agilent 60-mer cassava oligonucleotide microarray representing approximately 30,000 genes (Utsumi *et al*., submitted) and has used the microarray, also in collaboration with the research group at Mahidol University, to study the expression profiles of a variety of cassava genotypes in response to a variety of conditions. Transcriptome analysis using the cassava oligonucleotide microarrays developed by the RIKEN group is available for use in other collaborative projects.

3. Databases

Various databases of plant genome sequences and annotations are currently available as internet resources. The Phytozome database has retained genome sequence data of more than 40 species including cassava, the latter of which has been updated with full-length cDNA sequences and the genome sequence. These DNA sequence resources will enable the improvement of genome-wide analyses, with the goal of identifying the function of key genes in elite cultivars. Various additional databases are available for well-studied model plants, that provide further detailed information (Mochida and Shinozaki, 2010), ranging from molecular to phenomic datasets (Kuromori *et al*., 2006; Myouga *et al*., 2010; Sakurai *et al*., 2011).

A major objective of the current collaborative project is to perform a variety of comprehensive studies in cassava, as well as in model plant systems. Therefore, cassava database development for use in a variety of approaches, such as transcriptomics and genetics, is essential. One such database is the Cassava Online Archive (http://cassava.psc.riken.jp/). The Cassava Online Archive houses cassava mRNA sequences and ESTs, and their respective annotations that are currently available from NCBI (Genbank/EMBL/DDBJ). Thus far, this database permits searching by gene function, protein domain, gene ontology term, sequence accession number, and sequence similarity (BLAST). The annotations in the Cassava Online Archive are based on similarity search results against cassava, castor bean (*Ricinus communis*), poplar (*Populus trichocarpa*), grape (*Vitis vinifera*), and *Arabidopsis thaliana* genome sequences, as well as several protein databases (Viridiplantae, TAIR PLANTallAA; plant proteins, UniProt/TrEMBL plants). This database also provides information on the custom oligo microarray developed by RIKEN, thus facilitating the understanding of the cassava transcriptome. Information regarding the newly developed RIKEN cassava custom oligo microarray containing approximately 30,000 cassava genes, transcriptome data obtained with the microarray, and DNA polymorphisms among cassava accessions will also be available in this database in the future (Sakurai *et al*., 2013).

4. Establishment *of Agrobacterium*-mediated cassava transformation

Conventional breeding programs based on sexual hybridization have not been well developed in cassava. Cassava breeding faces many obstacles, including the high degree of heterozygosity, genetic overloading, separation of progeny, few flowers, low pollen fertility, self-incompatibility, and low fruit set (Ceballos *et al*., 2004). Therefore, the establishment of a transformation system can provide an excellent approach for overcoming the problems facing conventional breeding and accelerating the molecular breeding of cassava plants that have already been identified as carrying important traits. Various researchers have developed a transformation system using African cassava cultivars, including TMS60444, the most widely-used cultivars for cassava transformation. Although transformation using elite Asian cultivars, such as KU 50, which has high root yield, high starch content in roots, and vigorous plant growth in Asian countries (Sriroth *et al.,* 1999) has been reported, a high-efficiency transformation system has not yet been established in Asian elite cultivars. Since the current collaborative project is focusing on cassava production in Southeast Asia, the establishment of a stable transformation system for elite Asian cultivars is essential. As the first step toward accomplishing this goal, a transformation system in TMS60444 has been established and optimized, and successfully generated several transgenic lines in which candidate genes for biotic and abiotic stress tolerance, high root yield and high starch content, as well as the modification of starch quality by the diversification of the amylopectin structure and the conversion of amylose/amylopectin ratio, which is a main component of starch, and the regulation of amylose content have been introduced (Asai *et al*., 2014; Fujita *et al*., 2006; Fujita *et al*., 2007; Nakamura, 2002; Utsumi *et al*., 2011; Utsumi *et a*l., unpublished results). The analysis of these transgenic lines is currently in progress.

5. Cassava breeding utilizing heavy-ion beam irradiation

Heavy-ion beam irradiation has been widely used for both basic and applied research; such as generation of mutants, identification of novel gene function, and the breeding of useful plants (Abe *et al*., 2012; Hirano *et al*., 2015). Heavy-ion beam irradiation can induce a high frequency of mutation at relatively low doses of radiation, and the induced mutants show a wide range of variation. High rates of mutation, reflecting a wide range of phenotypes, can be achieved with the use of low doses of radiation which allow for high rates of survival. The mutants can also be directly used as non-GM plants and planted in the field without regulation. The Ion Beam Breeding Team of RIKEN Nishina Center has produced 26 plant cultivars utilizing heavy-ion beam irradiation. The current collaborative project has utilized heavy-ion beam irradiation on cassava KU 50 seeds. More than 10,000 KU 50 seeds have been subjected to the heavy-ion beam irradiation to date. Plants are grown on synthetic media after embryos have been rescued, grown on the media for several months, and then transferred and planted in cassava fields in Vietnam. The objective of this effort is to identify cassava lines that carry mutations that favorably influence storage root productivity, non-branched stems, and cassava biomass.

6. Conclusions and future perspective

RIKEN, together with AGI, Mahidol University and CIAT have developed an integrated cassava genomics platform for the global cassava research community that can be utilized to advance the molecular breeding of high-quality cassava varieties. The platform includes: 1) large-scale collection of full-length, cassava cDNA sequences (KU 50, MEcu72 and MPer417-003) (Sakurai *et al*., 2007; Fernando *et al*., unpublished data); 2) large-scale identification of ESTs using NGS (MEcu72, MPer417-003, Huay Bong 60 and Hanatee) (Fernando *et al*., unpublished data); 3) an integrative cassava database that meets international standards; 4) cassava microarray containing more than 30,000 genes; 5) a cassava transformation system for Asian cultivars, and; 6) cassava breeding system that utilizes heavy ion-beam irradiation for mutagenesis. The effective use of these databases and tools will allow cassava researchers to accelerate their efforts to develop high-yield varieties of cassava that also exhibit a variety of other high-value traits.

Marker-assisted selection (MAS) using molecular marker technology is essential for increasing the efficiency of generating elite germplasm with exceptional traits. This approach relies on the identification of important quality trait loci (QTL) combinations and pyramiding multiple sources of genes for useful traits into a set of new progenitors (Collard and Mackill, 2008; Joshi and Nayak, 2010). The heterozygous nature of cassava and its long generation time, however, make it difficult to develop appropriate genetic stocks for classical genetic approaches. High-throughput, single-nucleotide polymorphisms (SNP) marker genotyping can be used to accelerate the application of MAS strategies in breeding programs. This approach relies on the development of SNP marker resources using NGS, such as 454, GS FLX, and Illumina sequencing platforms. EST data sets of full-length cDNAs obtained from the RIKEN/CIAT project will be important resource for SNP discovery in cassava, especially for mapping expressed genes onto a genetic map.

The goal of the current, collaborative project is to advance the molecular breeding strategies for improving Asian varieties of cassava. These challenges include the development of a functional genomics platform, the integration of genotyping, phenotyping, and other large-scale datasets using systems biology. Increased genomic knowledge and genotyping capacity can provide many opportunities for the improvement of cassava varieties in a targeted manner and for increasing our understanding of the biology of cassava plants. The development of transformation systems and the utilization of heavy-ion beam irradiation for mutagenesis will help us to understand the molecular mechanisms and metabolic pathway associated with a variety of economic traits in cassava, as well as providing a potential gain to breeders and farmers. We hope that the approaches outlined in the present report will open new avenues for the molecular engineering of cassava to produce varieties with enhanced root yields, improved nutritional value, the ability to overcome PPD, increased environmental stress tolerance, and beneficial modifications of starch quality.

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CROSS-GENERA TRANSFERABILITY OF SSR AND EST-SSR MARKERS IN EUPHORBIACEAE

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ABSTRACT

Cassava (*Manihot esculenta* Crantz), rubber tree (*Hevea brasiliensis* Muell. Arg.), and physic nut (*Jatropha curcas* L.) are economically important crops, which are all members of the *Euphorbiaceae* family. Cassava is an important food crop world-wide. Rubber tree is the source of natural rubber used for many purposes. Physic nut is an interesting biodiesel crop, but research of this crop remains very limited. A total of 639 SSR and 143 EST-SSR primer pairs derived from cassava were utilized to assess their cross-genera transferability in two accessions each of cassava and rubber tree, and four accessions of physic nut. Of these, 495 (77.5%), 118 (18.5%) and 68 (10.6%) SSR primer pairs gave amplified PCR products in cassava, rubber tree and physic nut, respectively. In comparison between SSR and EST-SSR, the results showed that amplification ability of EST-SSRs was higher than SSRs. The ratios of percent amplifiable SSR:EST-SSR were 91.6:77.5 in cassava, 53.8:18.5 in rubber tree, and 13.3: 10.6 in physic nut. Moreover, informative polymorphisms for the amplified cassava SSR and EST-SSR loci were also observed in all three tested species. The results showed that informative cassava markers that could be applied for genetic analysis were obtained from 1.9% and 0.2% of cassava SSRs and 6.3% and 2.8% of cassava EST-SSRs when tested with rubber tree and physic nut, respectively. These informative primers will potentially be applied in genetic analysis and comparative linkage map construction among members of this family.

Key words: SSRs, EST-SSRs, transferability, *Euphorbiaceae*, cassava, rubber tree, physic nut.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), rubber tree (*Hevea brasiliensis* Muell. Arg.), and physic nut (*Jatropha curcas* L.) are economically important crops, which are all members of the *Euphorbiaceae* family. Cassava is one of the most important crops for use as primary human food and is found in several tropical and inter-tropical regions of the world, especially in the sub-Saharan region of Africa (Anderson *et al*., 2004). Rubber tree is a commercial cultivated tree species and the source of natural rubber (Feng *et al*., 2008). The natural latex from the rubber tree has many properties that have been used in industry, agriculture, national defense, transportation and in many items used in daily life (Yu *et al*., 2010). Similarly, physic nut is an interesting biodiesel crop, but research of this crop remains very limited (Wen *et al*., 2010). Due to the long growth period of these plants, breeding and development of new varieties require a long time and have a high cost (Feng *et al.*, 2008). Breeding improvement using DNA molecular marker technology would be a promising alternative in terms of both time and cost effectiveness. Comparative genetic linkage maps are based on mapping of the genes that are inherited and conserved in different species, and comparing their loci position with homologous linkage groups (Barreneche *et al*., 2004).

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DNA marker technology has shortened the time required to produce high-density genetic and physical maps, and made it easy to exploit the genetic map comparisons between both closely, and less commonly, distantly related species (Varshney *et al.*, 2005).

Co-linearity revealed the conservation of the gene orders between different species (Keller and Feuillet, 2000), and their very indispensable use for comparative maps by the use of common markers of one genus/species that are also present in another related genus/species (Van Deynze *et al.*,1998).

Among several types of molecular markers, microsatellites, or simple sequence repeat (SSR) markers, are used in many applications in plant genetics and breeding. SSRs have many advantages like multi-allelic variation, reproducibility, co-dominant inheritance, high abundance and whole genome coverage (Gupta *et al*., 2000). Nucleotide sequences of crop plants point to sufficient homology in the flanking regions SSR loci. Thus, primer pairs that are designed on the sequence from one species could be amplified SSR regions in related species. Therefore, the amplifications of SSR markers in non-donor species are called "transferability" (Kuleung *et al*., 2004). Microsatellites developed from ESTs, ESR-SSRs or genic SSRs present functional molecular markers and are expected to gain high transferability as they are the gene regions that are relatively conserved in the genome (Aggarwal *et al.*, 2007). In addition, the transferability from one species to another is a way to understand the main processes of genome evolution and mapping of comparative genomes (Barreneche *et al*., 2004).

In the study reported here, 639 SSR and 143 EST-SSR cassava primer pairs were investigated for the cross-genera transferability to rubber tree and physic nut, which belong to the same *Euphorbiaceae* family. Moreover, the amplifications of the primers were observed for polymorphism in order to search for informative markers for the construction of a comparative genetic linkage map.

MATERIALS AND METHODS

Plant materials and DNA extraction

Two accessions of cassava (Huay Bong 60 and Hanatee), two of rubber tree (RRII 105 and RRIM 600), and four accessions of physic nut (1, 2, 3 and 4) were used to evaluate the transferability of SSR and EST-SSR primers derived from cassava (**Table 1**). Genomic DNA of each sample was extracted using the CTAB method, as described in Fulton *et al*. (1995).

Six hundred thirty-nine SSR and 143 EST-SSR primer pairs of cassava obtained from the International Center for Tropical Agriculture (CIAT) and Mba *et al.* (2001) were used to screen with genomic DNA of cassava, rubber tree and physic nut for amplification and polymorphism.

The PCR reaction mixture (15 µl total) consisted of 50 ng of genomic DNA, 1X PCR buffer (Promega, Madison WI, USA) with 1.5 mM $MgCl_2$, 0.2 µM of each forward and reward primers, 200 mM of each dNTP, and 1 unit of Taq DNA polymerase (Promega). The PCR conditions consisted of the following steps as described by Sraphet *et al.* (2011): 94 °C for 2 min followed by 30 cycles of 94 °C for 30 sec, 55 °C for 45 sec and 72 ºC for 1 min; then the final step of 72 °C for 5 min. The amplified PCR products were analyzed using 5% (w/v) denaturing polyacrylamide gel electrophoresis, and were visualized by silver staining according to the method of Benbouza *et al.* (2006).

Table 1. Plant materials used for the cross-genera transferability test.

Species and name of accessions	Sources
Manihot esculenta Crantz	
Huay Bong 60	Thailand
Hanatee	Thailand
Hevea brasiliensis Muell. Arg.	
RRII 105	India
RRIM 600	Malaysia
Jatropha curcas L.	
1	Thailand
2	Thailand
3	Thailand
4	Thailand

Scoring and amplification analysis

The amplified PCR products were scored for presence or absence of alleles and the number of alleles per locus. The amplified fragments were classified into four classes: (1) informative polymorphism; (2) non-informative polymorphism; (3) monomorphic; and (4) non-specific amplified bands. To determine positive amplification of cassava SSR and EST-SSR primers in all tested samples, at least one of two accessions in cassava and rubber tree and two of four accessions in physic nut must be positively amplified.

Amplification percentage was calculated using the following formula:

Amplification (%) = (number of amplified primers/total number of tested primers) × 100

Percentage of transferability was the percentage of amplification of the SSR and EST-SSR markers that amplified in non-donor species ((Kuleung *et al*., 2004).

Data analysis

Genetic similarity among the different taxa was established based on 639 SSRs and 143 EST-SSRs of cassava that were amplifiable in all species. Clustering analysis and genetic relationships were performed with the Unweighted Pair-Group Method (UPGMA) using TFPGA package V 1.3 (Miller, 1997).

RESULTS

Transferability of SSRs and EST-SSRs derived from cassava

In order to determine the transferability of SSRs and EST-SSRs derived from cassava to rubber tree and physic nut, 639 SSRs and 143 EST-SSRs were tested in two accessions of cassava and rubber tree and four accessions of physic nut under the same PCR-conditions that used to amplify in cassava, which had already been done with this species. Of the tested primers, 495 (77.5%), 118 (18.5%) and 68 (10.6%) primer pairs gave amplified products in cassava, rubber tree and physic nut, respectively. Of these, no PCR product was observed when tested 144 (22.5%), 521 (81.5%) and 571 (81.5%) SSR pairs of primers with cassava, rubber tree and physic nut, respectively. Of the 143 tested EST-SSRs, 131 (91.6%) yielded amplicons in cassava, 77 (53.8%) in rubber tree and 19 (13.3%) in physic nut, while 12 (8.4%), 66 (46.2%) and 124 (86.7%) gave no PCR product when analyzed with cassava, rubber tree and physic nut, respectively (**Table 2**).

Moreover, polymorphic patterns were observed in all samples that showed amplified PCR products. In cassava, of the 495 tested SSRs, the results showed 218 (34.1%) informative markers, 18 (2.8%) non-informative markers, 116 (18.2%) monomorphic markers and 143 (22.4%) non-specific bands. On the other hand, of the 131 EST-SSR amplifiable markers 57 (39.9%) exhibited informative polymorphisms, 6 (4.2%) non-informative polymorphisms and 68 (47.6%) monomorphisms. In rubber tree, of the 118 SSR primer pairs 12 (1.9%) gave amplified PCR products that presented informative patterns, 47 (7.4%) monomorphic patterns and 59 (9.2%) non-specific patterns. Of the 77 amplified EST-SSRs, the results comprised of 9 (6.3%) informative markers, 51 (35.7%) monomorphic markers and 17 (11.9%) non-specific bands. In physic nut, one (0.2%) of 68 amplified SSRs was informative type, two (0.3%) were non-informative types, 35 (5.5%) were monomorphic and 30 (4.7%) were non-specific types. Of the total 19 amplifiable EST-SSRs, the results composed of four (2.8%), 14 (9.8%) and one (0.7%) of informative, monomorphic and non-specific patterns, respectively (**Table 2**).

Table 2. Results of amplification of cassava SSRs and EST-SSRs in rubber tree and physic nut.

Classes of amplification	Cassava		Rubber tree		Physic nut	
	SSR	EST-SSR	SSR	EST-SSR	SSR	EST-SSR
Amplifiable	495 (77.5%)	131 (91.6%)	118 (18.5%)	77 (53.8%)	68 (10.6%)	19 (13.3%)
- Informative polymorphism	218 (34.1%)	57 (39.9%)	12 (1.9%)	9 (6.3%)	1 (0.2%)	4 (2.8%)
-Non-informative polymorphism	18 (2.8%)	6 (4.2%)	0 (0%)	0 (0%)	2 (0.3%)	0 (0%)
- Monomorphic band	116 (18.2%)	68 (47.6%)	47 (7.4%)	51 (35.7%)	35 (5.5%)	14 (9.8%)
- Non-specific band	143 (22.4%)	0 (0%)	59 (9.2%)	17 (11.9%)	30 (4.7%)	1 (0.7%)
Non-amplifiable	144 (22.5%)	12 (8.4%)	521 (81.5%)	66 (46.2%)	571 (89.4%)	124 (86.7%)

Clustering analysis and genetic relationships

Cassava, rubber tree and physic nut, all belonging to the *Euphorbiaceae* family, were discriminated as their genetic differences. A dendrogram was constructed based on genetic relationships between cassava, rubber tree and physic nut according to the UPGMA clustering method. Two accessions of cassava and rubber tree, and four accessions of physic nut were separated into three distinct groups and showed the genetic similarity coefficient as presented in **Figure 1**. The genetic distances revealed among cassava, rubber tree and physic nut ranged from 0.3909 to 0.6417. The highest genetic distance (0.6417) occurred between cassava and physic nut, followed by between rubber tree and physic nut (0.4057), and the lowest genetic distance (0.3909) was obtained between cassava and rubber tree.

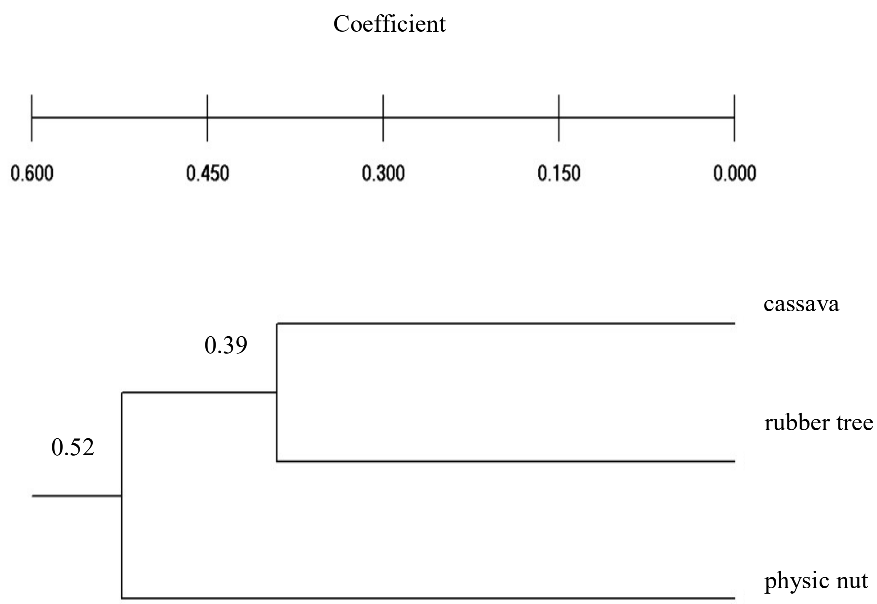

Figure 1. Dendrogram based on SSRs and EST-SSRs derived from cassava by UPGMA Cluster using Nei's (1978) unbiased distance.

Table 3. Nei's unbiased (1978) distance from TFPGA for cassava, rubber tree and physic nut using SSR and EST-SSR cassava markers.

Species	Cassava	Rubber tree	Physic nut
Cassava			
Rubber tree	0.3909		
Physic nut	0.6417	0.4057	

DISCUSSION

In the present study, the transferability of cassava SSRs and EST-SSRs to rubber tree and physic nut was investigated. The results showed that transferability of the cassava markers to rubber tree was higher than to physic nut. This result agrees with the lowest genetic distances (**Table 3**) presented between cassava and rubber tree (0.3909), indicating that they are more closely related than cassava and physic nut. Similar results were also found in a dendrogram that showed the genetic similarity coefficient between the species and clusters in the three groups. The dendrogram showed that the smallest genetic distance was between cassava and rubber tree, indicating a higher genetic relationship when compared to the relationship between cassava and physic nut (**Figure 1** and **Table 3**). In agreement with our results, Sukhuman *et al.* (2011) showed cross-genera transferability of SSR markers among cassava, rubber tree and physic nut, and that the smallest genetic distance was observed between cassava and rubber tree.

Comparing the transferability of SSR and EST-SSR markers of cassava to rubber tree and physic nut, it was found that transferability of cassava SSR was lower than that of EST-SSR markers. Similar results were also reported by Varshney *et al.* (2005), who found a higher level of transferability of EST-derived SSRs than genomic DNA-derived SSRs. This indicates higher conserved regions of coding sequences compared to non-coding genomic DNA. However, EST-SSR fragments have been reported as lower polymorphic than SSR products in crop plants because of the conservation transcribed regions of DNA sequences (Gauvêa *et al*., 2010). In addition, Gao *et al.* (2005) reported that the rate of transferability slightly decreased in closely related species, while lower transferability was found in the distantly related species of the same genus.

In conclusion, SSRs and EST-SSRs derived from cassava were exploited in cross-genera transferability in rubber tree and physic nut.The transferability of 1.9% and 0.2% of cassava SSRs, and 6.3% and 2.8% of cassava EST-SSRs in rubber tree and physic nut, respectively, demonstrates the potential of informative markers for the construction of comparative genetic linkage maps among these different species of the same family.

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EFFECT OF CYTOKININS IN CASSAVA SECONDARY SOMATIC EMBRYOGENESIS

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ABSTRACT

Cassava is one of the most important economic crops in Thailand. The increased demand for starch, animal feed and fuel ethanol will require an addition 4-6 million tonnes of fresh roots every year. A short term increase in production can be obtained from the dissemination of new clones with higher productivities. However, the diffusion rate of selected clones is limited by the traditional vegetative propagation method of this crop. Mass propagation by somatic embryogenesis (SE) can be a very promising technique to hasten their diffusion to the farmers. This work aimed to establish secondary somatic embryogenesis (SE) for cassava clones selected by the Rayong Field Crops Research Center. Rayong 9 has recently been selected for its suitability for high yield, and especially for ethanol production.

Secondary somatic embryogenesis cultures, also called cyclic, were established on solid and liquid media for the clone Rayong 9. The effect of cytokinins in secondary somatic embryogenesis was tested. This study aims to investigate the hypothesis that cassava secondary SE can be improved by a suitable hormonal balance between the two types of plant growth regulators during the induction step. The consequences of the addition of cytokinins on the regeneration of plantlets and their acclimatization will also be investigated.

Five different cytokinins, 6-benzylaminopurine (BAP), kinetin, zeatin, isopentenyladenine (2-iP) and adenine were added at 1 mg/l to the induction and maturation media to test their efficiency. From this experiment, it can be concluded that adenine doesn't have an inhibitory effect at the concentration assessed. Consequently, we tested higher adenine concentrations. The addition of adenine at 1, 5, 20 and 40 mg/l led to similar rates (9 to 13%). The conversion rate tended to be lower for adenine 10 mg/l. The acclimatization survival rate varied from 40 to 67 %: it tended to be higher for the plantlets issued from adenine concentrations higher than 10 mg/l. However, adenine at 10, 20 and 40 mg/l tended to improve the process with respect to embryoid sizes and plantlet survival rates in the greenhouse.

Key words: Cassava, cytokinins, cyclic culture, ethanol, induction, maturation, micropropagation, secondary embryogenesis.

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INTRODUCTION

Cassava is one of the most important economic crops in Thailand. The increase in demand for starch, animal feed and fuel ethanol will require an additional 4-6 million tonnes of fresh roots every year (Howeler, 2009). A short term increase in production can be obtained from the dissemination of new clones with higher yield potential. However, the diffusion rate of selected clones is limited by the traditional vegetative propagation method of this crop. Mass propagation by somatic embryogenesis (SE) can be a very promising technique to increase the rate of their diffusion to the farmers (Ducos *et al*., 2007). This research aimed to establish different SE processes (primary, secondary and indirect SE) for five cassava clones selected by the Rayong Field Crops Research Center: Rayong 9 has recently been selected for its suitability to produce ethanol (Charoenrath *et al.,* 2006).

Tissue culture techniques are currently being used in conjunction with traditional methods for improvement of cassava. Such techniques include the use of shoot-tip cultures for long-term germplasm storage (CIAT, 1980; 1985), cryo-preservation (Mycock *et al*., 1995; Stewart *et al*., 2001) and meristem cultures in association with thermotherapy for virus elimination (Kartha and Gamborg, 1979; Adejare and Coutts, 1981).

Most of the studies on participation of these compounds in SE have been conducted with the classical group: auxins, cytokinins (CKs), gibberellins, abscisic acid (ABA) and ethylene (see for reviews: Jimenez, 2001; Jimenez, 2005). The ratio of different PGR required for inducing callus or embryo formation varies with the type of plant. In the majority of the species studied, auxins and CKs are key factors in the determination of embryogenesis response, probably because they strongly participate in cell cycle regulation and cell division (Francis and Sorrell, 2001; Fehér *et al*., 2003; Gaj, 2004).

Many aspects of cellular differentiation and of organogenesis are controlled by interaction between auxin and cytokinin concentrations. The type of the morphogenetic response is usually determined by the ratio between the two kinds of PGR (see review Van Staden *et al*., 2008). Raemakers *et al.* (1995) reported that about 50% of the dicotyledonous species evaluated needed a combination of auxin and cytokinin for SE induction. In most species, a low concentration of cytokinin tends to stimulate the induction of embryogenic cultures. For example, the induction medium must contain a cytokinin for coniferous species (Gupta and Timmis, 2005), *Hevea brasiliensis* (Etienne *et al*., 1993), rice (Inoue and Maeda, 1980) and pepper (Binzel *et al*., 1996; Steinitz *et al*., 2003). Fujimura and Komamine (1975) reported the positive effect of the cytokinin and zeatin on SE in carrot, and suggested that this effect results from the promotion of cell division.

Surprisingly, the different induction media described in the literature for cassava are devoid of cytokinins. In the only study on this topic, Ma and Xu (2002) reported that the addition of the cytokinin BAP to the 2,4-D-containing induction medium leads to a complete inhibition of cassava cyclic SE.

This study aims to investigate the hypothesis that cassava secondary SE can be improved by a suitable hormonal balance between the two types of plant growth regulators during the induction step. The consequences of the addition of cytokinins on the regeneration of plantlets and their acclimatization will also be investigated.

MATERIALS AND METHODS

Plant material and culture conditions

Cuttings of cultivar Rayong 9 were obtained in 2007 from the Rayong Field Crops Research Center, Department of Agriculture in Thailand, and grown in Nestlé Research and Development Center-Tours greenhouse (NR&DC-T) in France. The plants were multiplied *in vitro* through nodal segments on standard cassava micro-propagation medium comprising basal MS medium (Murashige and Skoog, 1962) supplemented with 0.5 mg/l copper sulfate, 0.05 mg/l naphthalene acetic acid (NAA), 0.02 mg/l 6-benzylaminopurine (BAP), 0.05 mg/l giberellic acid (GA3) and 20 g/l sucrose. The medium was solidified with Gelrite™ at 2.5 g/l. Before autoclaving the pH was adjusted to 5.8 with 1.0 N KOH. Microcuttings were maintained at 25°C with a light intensity of 20 µmol/m^2/s (16 h light period).

Primary and secondary somatic embryogenesis

For primary somatic embryogenesis, young leaf lobes measuring 5 to 10 mm long of the plants growing in the greenhouse, or micro-cuttings growing *in vitro* were cultured onto basal MS medium. They were placed in 90×10 mm Petri dishes containing 50 ml of induction medium. The latter was supplemented with 0.5 mg/l copper sulfate, 4 mg/l 2,4-D, 20 g/l sucrose and was solidified with Gelrite™ at 2.5 g/l. After four weeks, the primary explants with the adjoining tissues were subcultured onto maturation medium consisting of MS salts, Gamborg vitamins (Gamborg *et al*., 1968), 0.5 mg/l copper sulfate, 2 mg/l glycine, 30 g/l sucrose and 2.5 g/l Gelrite™. The cultures were maintained in the maturation medium mentioned earlier for 3 to 4 weeks at 25°C and with a light intensity of20 µmol/m^2/s, that is, 16 h light period, until the somatic embryos were obtained.

Regarding secondary somatic embryogenesis, cotyledonary stage embryos collected at the end of the maturation step were used as source of explants for inducing secondary somatic embryogenesis. They were divided into 3 to 7 small fragments measuring 1 to 3 mm long and transferred first onto the induction medium, then to the maturation media. The composition of both media and the culture conditions were identical to the ones described earlier. Different cytokinins, i.e. BAP, kinetin, zeatin, 2-iP and adenine, were tested to compare their effectiveness on cyclic somatic embryogenesis by adding them at 1 mg/l to the induction medium containing 2,4-D at 4 mg/l, then to the maturation medium. A treatment consisted of 10 Petri dishes containing 50 ml of induction medium and inoculated with five explants, each Petri dish being a replicate. In total, each treatment comprised 50 explants. After 4 weeks of incubation under dark conditions, the cultures were transferred onto maturation media containing the same cytokinins. The cultures were microscopically examined at the end of the induction and maturation steps to assess the frequency of somatic embryogenesis, defined as the percentage of explants forming at least one embryoid (responsive explants) and its intensity, which is defined by the number of embryoids formed per replicate of five explants.

Germination and acclimatization

For germination, after three weeks of culturing on maturation medium, clumps of embryoids were isolated and transferred onto 90×10 mm Petri dishes containing 50 ml of germination medium. This medium comprised half-strength MS salts and MS vitamins supplemented with 0.5 mg/l copper sulfate, 0.05 mg/l NAA, 0.02 mg/l BAP, 0.05 mg/l GA3 and 20 g/l sucrose. The medium was solidified with agar at 8 g/l. The parameters evaluated after five weeks were the number of shoots and the number of plantlets (structures with shoot and root) scored per replicate. Shoots were rooted by transfer onto standard cassava micro-propagation medium. Concerning acclimatization, plantlets with a well-established root system and a shoot having at least a pair of leaves were transferred to small pots filled with peat. After 1 month, the surviving plants were transferred to larger pots filled with a mixture of peat and soil (50/50 % v/v).

Statistical analysis

Analysis of variance was performed using NCSS software. The treatment means were separated by the Newman and Keuls test at 5% significance level.

RESULTS

Effect of different cytokinins

Different cytokinins, i.e. BAP, kinetin, zeatin, 2-iP and adenine were tested to compare their effectiveness on cyclic SE by adding them at 1 mg/l to the induction medium containing 2,4-D at 4 mg/l, then to the maturation medium. Each treatment was repeated ten times (five explants per replicate) in a total of 50 explants per treatment. After four weeks incubation under dark conditions, the cultures were transferred onto the maturation media containing the same cytokinins.

Table 1. Effect of the addition of different cytokinins at 1 mg/l to the induction (with 2,4-D 4 mg/l) and maturation media on cassava variety Rayong 9's secondary SE. The data are the average of 10 replicates, each one consisting of five fragments of green embryoids.

	Induction		Maturation		Germination		
Cytokinin	Responding explants (Average)	Embryoid structures (nbr/repli-cate)	Responding explants (Average)	Embryoid structures (nbr/repli-cate)	Foliose (nbr/repli-cate)	Shoots (nbr/repli-cate)	Plantlets (nbr/repli-cate)
Control (0)	88^{a}	18.8^{a}	70^{b}	8.7^{b}	2.6^{b}	0.7^{a}	1.6^{b}
BAP	96^{a}	11.1^{b}	25^{a}	2.9^{a}	1.9^{bc}	0.1^{a}	0.2^{a}
Kinetine	88^{a}	9.2^{b}	55^{ab}	6.4^{ab}	3.2^{b}	0.2^{a}	0.1^{a}
Zeatin	90^{a}	7.8^{b}	38^{ab}	2.2^{a}	2.2^{b}	0.0^{a}	0.1^{a}
2-i P	100^{a}	12.5^{b}	32^{ab}	4.0^{ab}	3.3^{b}	0.2^{a}	0.0^{a}
Adenine	98^{a}	20.6^{a}	68^{b}	11.9^{bc}	4.2^{ab}	1.3^{b}	1.8^{b}

Note: Te evaluations were performed after 4 weeks on induction medium, 3 weeks on maturation medium and 5 weeks on germinatin medium. Means followed by the same letter are not significantly different at 5% (Newman-Keuls test)

At the end of the induction step, the frequency of somatic embryogenesis, expressed as the percentage of explants having embryoids, ranged between 88 to 100%, irrespective of which cytokinin was added (**Table 1**). However, the number of embryoids per replicate was significantly higher when no cytokinin was added (control) and with adenine.

During the maturation step, these two parameters decreased for all the treatments, indicating that many of the embryoid structures failed to progress beyond the globular stage and/or were overgrown by callus. However, the production of embryoids per replicate remained higher in the control and in the presence of adenine. Each fragment produced 1.7 and 2.4 embryoids, for the control and the adenine treatments, respectively.

The inhibitory effect of cytokinins was confirmed on the number of plantlets regenerated at the end of the germination step, with the notable exception of the adenine. Shoots were also observed, which could be rescued by rooting them after additional subculturing on germination medium. In total, 2.3 and 3.1 transplantable plantlets were obtained per replicate, for the control and the adenine treatments, respectively. In both these cases, the conversion rate of the embryoids into plantlets was 26% (**Table 2**). For the other cytokinin treatments, the conversion rate ranged from 0 (zeatin) to 10% (BAP).

Table 2. Embryoid-to-plantlet conversion rate after induction and maturation steps conducted with different cytokinins at 1 mg/l.

	Maturation	Germination			Embryoid-to-plantlet conversion rate
Cytokinin	Embryoid structures (number)	Shoots (number)	Plantlets (number)	Shoots + plantlets (number)	(%)
Control (0)	8.7	0.7	1.6	2.3	26.4
BAP	2.9	0.1	0.2	0.3	10.3
Kinetine	6.4	0.2	0.1	0.3	4.6
Zeatin	2.2	0.0	0.1	0.1	4.5
2-i P	4.0	0.2	0.0	0.2	5.0
Adenine	11.9	1.3	1.8	3.1	26.0

From this experiment it can be concluded that adenine does not have an inhibitory effect at the concentration assessed. Consequently, we tested higher adenine concentrations.

Effect of adenine concentration

Table 3 shows the results of cultivating small pieces of green somatic embryos in culture media containing 1 to 40 mg/l of adenine. At the end of the maturation step, only a concentration of 10 mg/l led to a significant increase in the number of embryoids compared to the control (10.3 instead of 4.3 embryoids per explants). The embryoids produced on medium containing 10 mg/l of adenine or more were generally bigger than in the control (**Figure 1ab**). Moreover, typical heart and torpedo-stage embryos can frequently be observed in these cases, contrary to the control or to the lowest adenine concentrations (**Figure 1cde**).

Table 3. Effect of andenine concentration in the induction (with 2,4-D 4 mg/l) and maturation medium of cassava variety Rayong 9's secondary SE. The data are the average of ten replicates, each one consisting of five fragments of green embryoids.

Adenine (mg/l)	Induction		Maturation		Germination		
	Responding explants (Average)	Embryoid structures (nbr/repli-cate)	Responding explants (Average)	Embryoid structures (nbr/repli-cate)	Foliose (nbr/repli-cate)	Shoots (nbr/repli-cate)	Plantlets (nbr/repli-cate)
0	100[b]	30.0[cd]	80[b]	21.6[a]	1.7[a]	1.4[ab]	0.9[a]
1	84[ab]	13.1[abcd]	42[a]	10.6[a]	1.7[ab]	0.3[a]	1.0[a]
5	78[ab]	10.9[a]	60[a]	7.4[a]	1.0[a]	0.4[a]	0.3[a]
10	100[b]	43.5[e]	91[b]	52.2[b]	4.1[d]	1.2[ab]	1.4[a]
20	98[b]	23.8[abcd]	76[b]	16.6[a]	3.4[bd]	0.8[ab]	1.4[a]
40	88[b]	27.2[bcd]	73[b]	23.9[a]	3.9[d]	1.9[b]	1.3[a]

Note: The evaluations were preformed after four weeks on induction medium, three weeks on maturation media and five weeks on germination media. Means followed by the same letter are not significantly different at 5% (Neuman-Keuls test).

At the end of germination, despite a variation from 0.3 to 1.4 plantlets per replicate, the assessed adenine concentrations did not lead to any significant effect. After rescuing the shoots, the highest number of plantlets per replicate (3.2) was observed when the production of the embryoids occurred in the presence of adenine at 40 mg/l.

Table 4. Embryoid-to-plantlet conversion rate after induction and maturation steps conducted with different adenine concentrations.

Adenine (mg/l)	Maturation	Germination			Embryoid-to-plantlet conversion rate
	Embryoid structures (number)	Shoots (number)	Plantlets (number)	Shoots + plantlets (number)	(%)
0	21.6	1.4	0.9	2.3	10.6
1	10.6	0.3	1.0	1.3	12.2
5	7.4	0.4	0.3	0.7	9.4
10	52.2	1.2	1.4	2.6	4.9
20	16.6	0.8	1.4	2.2	13.2
40	23.9	1.9	1.3	3.2	13.3

For the control, the conversion of the embryoids into plantlets was 10% in this experiment (**Table 4**), instead of 26% in the previous experiment. The addition of adenine at 1, 5, 20 and 40 mg/l led to similar rates (9 to 13%). The conversion rate tended to be lower for adenine at 10 mg/l.

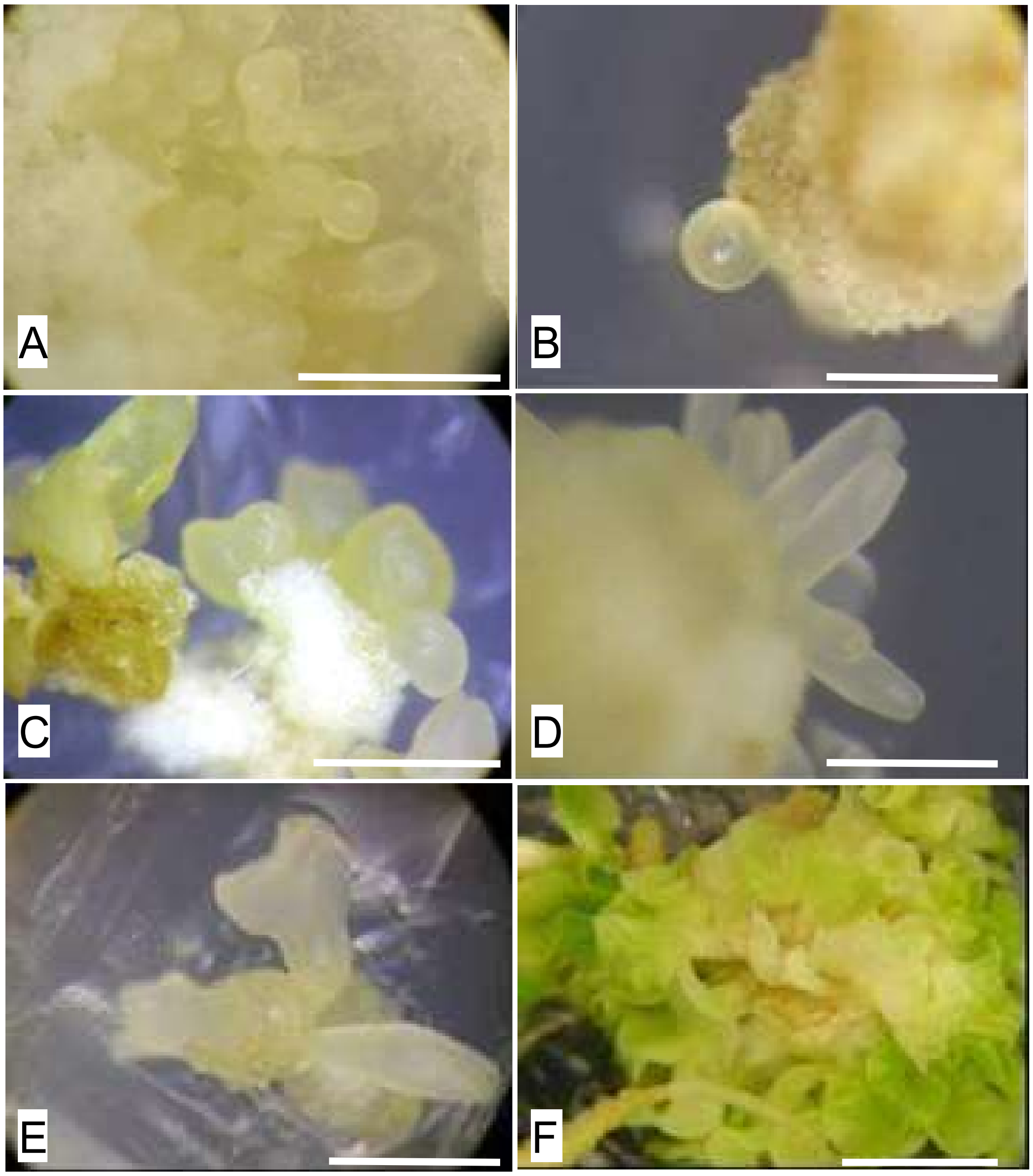

Figure 1. Effect of adenine at 10 mg/l on Rayong 9 cassava cyclic somatic embryogenesis. At the end of the induction step: (A) Globular-stage embryos without adenine; (B) Globular-stage embryos with adenine 10 mg/l; (C) Heart-stage embryos with adenine 10 mg/l; (D) Early torpedo-stage embryos with adenine 10 mg/l; (E) Late torpedo-stage embryos with adenine 10 mg/l. At the end of the maturation step: (F) cotyledonary-stage embryos with adenine 10 mg/l. Scale bar: 0.5 mm.

The acclimatization survival rate varied from 40 to 67%; it tended to be higher for the plantlets issued from adenine concentrations higher than 10 mg/l (**Table 5**) (**Figure 2).**

Table 5. Acclimatization of cassava variety Rayong 9 plantlets after induction and maturation steps conducted with different adenine concentrations.

Adenine concentration (mg/l)	Plantlets ex-vitro transferred (number)	Surviving plantlets (number)	Survival rate (%)
Control (0)	22	9	41
1	20	8	40
5	5	2	40
10	12	8	67
20	14	7	50
40	13	7	54

DISCUSSION

With the exception of adenine, the application of cytokinins during the induction step inhibited considerably the secondary SE of the Rayong 9 cassava clone. This inhibitory effect of exogenous cytokinins suggests that the endogenous level of cytokinins is probably adequate and that it can probably result from supra-optimal concentrations. Cassava species seem similar to graminaceous tissues for which exogenous cytokinins inhibit SE at very low concentrations (Somleva *et al*., 1995). In orchard grass, the non-embryogenic genotypes contain 3 to 4-fold higher concentrations in endogenous cytokinins than embryogenic genotypes (Wenck *et al*., 1988). In wheat, immature zygotic embryos, which are competent tissues, have a lower concentration in these hormones than non-competent ones (Kopertekh and Butenko, 1995). Similar observations were also reported for some dicotyledonous species: levels of endogenous cytokinins are higher in non-embryogenic calli of the leguminous *Medicago arborea* than in embryogenic calli (Pinto *et al*., 2002). The presence of endogenous cytokinins at supra-optimal concentrations can hamper the embryogenic process from cassava tissues.

In this research, adenine concentrations up to 40 mg/l were applied without any detrimental effect on the induction and maturation of cassava somatic embryos. On the contrary, adenine concentrations higher than 5 mg/l tended to improve the process in terms of embryoid size and plantlet recoveries in the greenhouse. These experiments confirm the absence of toxicity of adenine, which could probably be used at higher concentrations.

The mode of action of adenine is not fully explained and it is considered as a substrate for the synthesis of natural cytokinins as well as a product of their degradation (Van Staden *et al*., 2008). It is recognized that the activity of adenine is much less than the true cytokinins and 25-100 times the concentrations may be required for producing similar results. On carrot, adenine is generally added to the 2,4-D induction media (Halperin, 1964). Zamarripa (1993) showed that adenine at 40-80 mg/l combined with BAP at 5 mg/l had a positive effect on the production of embryos from callus in the case of some *Coffea canephora* genotypes.

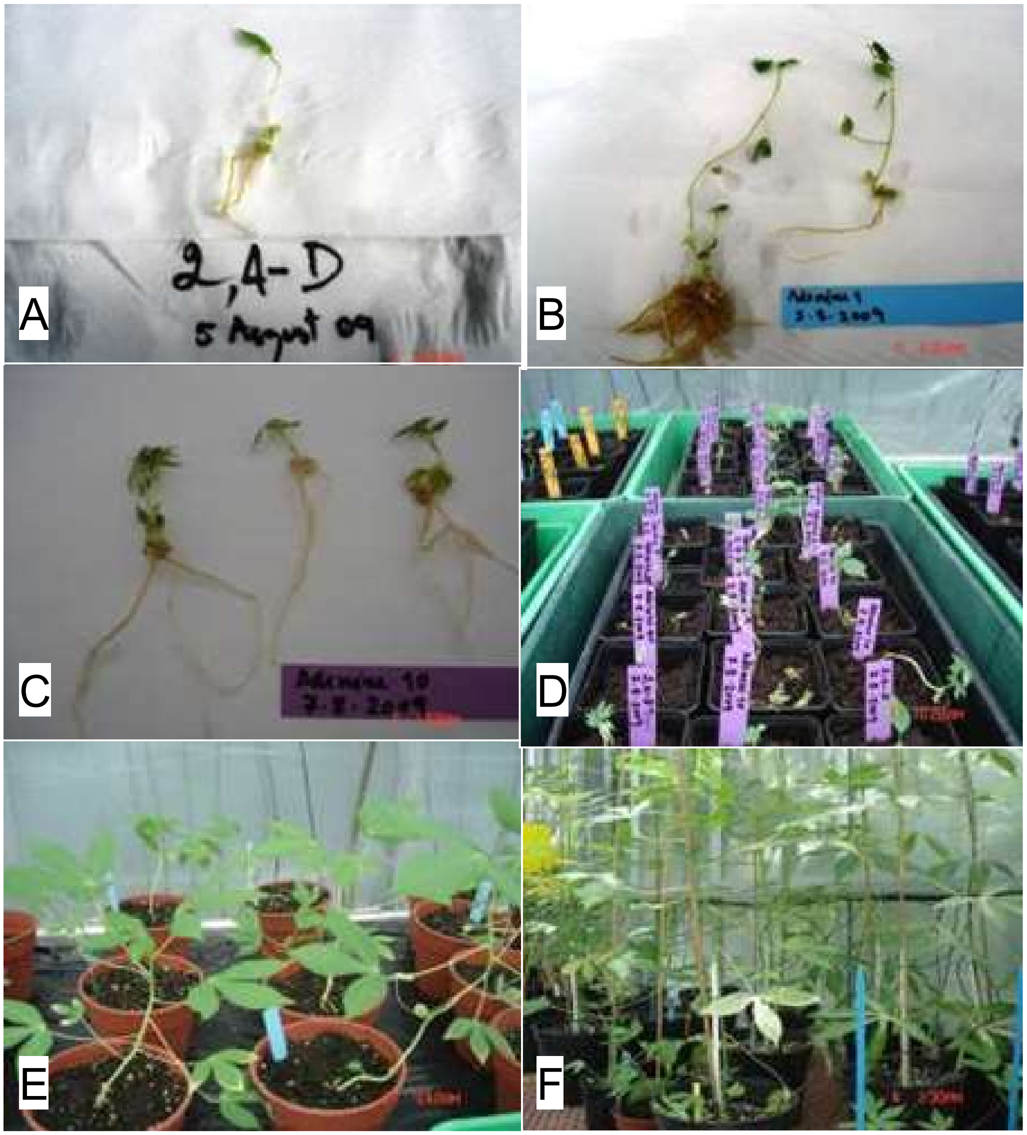

Figure 2. Rayong 9 cassava plant recoveries from the cyclic somatic embryogenesis process: (A) Plantlets issued from the control (adenine 0 mg/l); (B) Plantlets issued from adenine 1 mg/l;(C) Plantlets issued from adenine 10 mg/l; (D) Acclimatization in greenhouse (2 weeks); (E) Plants after 1 month; (F) Plants after 3 months.

Calli are formed in commitment with embryoids. Probably due to the callusing reaction, which can have a negative effect on their further development; many embryoids scored at the end of the induction step became arrested in their development. As a consequence, only a fraction of them, 50 to 70% depending on the experiments, could still be scored at the end of the maturation step.

The highest percentage of embryogenic explants and the highest number of embryoids per replicate, obtained with adenine or without any cytokinin, were 70 to 80%, and 10 to 20%, respectively. For these treatments, taking account of the shoots which can be rescued after their rooting, the embryoid-to-plantlet conversion rate ranged between 10 to 26% depending on the experiments. It must be emphasized that these experiments were performed without supplementing the maturation medium with charcoal, so higher embryoid productions can be expected if charcoal is added.

As one green embryoid collected from cyclic cultures in liquid medium can roughly be cut into five fragments (i.e. one replicate in these experiments), it can be assumed that one Rayong 9 cassava embryoid can produce at least 10 to 20 new embryoids within 7 weeks, from which 2 to 3 plantlets can be regenerated and transferred to the greenhouse.

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PROTEOMICS AS A TOOL FOR IMPROVEMENT OF CASSAVA BREEDING

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ABSTRACT

Cassava is an annual crop in tropical and subtropical regions and is planted for its edible starchy tuberous roots. In Asia, cassava products are used for multiple uses, including human food, starch, flour, animal feed as well as for industrial uses, such as ethanol. These various needs prompt cassava-breeders to provide multiple varieties for multiple uses for multiple markets. However, cassava breeding faces several challenges including low seed set, high genetic heterozygosity and high segregating progenies, which make improvement of the crop difficult.

Proteomic analysis is one of several approaches which can be used to overcome the constraints in the current methodologies for the genetic improvement of cassava. Proteomics is a technology for the high-throughput analysis of proteins on a genome-wide scale. It has become a major field of functional genomics. In this study the application of proteomics for traceability of the effect of genotypes on cassava proteins are addressed. The results showed that proteomics can be used to find marker proteins in cassava genotypes and identify the function of differential proteins in the metabolic pathways. It could also be used to validate the evaluation of cassava-genotype traits and improve the efficiency of molecular design. This capability is especially useful for cassava as it may give clues not only about photosynthetic potential, but also about starch accumulation and how these factors are affected by cassava genotypes. Additionally, proteomic analysis of pathway cross-talking between scion and stock highlighted the yield improvement mechanism in grafting cassava. The cassava global protein alteration involved in polyploid cultivars/lines is also discussed with proteomics approaches.

The present study is intended to give the molecular biologist a rudimentary understanding of the technologies behind proteomics and their application to address biological questions. Diverse integrated approaches, such as advanced proteomic techniques combined with functional genomics, bioinformatics, metabolomics and molecular cell biology will certainly be beneficial for fine-tuning the molecular breeding and transformation approaches, so as to achieve significant progress in cassava varietal improvement in the future.

Key words: Cassava, proteomics, breeding improvement.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial woody shrub of the Euphorbiaceae family and its domestication occurred approximately 12,000 to 7,000 years

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ago by indigenous South Americans, as supported by DNA sequence analysis of a single locus, and by archaeological and fossil records (Wang *et al.,* 2014). It is one of the three root crops in the world with 20-40% starch content in the tuberous roots; it is therefore called "the King of Starch" and "Underground Granary" to provide the raw materials for starch processing and bioenergy production. So far, China has a 200-year cassava cultivation history, and the crop is currently planted in various South China regions, such as in Guangxi Province, Guangdong Province, Yunnan Province, Hainan Province, Fujian Province and Jiangxi Province.

The current cassava-breeding objective in China is to select those cassava varieties/genotypes with desirable and acceptable qualities, such as high yield, high starch content, erect plant type, compact root clumps to facilitate mechanized harvesting, as well as high carotenoid and high protein content. However, improvement of cassava varieties faces several limitations including low seed set, high heterozygous genetic trait and high segregating progenies making it time consuming to breed a new variety (Ceballos *et al.,* 2004). It is very difficult to implement the breeding objective described above by means of traditional cross breeding. Wang *et al* (2014) presented the draft genome sequences of a wild ancestor and a domesticated variety of cassava. Comparative analyses with a partial inbred line have been implemented, which identified 1,584 and 1,678 gene models specific to the wild and domesticated varieties, respectively. In addition, the mechanism of cassava's high heterozygosity and millions of single-nucleotide variations were discovered, and the genes involved in photosynthesis, starch accumulation and abiotic stresses have been positively selected (Wang *et al*., 2014). However, using cassava genome data, we can only indirectly tell the function of the proteins, because the process from mRNA transcription to protein translation will contain post-translational modification, such as glycosylation, phosphorylation, and many other factors. These factors are likely to change the functions of proteins used as a direct role. Therefore, it would be very important to directly study the changes of proteins which are responsible for almost all biological functions of cells. Proteomic analysis for cassava genotypes and their subcellular structures in different growth stages will be helpful to cassava breeders for a broad and complete understanding of protein regulated mechanism in response to biotic and abiotic stresses and their biological functions in different metabolic pathways.

Proteomic analysis is one of several approaches which can be used to overcome the constraints in the current methodologies for the genetic improvement of cassava. Proteomics is a leading technology for the high-throughput analysis of proteins on a genome-wide scale. It has become a major field of functional genomics. In recent years, the term proteomics has also been applied to all the proteins expressed in a particular organelle or tissue or in response to a particular stress. Proteomic studies have revealed which proteins are responsible for cell differentiation in *Arabidopsis* under salt and osmotic stress, and the drought responsiveness in maritime pine, maize, and wild watermelon. This approach was also used to investigate the molecular adaptation mechanisms of salt stress in tomato (Chen *et al*., 2009a). In order to further understand the effects of cell differentiation on the growth of organelle or tissue under biotic and abiotic stresses, subcellular proteomics in combination with classic biochemical fractionation methods and tools was introduced to analyze the protein-protein interaction in subcellular structures. It is a prerequisite for the detection of important regulatory events, such as protein translocation in comparative studies (Dreger, 2003). Chen *et al.* (2009c) used subcellular proteomics to reveal how altered Chk1 activity influences protein interactions in chromatin. Chen *et al.* (2009b) indicated that the cross-talk between signal transduction and the cytoskeleton emphasizes how structural and kinase-based networks are integrated in mammalian cells to fine-tune metabolic responses; these data could provide a beneficial clue to improve cassava breeding against extreme environments.

In this study the application of proteomics for improvement of cassava breeding is addressed. Proteomics can be used to find marker proteins in cassava genotypes and identify the function of differential proteins in the metabolic pathways. It could also be used to validate the evaluation of cassava-genotype traits and improve the efficiency of molecular designs. It may give clues not only about leaf photosynthetic potential, but also root starch accumulation in different cassava varieties. Proteomic analysis of pathway cross-talking between scion and stock has been highlighted in grafting cassava and the cassava global protein alteration involved in polyploid cultivars/lines has been discussed using proteomic approaches.

PROTEOMIC APPLICATION IN IMPROVING CASSAVA BREEDING

1. Proteomics play an important role in finding cassava marker proteins in different genotypes

Progress in increasing the carotenoid content of cassava roots has been significant during the last few years. Maximum levels of total carotenoids reported in 2005 were around 10 μg/g of fresh root, whereas by 2010 the maximum level was almost 25.5 μg/g of fresh root (Ceballos *et al.,* 2012; Sánchez *et al*., 2014). However, so far, the key factors that determine the carotene accumulation in the high-carotene clones in different cycles of selection grown together and simultaneously in the same experiment are poorly known. It was reported that the carotene content of cassava roots depends on a few genes (Akinwale *et al*., 2010), with some of them having a recessive behavior (Morillo *et al*., 2012). Carvalho *et al*. (2012) isolated carotenoid-protein complex (CPC) and non-carotenoid-associated proteins (NCP) from chromoplast-enriched suspensions of cassava tuberous roots using size exclusion chromatography. All proteins in both complexes were identified using LC-MS/MS in combination with publically available databases. The results indicated that small Heat Shock Proteins (sHSPs) were the most abundant proteins identified in CPC and NCP. Western blot analysis showed that Fribrillin and Or-protein were presented in NCP of chromoplast-enriched suspensions of yellow roots, but not in the CPC complex of white roots. The results from qRT-PCR helped identify an isoform of HSP21 possessing four single point mutations in the intense yellow cassava tuberous roots that may be responsible for increased sequestration of β-carotene. These proteins, including fribrillin, Or-protein and the four sHSPs may be used as the marker proteins in the cassava varieties with high carotenoid content. Further elucidation of the roles of sHSP in binding specifically with β-carotene or in inducing accumulation of carotenoid in cassava tuberous roots would provide a significant contribution to our understanding of the molecular mechanism controlling carotenoid accumulation in non-green tissues.

2. Proteomics can show the differences in leaf photosynthesis and root starch accumulation between cassava cultivars and wild *Manihot* species

El-Sharkawy and Cock (1987) reported that cassava and wild *Manihot* species represent an intermediate photosynthesis between the typical C3 and C4 species. It is possible that the genus *Manihot* represents an evolutionary step towards the C4 pathway. Contrary to this hypothesis, others (Edwards *et al.,* 1990; Angelov *et al.,* 1993; Calatayud *et al.,* 2002) have concluded that neither cassava nor their wild relatives possess C4 photosynthesis, based on the dynamics of 14C labeling and CO_2 compensation point. Calatayud *et al*. (2002) reported that the wild species of cassava, including *M. esculenta* ssp. *flabellifolia*, the potential wild progenitor of *M. esculenta* (Fregene *et al.,* 1994; Roa *et al.,* 1997), exhibit traits typical of C3 photosynthesis, indicating that cultivated cassava, despite its peculiar photosynthetic characteristics, is not derived from C4 species. In order to find the truth regarding the argument on whether cassava is a C3 or C4 species, our cassava proteomic team in CATAS used 2-DE combined with MALDI-TOF-MS to analyze the global proteins in the leaves from a cassava cultivar and its wild species to try to explain the phenomenon; for instance, Li *et al.* (2010) identified 112 proteins in somatic embryos, 110 proteins in leaves, 147 proteins in adventitious roots and 155 proteins in tuberous roots, i.e. a total of 524 proteins (including their isoforms) in the cassava cultivar SC8. They also showed that 54, 59, 74 and 102 identified proteins are unique to somatic embryos, leaves, adventitious roots and tuberous roots, respectively. In the leaves of cassava cultivar SC8, the proteins involved in photosynthesis were among the largest group identified (21.8%). The results also indicated that chlorophyll a/b-binding protein, oxygen-evolving enhancer protein 1 (OEE1), are involved in photosynthesis and are unique to leaves and adventitious roots. These proteins in cassava cultivars may be synthesized in the leaves and then translocated to the roots. To understand the differences in global protein expression from cassava and its wild relatives, we identified a total of 148, 157 and 152 protein spots in the leaves from *M. esculenta* subsp. *flabellifolia* (W14), cassava cultivar SC205 and SC8, respectively. These included 26 up- and 10 down-regulated in SC205, and 21 up- and 10 down-regulated in SC8 compared to W14. We also identified a total of 196, 228 and 232 proteins in the tuberous roots of W14, SC205 and SC8, respectively, in which 19 up- and 20 down-regulated proteins in the pairwise comparison of SC205/W14, 18 up- and 20 down-regulated in the comparison of SC8/W14 were shown (unpublished data). These proteins would be marker proteins to indicate the key biological regulated network in leaf photosynthesis and starch accumulation in tuberous roots between cassava cultivars and this wild relative. In our study, we also detected that cassava cultivar SC205 leaves possess C4 plant photosynthesis enzyme PEPC under strong sunlight at 11:00 am, but its expression level was far less than in maize. We didn't find the expression of PEPC in cassava wild species. It means that cassava has the trait of C4 plant photosynthesis, but it is completely different from the typical C4 plant (unpublished data).

3. Proteomics analysis shows the pathway cross-talk between scion and stock in grafting cassava

Grafting is an old plant propagation practice. It also plays an important role in plant breeding and genetic improvement. However, the molecular mechanisms of affecting cassava genetic traits are as yet insufficiently understood. An (2011) did a cassava grafting experiment using SC8 (high yield cultivar) as scion and SC205 (adaptation cultivar) as stock, and studied the possible cross-talk pathways between scion and stock. Leaf protein analysis from SC8 grafted onto SC205 revealed that the increase of protein expression was involved in the pathways of photosynthesis and signal transportation. It may suggest that the two pathways in scion and stock may cross-talk with each other. This may increase the abilities of the "source" and the "flow" for improving the "sink" ability to accumulate starch in tuberous roots. However, the proteomic analysis of SC205 tuberous-roots showed that the metabolic pathways participated by differentially expressed proteins were not related with starch accumulation. It indicated that the cross-talk in photosynthesis and signal transportation in grafting cassava leaves didn't significantly increase the yield of stock SC205 tuberous roots, which is supported by the results of fresh weight of roots harvested in the fields. The grafting mechanism, which was investigated for the first time using proteomics, will be further helpful to improve the yields of cassava tuberous roots.

4. Proteomic analysis indicates cassava polyploidy can increase tolerance to stresses

Polyploid crops, influenced by nuclear genome size, have much larger cells than the diploid ones (Jellings and Leech, 1984). The increase in DNA content in the synthesized polyploids led to the description of structural changes, such as chromosomal rearrangements and gains or losses of DNA sequences, which demonstrates the occurrence of modifications at the level of gene expression. Studies of *Brassica*, potato and cotton polyploids have shown that some genes are silenced after polyploidization, while others are depressed (Albertin *et al*., 2006; Cai *et al*., 2012; Hu *et al*., 2011). Polyploidy of cassava plants highly affect cell volumes, anatomical structures, and agronomic traits. However, the mechanism of this effect is poorly understood. In order to validate the changes between cassava diploid and polyploid at global protein levels, An *et al.* (2014) used 2-DE in combination with MALDI-TOF-MS to indicate the tolerant molecular mechanism between cassava cultivar Nanzhi 199 diploid and autotetraploid at proteomic levels. The results show that 47 differential proteins were up-regulated and 5 were down-regulated in the autotetraploid genotype compared with the diploid genotype. The classified functions of 32 upregulated proteins were associated with the pathways of photosynthesis and defense system, protein biosynthesis, chaperones, amino acid metabolism and signal transduction. The remarkable variation in photosynthetic activity and resistance to salt stress between diploid and autotetraploid genotypes is closely linked with expression levels of proteomic profiles.

To indicate the changes of starch accumulation, and further understand the protein regulatory mechanisms in tuberous roots between diploid and its polyploid, An *et al.* (2015) used 2-DE in combination with MALDI-TOF-MS to analyze the tuberous roots of SC8 diploid and its autotetraploid at 10 months after planting. The results showed that twenty differential expressed protein spots were found in the cassava autotetraploid, including 2 up-regulated spots and 18 down-regulated spots. Nineteen spots were successfully matched in the database. The functions of the 17 down-regulated proteins were associated with carbohydrate and energy metabolism, structure, DNA and RNA metabolism, chaperones, HCN metabolism, antioxidant, protein synthesis and other unknown functions. Two up-regulated proteins were stem-specific proteins. Proteins related with carbohydrate and energy metabolism, nucleic acid metabolism and chaperones were down-regulated, The SPS expression decreased, but the expression of β-amylase increased, indicating low starch synthesis and high starch decomposition in tetraploid cassava. In order to test the proteomic data, the agronomic traits of tuberous roots of SC8 were analyzed and the results showed that the dry matter content, starch content and fresh root weight were significantly decreased by 12.18%, 11.41%, and 35.34%, respectively. No significant changes in amylose and amylopectin proportion were found. The remarkable variation in dry matter content, starch content and fresh root weight between diploid and autotetraploid genotypes is closely linked with expression levels of proteomic profiles.

CONCLUSIONS

This study summarizes proteomics as a tool for improvement of cassava breeding. It indicates the various uses of proteomics, including finding cassava marker proteins in different genotypes and shows differences in leaf photosynthesis and root starch accumulation between cassava cultivars and their wild species. It has also been used as a tool to show the pathway cross-talk between scion and stock in grafting cassava, and indicates the mechanism of cassava polyploidy in increasing the tolerance to stresses. In addition, it could also be helpful in enhancing photosynthesis efficiency and, in turn, increasing the productivity in cassava molecular breeding in combination with functional genomics, bioinformatics, metabolomics and molecular cell biology.

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SUSTAINABLE MANAGEMENT OF SHORT-DURATION CASSAVA FOR CROP DIVERSIFICATION IN THE LOWLANDS OF SOUTH INDIA

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ABSTRACT

Presently, cassava cultivation in Kerala has shifted from the uplands to the lowlands, planted sequentially after the main crop of rice, banana or vegetables. Under those conditions, short-duration cassava varieties, with a crop duration of only 6-7 months, hold promise.

To develop sustainable management practices for short-duration cassava, three separate field experiments were conducted from November to May for seven consecutive years (2003/04 to 2009/10) at the Central Tuber Crops Research Institute (CTCRI) in Thiruvananthapuram, Kerala, India, under lowland conditions similar to a rice fallow.

In Experiment I, ten short-duration/early-bulking lines of cassava, i.e. CI-732, CI-848, H-165, Kalpaka, Sree Jaya, Sree Prakash, Sree Vijaya, Triploid 2-18, Triploid 4-2 and Vellayani Hraswa, were evaluated using a randomized block design (RBD) with three replications.

In Experiment II, five short-duration lines, i.e. Kalpaka, Sree Jaya, Sree Vijaya, Triploid 2-18 and Vellayani Hraswa, were tested using a split plot design with varieties in main plots and four fertilizer levels, i.e.100% FYM (12.5 t/ha) + 100% NPK ($N:P_2O_5:K_2O$ @100:50:100 kg/ ha), 75% FYM + 75% NPK, 50% FYM + 50% NPK and a fertilizer level based on soil test data in sub-plots. A green manure crop of cowpea was grown before cassava.

In Experiment III, two short-duration cassava varieties, i.e. Vellayani Hraswa and Sree Vijaya were evaluated in two cropping systems (sequential cropping and intercropping) involving two types of cowpea, i.e. vegetable cowpea, variety Pusa Komal, and a grain type, variety C.152, under two fertilization levels (full recommended dose of NPK; and 1/2 N + full P + full K) using a split plot design. Varieties were assigned to main plots and a combination of cropping systems and fertilizer levels to sub-plots. This paper attempts to evaluate the growth, yield and quality performance of ten short-duration cassava lines, determine the best nutrient management practices and develop feasible short-duration cassava-legume systems under lowland conditions similar to those of a rice fallow.

The results indicate that Triploid 2-18 had the highest yield (38.34 t/ha), followed by Triploid 4-2, Sree Vijaya, Sree Jaya and Vellayani Hraswa, which had similar yields of 30-32 t/ha. These high yielding lines had appreciably higher total biomass, mean root bulking rates and harvest indices. Vellayani Hraswa, Sree Vijaya and Triploid 4-2 had significantly higher root dry matter contents (37-38%) and somewhat higher starch contents (27-28%). The diploid lines, Sree Vijaya, Sree Jaya, Vellayani Hraswa and Kalpaka were ideal for cultivation in rice fallows for table purpose due to their high yield, good cooking quality and low cyanogen contents (29.20-43.80 μg/g).

Nutrient management based on soil test data resulted in savings of the entire quantity of P, 10% of N and 15% of K (farmyard manure at 12.5 t/ha and NPK at 90:0:85 kg/ha) by the third year. This treatment promoted growth, biomass production and root bulking, harvest index, nutrient uptake, and produced a higher root yield (24.18 t/ha), dry matter and starch content, besides maintaining the organic C, available N, P and K status of the soil, leading to a positive nutrient balance. Both vegetable cowpea and grain cowpea were found to be equally compatible with short-

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duration cassava under both the systems, though sequential cropping proved superior. Savings of full P and half N for short-duration cassava was possible in these systems. An economic analysis indicated that sequential cropping of vegetable cowpea followed by short-duration cassava under full N was the most profitable, generating the highest net returns (Rs. 97398/ha) and B:C ratio (2.15).

Key words: Crop intensification, early maturing cassava, soil testing, growth dynamics, cowpea, yield, B:C ratio, India.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an important tropical root crop that plays a significant role in the food and nutritional security of many rural households, especially in the coastal and tribal areas. The normal harvesting age of cassava varies from 9-24 months while most of the varieties give the maximum targeted yield at 10-12 months. The ongoing intensification of agriculture, with a focus on increasing productivity spatially and temporally, has necessitated the development of short-duration cassava that can be grown intensively in various cropping systems. Moreover, during the past two decades, cassava cultivation in the uplands has declined, whereas it has increased in the lowlands by sequentially cropping of cassava after the main crop of rice, banana or vegetables. Under these conditions short-duration cassava varieties hold much promise.

Short-duration or early-bulking lines of cassava that can be grown with the available soil moisture after the harvest of rice enables small and marginal rice farmers the effective utilization of resources like land, moisture and nutrients, as well as a diversification of their farm enterprise and income. In addition, cassava has been changing its role from a traditional human food to an efficient crop for animal feed and starch production (FAO, 2001). At present, about ten short-duration/early-bulking lines are available for cultivation. Information on growth and development, growth physiology and dry matter production characteristics of cassava having a 10-12 month growth cycle is available. Information on growth dynamics of short-duration cassava is lacking. The comparative performance of these short-duration cassava lines based on growth characters, biomass production, yield and quality will help in the further delineation based on diverse end uses, such as food, feed and industry.

Cassava is often considered a nutrient exhausting crop, which responds well to the application of organic manures and chemical fertilizers. A crop of cassava yielding 30 t/ha of fresh roots in ten months removes 180-200 kg of N, 15-22 kg P and 140-160 kg K per ha. The prevalent nutrient recommendation for cassava in Kerala is farmyard manure (FYM) at 12.5 t/ha and 100:50:100 kg $N:P_2O_5:K_2O$/ha. This high rate of manure application is very expensive (Rs.13,000/ha), and many cassava farmers do not adopt the above recommendation. However, when short-duration varieties are integrated into the existing cropping systems, utilization of residual moisture and nutrients will be possible by modifying the current management practices. Hence, it is imperative to assess the possibility of saving costly nutrient inputs by formulating more suitable nutrient management practices for short-duration cassava in the lowlands. The practice of growing a grain- or forage-legume, like cowpea, peanut, pigeon pea, velvet bean, *Centrosema pubescens*, *Indigofera hirsuta* and *Pueraria phaseoloides* and incorporating the forages and crop residues into the soil prior to planting cassava, was reported to improve soil fertility and yield of normal duration cassava, cv. MCol 1684 (Howeler, 2012). However, information on cropping systems involving short-duration cassava is not available.

Taking all these into consideration, this paper attempts to evaluate the growth, yield and quality performance of ten short-duration cassava lines, determine the most suitable nutrient management practices, and develop feasible short-duration cassava-legume systems under lowland conditions similar to a rice fallow.

MATERIALS AND METHODS

Site description, plot size, and planting season

Three separate field experiments were conducted from November to May for seven consecutive years (2003/04 to 2009/10) at the Central Tuber Crops Research Institute in Thiruvananthapuram (8^0 29'N, 76^0 57'E, 64 m altitude) in Kerala, India, under lowland conditions similar to a rice fallow. The soil of the research site is a well drained acid Ultisol with pH 4.35, and is characterized by low available N (252 kg/ha), high available P (28 kg/ha), medium available K (151 kg/ha) and organic C (0.747%) contents. The site has a typical humid tropical climate. The mean annual rainfall was 1,204 mm and the annual means of daily temperature maxima and minima were 31.65 ºC and 25.02 °C, respectively.

In these experiments the gross plot size was 5.4 x 5.4 m (36 plants) accommodating 16 net plants. Planting and other agronomic practices were done in accordance to the package of recommended practices (KAU, 2002). Cassava was planted vertically on top of 25-30 cm high mounds, spaced at 90 x 90 cm. Cassava was planted during November of each year, was mainly rainfed, and was harvested after six months.

Experiment I: Evaluation of production potential of short-duration cassava lines

Experimental design and treatments

During 2003/04, ten short-duration/early-bulking lines of cassava, either released varieties from CTCRI and Kerala Agricultural University (KAU) (CTCRI, 2006; KAU, 2002), or indigenous selections, as well as the triploid lines from CTCRI, were evaluated in a randomized block design (RBD) with three replications for total biomass production, root yield and quality under conditions similar to that obtained after a crop of rice. The ten lines were CI-732, CI-848, H-165, Kalpaka, Sree Jaya, Sree Prakash, Sree Vijaya, Triploid 2-18, Triploid 4-2 and Vellayani Hraswa.

Field culture

Farmyard manure (FYM) at 12.5 t/ha (on DW basis) was applied at the time of planting. Urea, Mussorie rock phosphate and muriate of potash to supply 100:50:100 kg/ha of N, P_2O_5 and K_2O were used. The whole dose of P and half that of N and K were applied immediately after sprouting of the stakes. After one month the remaining quantities of N and K were applied along with weeding and earthing up.

Experiment II: Nutrient management for short-duration cassava

Experimental design and treatments

The experiment was laid out in a split plot design with three replications. Five short-duration/early-bulking lines of cassava (V_1=Kalpaka, V_2=Sree Jaya, V_3=Sree Vijaya, V_4=Triploid 2-18 and V_5=Vellayani Hraswa) were assigned to main plots. Four fertilizer levels (F_1=100% FYM (12.5 t/ha) + 100% $N:P_2O_5:K_2O$ (100:50:100 kg/ha); F_2=75% FYM + 75% NPK; F_3=50% FYM + 50% NPK; and F_4=fertilizer level based on soil test data ($N:P_2O_5:K_2O$ at 95:40:105, 95:35:95 and 90:0:85 kg/ha along with 100% FYM were applied in 2004, 2005 and 2006, respectively) were assigned to sub-plots.

Field culture

Prior to planting cassava, every year a crop of green manure cowpea was grown and incorporated at 45-60 days. Green manure cowpea 'C-152' added 17.52, 15.85 and 18.45 t/ha of fresh biomass during 2004, 2005 and 2006, respectively. The average nutrient content (on DW basis) was 3.4% N, 0.3% P and 2.3% K, which contributed to 160.80 kg N, 14.19 kg P and 108.79 kg K/ha in 2004; 140.11, 12.36 and 94.78 in 2005; and 181.9, 16.05, 123.05 in 2006. FYM having 0.5% N, 0.2% P and 0.4% K (on DW basis) was applied at the required quantity at the time of planting as per the treatments. Urea, Mussorie rock phosphate and muriate of potash to supply N, P and K at the various fertilizer levels were used (schedule of application similar as in Experiment I). The nutrient status of the soil was determined at two weeks after incorporation of green manure cowpea (before planting cassava) and showed the following soil test values: 0.67% organic C, 236.6 kg/ha of available N, 14.23 kg/ha available P and 112.15 kg/ha available K in 2004; 0.66% and 162.10, 19.50, 151.33 kg/ha in 2005; and 0.76% and 133.10, 66.35, 171.36 kg/ha in 2006. During each year, the fertilizer level based on soil test data was arrived at based on the nutrient status of the soil after cowpea incorporation, as mentioned in fertilizer level F_4.

Experiment III: Cassava production systems involving legumes

Experimental design and treatments

In Experiment III, two short-duration cassava varieties, Vellayani Hraswa and Sree Vijaya, were evaluated in two cropping systems, i.e. sequential cropping and intercropping, involving two types of cowpea, i.e. vegetable cowpea variety Pusa Komal and grain type cowpea variety C.152 under two fertility levels, i.e.full recommended dose of NPK and 1/2 N + full P + full K in a split plot design. Varieties were assigned to main plots and combinations of cropping systems and fertility levels to sub-plots. A sole crop of cassava was also maintained for comparison.

Field culture

The seeding rates for the sequential crops of vegetable cowpea and grain cowpea were 20-25 and 50-60 kg/ha, respectively. The spacing adopted was 30x15 cm and cowpea was sown during August every year. Farmyard manure (FYM) was applied to the sequential crop of cowpea at 20 t/ha, and N, P_2O_5, and K_2O at 20:30:10 kg/ha. The full dose of FYM, P_2O_5, and K_2O and a half dose of N were applied basally at final plowing, and the remaining N was applied 15-20 days after sowing (DAS).

For cassava, the FYM was applied at 12.5 t/ha at the time of planting every year. Based on soil test data, urea, Mussorie rock phosphate and muriate of potash to supply N, P_2O_5 and K_2O at 100:12.5:100 kg/ha were applied during the first two years under the full recommended dose. By the third year, the entire quantity of P could be saved for cassava and N, P_2O_5, and K_2O at 100:0:100 kg/ha was used in this treatment. Hence, obviously under the reduced fertilizer level (half N, full P, full K), N, P_2O_5 and K_2O were applied at 50:12.5:100 kg/ha for the first two years, and thereafter N, P_2O_5, and K_2O were applied at 50:0:100 kg/ha (the schedule of application was similar as in Experiment I).

Both grain cowpea and vegetable cowpea were intercropped in additive series with cassava. Two rows of grain cowpea were intercropped in between two rows of cassava at a spacing of 30x15 cm and at a seeding rate of 20 kg/ha. One row of vegetable cowpea was intercropped in between two rows of cassava at a spacing of 90x20 cm adopting a seeding rate of 8 kg/ha. FYM and the whole of P_2O_5 and half the doses of N and K recommended for cassava were applied to both crops as basal. One month after sowing cowpea, N, P_2O_5, and K_2O were applied at the rate of 10:15:10 kg/ha to cowpea. Grain cowpea was harvested at 90-100 days and vegetable cowpea at 65-70 days. After the harvest of cowpea, the haulms were incorporated and the remaining quantities of N and K_2O were applied to cassava along with weeding and earthing up.

Observations

Biomass measurements were made at 2, 4 and 6 months after planting (MAP) by sampling three plants at random per plot at each stage. The uprooted plants were separated into leaves, stems and roots; air dried and then oven dried at 70°C to constant weight. The dry weights of leaves, stems and roots were recorded and the total plant dry weights were computed and expressed in g/plant. From the values of dry weight, mean root bulking rate (RBR) and harvest index (HI) were computed using the growth analysis techniques of Hunt (1982).The fresh root yield, root dry biomass and total dry biomass production in t/ha were computed from the net plants. The contents of dry matter, starch and cyanogenic glucosides in the roots were determined by standard procedures. The plant uptake of N, P and K was calculated as the **sum of the** product of the nutrient concentration **of each plant part** and dry weights of **the respective plant part** and expressed as kg/ha. Chemical parameters of soil, i.e. pH, organic C, available N, P and K status of the soil were estimated by standard analytical procedures. Nutrient balances for available N, P and K for the different years were calculated. The net income and benefit cost (B:C) ratio were also computed. **Pooled analysis of yield data was done.** The analysis of variance of the data was done using the package GenStat (GenStat Seventh Edition (DE3), 2007).

RESULTS AND DISCUSSION

Experiment I. Evaluation of production potential of short-duration cassava lines

Growth indices and dry matter production

The mean root bulking rate (RBR) of Triploid 2-18 was the highest (5.732 g/plant/day) and was on a par with those of Sree Vijaya, Triploid 4-2 and Vellayani Hraswa (5.1-5.4 g/plant/day). Almost all the short-duration lines, except CI-732 and CI-

848, were found to be promising with significantly higher efficiency to distribute assimilates to tuberous roots resulting in higher harvest indices (**Table 1**).

Root dry matter production of Triploid 2-18 was also the highest (12.74 t/ha) and again almost similar to that of Sree Vijaya, Triploid 4-2 and Vellayani Hraswa. This may be due to the significantly higher root bulking rate, root dry matter content and fresh root production observed in these varieties. Total dry matter production of Triploid 4-2 was the highest (20.64 t/ha), which remained on a par with those of Triploid 2-18, Sree Vijaya and Vellayani Hraswa (20.43, 20.29, 19.63 t/ha) (**Table 1**). As reported by Sreekumari and Abraham (2001) the triploids were better suited for industrial uses owing to their high root dry matter production.

Root yield and quality

Of the ten short-duration lines evaluated, Triploid 2-18 produced significantly higher fresh root yield (38.34 t/ha) (**Table 1**). This was followed by Triploid 4-2, Sree Vijaya, Sree Jaya and Vellayani Hraswa, which yielded on par (30-32 t/ha). The variation in the yield performance of cassava cultivars could be explained on the basis of significant differences in canopy size, which largely determines the light utilization efficiency and also affects the partitioning of dry matter for storage root growth. Further, Ramanujam (1991) concluded that yielding ability of cassava cultivars is largely governed by total biomass production. Thus, the high yielding ability of the Triploids (2-18 and 4-2), Sree Vijaya, Sree Jaya and Vellayani Hraswa in this study may be attributed to their substantially higher canopy size, total dry biomass, mean RBR and HI. The early bulking nature and superior yield performance of the Triploids 2-14 and 4-2 (34-35 t/ha), Sree Jaya and Sree Vijaya (25-30 t/ha) has been reported earlier by Unnikrishnan *et al*. (2001) and Pamila *et al*. (2006).

Vellayani Hraswa, Sree Vijaya and Triploid 4-2 had significantly higher root dry matter contents (37-38%), and somewhat higher starch contents (27-28%) (**Table 1**). The root cyanogen contents of all the lines, except Triploid 4-2, Triploid 2-18 and H-165, was relatively low and within tolerable limits (29.20-43.80 µg/g), indicating the suitability of most of the lines for consumption as food. The diploid lines, Sree Vijaya, Sree Jaya, Vellayani Hraswa and Kalpaka were ideal for cultivation in rice fallows for table purpose due to their high yield, good cooking quality and low cyanogen content.

Experiment II. Nutrient management for short-duration cassava

Dry matter production, root yield and quality

Pooled analysis indicated that application of nutrients based on soil test data was sufficient to realize the same root and total biomass production as with the full recommended dose of FYM and NPK. Further, application of nutrients based on soil test data resulted in the same mean RBR (4.314 g/plant/day) as that obtained with the full dose of farmyard manure and NPK (4.576 g/plant/day) (**Table 2**). Nutrient management based on soil test data for organic C, available P and K status, resulted in the saving of full amount of P, 10% of N and 15% of K by the third year and was found to be sufficient for obtaining high yields of short-duration cassava (24.18 t/ha) (**Table 2**). In the present study it was possible to save the entire quantity of fertilizer P, the costliest among the major nutrients on per unit nutrient basis, by the third year, by basing fertilizer rates on soil test results. Moreover, a low recovery of applied P fertilizers (15-25%) due to fixation in the soil and depletion of deposits of natural sources needed for the manufacture of P fertilizers, strongly suggests the importance of need-based application of fertilizers. Therefore, in the present day energy crisis and increasing cost of fertilizers the emphasis should be more on a rational approach of basing fertilizer recommendations on soil test results

Table 1. Yield, dry matter (DM) production and quality attributes of short-duration cassava lines evaluated in Experiment I. (data are the means of two years)

Short-duration cassava lines	Fresh root yield (t/ha)	Mean root bulking rate (g/plant/day)	Root DM produc-tion (t/ha)	Total DM produc-tion (t/ha)	Harvest index	Root dry matter content (%)	Root starch content (%) FW basis	Root cyanogen content (μg/g) FW basis
CI -732	20.62	3.146	6.99	14.22	0.492	33.87	24.88	30.70
CI - 848	25.57	3.887	8.64	16.65	0.519	33.76	24.30	30.40
H-165	25.18	3.288	7.31	13.24	0.552	28.80	22.17	74.10
Kalpaka	24.95	3.960	8.80	15.40	0.571	35.21	23.96	35.20
Sree Jaya	30.31	4.401	9.78	17.14	0.570	32.85	24.13	43.80
Sree Prakash	27.71	3.695	8.21	14.99	0.547	29.58	24.49	37.30
Sree Vijaya	31.70	5.372	11.94	20.29	0.588	37.53	27.19	42.50
Triploid 2-18	38.34	5.732	12.74	20.43	0.623	33.06	25.30	76.20
Triploid 4-2	32.06	5.382	11.96	20.64	0.579	37.41	28.46	114.30
V. Hraswa	29.81	5.079	11.28	19.63	0.574	38.21	28.39	29.20
CD (0.05)	2.459	0.8409	1.868	2.420	NS	1.409	NS	15.52

Source*: Suja et al., 2010a.*

The cyanogen content was not found to be under the influence of fertility levels (**Table 2**). Fertilizer rates based on soil test data resulted in root dry matter content (39%) on par with that of full FYM+NPK (40%). The mean data of starch content indicates that the fertilizer rate based on soil test data resulted in similar root starch content as full FYM + NPK or 75% FYM + NPK. This further reiterates that nutrient management based on soil test results promotes both high root yields as well as root quality parameters.

Table 2. Yield, dry matter (DM) production and quality attributes of short-duration cassava lines as affected by fertility levels in Experiment II. (data are the means of three years)

Treatments	Fresh root yield (t/ha)	Mean root bulking rate (g/plant/ day)	Root DM produc-tion (t/ha)	Total DM produc -tion (t/ha)	Harvest index	Root dry matter content (%)	Root starch content (%) FW basis	Root cyanogen content (µg/g) FW basis
Varieties								
Kalpaka	21.81	3.921	8.71	14.61	0.590	39.22	22.92	29.51
Sree Jaya	20.74	3.798	8.44	14.41	0.586	39.26	27.04	27.99
Sree Vijaya	23.04	3.912	8.69	14.11	0.618	37.89	22.35	35.70
Triploid 2-18	28.45	4.763	10.58	16.93	0.627	34.79	23.43	60.98
Vellayani Hraswa	24.77	4.590	10.20	15.61	0.652	42.27	22.16	37.22
CD (0.05)	2.866	0.4536	1.008	1.23	0.028	1.735	0.856	12.824
Fertilizer rates								
Full FYM+NPK	25.05	4.576	10.16	16.78	0.603	39.95	24.85	34.63
75%(FYM+NPK)	23.48	4.067	9.04	14.61	0.618	38.52	23.18	43.83
50%(FYM+NPK)	22.33	3.830	8.51	13.22	0.637	37.25	21.96	43.57
Based on soil test data	24.18	4.314	9.59	15.93	0.599	39.02	24.33	31.07
CD (0.05)	1.389	0.4057	0.902	1.10	0.025	1.552	0.765	NS

***Source**: Suja et al., 2010b.*

Nutrient balances

The N, P and K uptake was significantly influenced by fertilizer application rates. Application of full FYM and NPK resulted in significantly higher N uptake. The uptake of P and K was also highest but almost the same for the addition of 100% FYM and NPK as for the fertilizer rates based on soil test data. This further indicates the feasibility of basing fertilizers rates on soil test data (**Table 3**).

During the first year, the effect of fertilizer rates based on soil chemical properties was not significant. However, the soil could be rated as medium for organic C status, low for available N, sufficient for available P and available K in plots that received full FYM and NPK or nutrients based on soil test results, which indicates that except for N, the soil fertility level was sufficient. This underscores the importance of nutrient management based on soil test data. In the subsequent two years, the organic C, available N, P and K status of the soil after harvest of the crop in the treatment of fertilizer rates based on soil test data was higher and on a par with that of full FYM + NPK. Even after three crop cycles, the organic C and available K status were medium and the available P content was still high in these plots. Thus, the soil fertility status could be maintained rationally even after three years of continuous cropping of a nutrient exhausting crop like cassava by judicious application of nutrients based on soil testing. Thus, judicious application of nutrients based on soil testing resulted in a positive balance for N, P and K due to lower losses in the treatment with less fertilizer inputs (**Table 3)**.

Table 3. Average nutrient balance for N, P and K (kg/ha) as affected by different fertilizer rates applied during three consecutive years to five short-duration cassava varieties in Experiment II.

	N added			N uptake			Available N status			N balance		
Fertilizer rate	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Full FYM+NPK	162.5	162.5	162.5	204.9	128.1	179.1	134.3	161.4	138.0	-59.9	-35.1	21.5
75% FYM+NPK	121.9	121.9	121.9	165.8	104.2	130.1	128.7	131.8	124.7	-63.9	-48.0	-0.2
50% FYM+NPK	81.3	81.3	81.3	153.5	93.8	106.8	123.9	103.5	110.4	-40.4	-46.0	2.9
Based on soil test data	157.5	157.5	152.5	181.4	98.6	169.2	135.9	176.2	135.4	-76.8	-44.8	19.0
Initial status							236.6	162.1	133.1			

	P added			P uptake			Available P status			P balance		
Fertilzer rate	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Full FYM+NPK	45.0	45.0	45.0	67.8	44.5	64.3	40.1	41.0	45.7	48.8	22.9	-1.3
75% FYM+NPK	35.3	35.3	35.3	61.3	41.0	51.2	32.7	39.8	38.7	44.6	28.5	-11.6
50%FYM+NPK	23.5	23.5	23.5	50.8	31.8	37.0	32.9	34.1	32.3	45.7	24.9	-20.5
Based on soil test data	42.5	40.3	25.0	64.7	40.0	63.5	39.7	35.2	46.7	47.6	14.8	18.8
Initial status							14.2	19.5	66.4			

	K added			K uptake			Available K status			K balance		
Fertilizer rate	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Full FYM+NPK	133.3	133.3	133.3	153.3	101.4	148.7	144.6	215.3	252.7	52.1	32.1	96.8
75% FYM+NPK	100.0	100.0	100.0	135.6	87.7	116.0	129.3	165.9	219.1	52.4	2.3	63.7
50%FYM+NPK	66.7	66.7	66.7	127.6	76.0	99.2	128.6	147.6	177.7	77.0	5.5	38.7
Based on soil test data	137.5	129.2	120.8	145.5	89.2	148.7	151.6	189.9	237.8	47.1	-1.4	94.3
Initial status							112.5	151.3	171.4			

***Source**: Suja et al., 2010.*

Experiment III. Cassava production systems involving legumes

Productivity and profitability

The average over three years indicated that the cassava variety Vellayani Hraswa produced significantly higher yield than Sree Vijaya in systems involving cowpea (24.55 and 21.46 t/ha, respectively) (**Table 4**). The yield reduction noticed in Vellayani Hraswa and Sree Vijaya in cropping systems, especially under intercropping, over sole cropping was 1.88 and 14.37%, respectively. Sequential cropping enhanced yield by 4%, whereas intercropping reduced yield by 20.36% over sole cropping. The superior performance of Vellayani Hraswa and Sree Vijaya due to sequential cropping has been reported earlier (Suja *et al*., 2010a; Suja *et al*., 2010b; Suja *et al*., 2011). Of the two systems, sequential cropping (26.07 t/ha) proved superior to intercropping (19.94 t/ha). Both vegetable cowpea (variety Pusa Komal) and grain cowpea (variety C-152) were found to be equally compatible with short-duration cassava under both systems. Saving of the full P and half N application for short-duration cassava was possible in both sequential and intercropping systems with cowpea.

Table 4. Yield of two short-duration cassava varieties as influenced by either sequential cropping or intercropping with cowpea and two levels of application of N in Experiment III.

Treatments	Fresh root yield (t/ha)
Short-duration varieties	
Vellayani Hraswa	24.55
SreeVijaya	21.46
CD (0.05)	1.159
Cropping systems	
Sequential cropping	26.07
Intercropping	19.94
CD (0.05)	5.912
Cowpea types	
Vegetable cowpea	23.52
Grain cowpea	22.50
CD (0.05)	NS
Fertilizer rates	
Full N	23.96
Half N	22.05
CD (0.05)	NS
***Control* (Sole cassava)**	
Vellayani Hraswa	25.02
Sree Vijaya	25.06

Source*: Suja and Shreekumar, 2015.*

Economic analysis indicated that sequential cropping of vegetable cowpea followed by short-duration cassava under full N was the most profitable system, generating the highest net returns (Rs. 97,398/ha) and B:C ratio (2.15) (**Table 5**). This was closely followed by sequential cropping of vegetable cowpea with short-duration cassava under half N (B:C ratio of 1.86) (**Table 5**).

Table 5. Economic analysis of short-duration cassava, cowpea cropping systems and N fertilizer application rate in Experiment III. Data are based on the mean yields of three years.

Treatments	Mean root yield (t/ha)	Cowpea yield (kg/ha)	Gross income (Rs/ha)	Gross costs (Rs/ha)	Net income (Rs/ha)	B:C ratio
Sequential cropping						
VC-Cassava + full N	27.32	2,500	181,954	84,556	97,398	2.15
VC-Cassava + half N	25.94	1,918	154,521	83,156	71,365	1.86
GC-Cassava + full N	26.33	815	127,875	74,256	53,619	1.72
GC-Cassava + half N	24.69	750	119,080	73,656	45,424	1.62
Intercropping						
Cassava + VC+ full N	21.51	1,100	108,517	70,256	38,261	1.54
Cassava + VC+ half N	19.30	880	93,090	69,656	23,434	1.34
Cassava + GC+ full N	20.70	530	93,904	66,256	27,648	1.42
Cassava + GC+ half N	18.28	428	80,503	65,656	14,847	1.23
Sole cassava + full N	25.04		75,119	59,256	15,863	1.27

Note: VC = Vegetable cowpea; GC = Grain cowpea
Source*: Suja and Sreekumar, 2015.*

CONCLUSIONS

Short-duration cassava varieties, Sree Vijaya, Sree Jaya, Vellayani Hraswa and Kalpaka hold much promise for crop intensification under lowland conditions. Nutrient management based on soil test data is appropriate for these varieties. Sequential cropping of vegetable cowpea with short-duration cassava is a feasible option as it saves nutrients and provides additional income. Further research should focus on resource management to develop feasible cropping systems involving short-duration cassava and high value crops like pulses, vegetables, spices etc.

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RECENT PROGRESS IN CASSAVA BREEDING AND CULTURAL PRACTICES IN THE DEPARTMENT OF AGRICULTURE, THAILAND

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ABSTRACT

During the period from 2006 to 2010 research was conducted on varietal improvement, plant protection, cultural practices, and post-harvest management of planting material, with the objective to increase cassava starch yields for industrial use. With respect to cassava varietal improvement, two new cassava varieties were released for industrial use: Rayong 9, released in 2006, is a high starch and ethanol producing variety, while Rayong 11, released in 2010, is another high starch variety. In addition to cross breeding, cassava selfing was undertaken during the past five years. Some lines having a low HCN content, yellowish-orange or light purple flesh, high sugar or high protein contents were selected from various selfing populations.

Progress in pest and disease protection, an evaluation on mealybug resistance in cassava varieties under natural conditions indicated that four varieties showed less damage than others, and were considered potential sources of mealybug resistance. To identify varieties with cassava bacterial blight (CBB) resistance, 348 clones were inoculated with *Xanthomonas axonopodis* pv. *manihotis* and evaluated under greenhouse conditions. Nine clones were identified as potential sources of CBB resistance. For possible sources of anthracnose resistance or tolerance, inoculation with *Colletotrichum gloeosporioides* sp. *manihotis* under greenhouse conditions indicated that all released varieties are susceptible to anthracnose. Cassava root rots in Thailand are the result of different causes and thus require different remedies. Planting on high ridges, breaking the hard pan, elimination of infected plants and using various chemicals are suggested to farmers. Weeds are a major problem during the early growth stage of cassava. It can be concluded from this project that the most effective weed control is to use manual weeding twice during the first two months after planting cassava. Two applications of glyphosate at 2.25 kg a.i./ha can substitute for manual weeding in case of a labor shortage, but yields were reduced due to its adverse effect on cassava.

For soil and water management, the response of cassava to NPK fertilizer applications was studied in various soil series. It was concluded that the most economic rate under the current high price of chemical fertilizers is 100-50-100 kg/ha of N-P_2O_5-K_2O. A study of the yield potential of released varieties found that varieties performed differently in the various soil series. Drip-irrigation during dry periods in both the early-rainy season and early-dry season planting trials in Rayong province increased root yields of Rayong 5, Rayong 9 and Rayong 11. However, similar trials

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conducted in Ubon Rachathani and Kalasin provinces, using sprinkler and furrow irrigation, respectively, did not show a positive effect of irrigation on cassava yields. Various bio-fertilizers, plant hormones, growth regulators, and some minor element applications were introduced to cassava farmers by the private sector during the past five years. From our research it was concluded that the tested plant hormones, growth regulators and minor elements did not improve cassava yields in the tested areas.

Studies on post-harvest planting material management revealed that to obtain good sprouting and high survival rates of cuttings requires proper management. The application of 100-50-100 kg/ha. of N-P_2O_5-K_2O to mother plants is recommended. When stems have to be stored for more than one month, sprouting can be accelerated by soaking the cuttings in water for two hours, followed by incubation in nylon mesh bags overnight before planting. In case of an abundant supply of planting material, an increase in cutting length from 20 cm up to 50-80 cm is recommended for improved weed control, especially where herbicides are commonly used.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is one of the most important economic crops in Thailand. It can grow in places where other crops do not grow well. It can tolerate drought and can grow in low-fertility soils. Thailand was the first country to exploit the industrial use of cassava on a large scale. In 2010 the cassava planting area in Thailand was about 1.21 million hectares, and total production was around 22 million tonnes (Office of Agricultural Economics, 2010). Nearly all the harvested roots are processed into dry chips, pellets, starch, and ethanol, both for use in the country and for export.

One of the main problems for cassava farmers in Thailand is the instability of the fresh root price, while the price of inputs tend to increase. Moreover, the serious spread of pests and diseases resulted in large yield losses of cassava in recent years.

The Department of Agriculture of Thailand (DOA) has a major objective to increase the root yield and starch content of cassava. In addition, it aims to develop new technologies to reduce production costs and increase the income of Thai cassava farmers.

Progress in Cassava Varietal Improvement

The aims of the cassava breeding program in Thailand are to produce high yield varieties with high starch contents, early harvestability and pest and disease resistance. Rayong 9 and Rayong 11 are the latest varieties released for industrial use.

Rayong 9 was released in 2006, the result of a cross, made in 1992 at Rayong Field Crop Research Center, of a high-starch content female parent, CMR31-19-23, and the male parent OMR29-20-118. This variety performs well on loamy-sand or sandy-loam soils, in areas with an average annual rainfall of more than 1,000 mm, but does not do well in areas of very wet soils. The outstanding characteristics of Rayong 9 includes its high yield, high starch content, and high rate of conversion to ethanol, cassava flour, chips or pellets. Its average starch yield at 12 months after planting in over 35 locations was 9.50 t/ha. The average fresh root yield at 12 months was 30.88 t/ha, about 2% and 4% higher than those of Rayong 5 and KU 50, respectively. Laboratory tests indicated that the conversion rates of roots, harvested at 8, 12 and 18 months, to ethanol were 191, 208 and 194 liters per ton of fresh roots, respectively (**Table 1**). Cassava is now considered the best energy crop used to produce ethanol. This is because the ethanol yield from cassava per unit land area is the highest among all energy crops (Adelekan, 2010). Moreover, Rayong 9 is the variety that is most tolerant of witches' broom disease, and has a high rate of multiplication.

Table 1. Average fresh root yields, starch contents, starch yields and ethanol conversion rates of Rayong 9, Rayong 5, Rayong 72, Rayong 90 and Kasetsart 50 (KU50) varieties obtained in yield trials conducted in 23 locations in Thailand from 1995 to 1999.

Varieties	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)	Ethanol conversion rate (liters/t starch)	(liters/t fresh roots)	(liters/ha)
8 month harvest						
Rayong 9	22.81	28.9	6.56	661	191	4,356
Rayong 5	27.25	25.0	6.81	576	144	3,931
Rayong 72	28.25	23.1	6.50	632	146	4,131
Rayong 90	24.69	27.5	6.75	620	170	4,200
KU 50	26.88	23.1	6.19	602	139	3,744
12 month harvest						
Rayong 9	30.88	30.8	9.50	675	208	6,419
Rayong 5	30.06	25.5	7.63	576	147	4,425
Rayong 72	34.12	23.5	8.00	617	145	4,956
Rayong 90	31.19	27.5	8.56	633	174	5,425
KU 50	29.63	25.6	8.00	601	154	4,819
18 month harvest						
Rayong 9	48.75	29.3	14.25	662	194	9,450
Rayong 5	43.31	23.5	10.19	591	139	6,012
Rayong 72	40.56	20.9	8.44	646	135	5,494
Rayong 90	41.00	25.6	10.50	605	155	6,344
KU 50	45.88	23.8	10.94	546	137	6,300

***Source**: Limsila, 2005.*

Rayong 11, was released in 2010, the result of a cross, made in 1992 at Rayong Field Crop Research Center, of a high-yield female parent, Rayong 5, and a high-starch content male parent, OMR29-20-118. Its average fresh root yield over 53 locations was 27.75 t/ha and its starch content was 26.1% (**Table 2**). Rayong 11 is resistant to Cassava Bacterial Blight (CBB) and Brown Leaf Spot. Furthermore, this variety can grow well on calcareous soils, better than Rayong 5, Rayong 7 and Rayong 9, and also grows well on soils that are relatively high in organic matter (OM>1.5%).

Other advanced lines are now in yield trials under the 2011-2015 project. The most promising line is CMR46-39-42, which had an average starch yield of 8.0 t/ha over 17 locations. In addition to cross breeding, the selfing of cassava lines was undertaken during the past five years. Two clones having low HCN contents, three clones of yellowish-orange flesh, three clones of light purple flesh, three clones with high sugar contents (higher than 10% Brix) and ten clones with high protein (higher than 2%) contents were selected from these selfing populations.

Table 2. Average yield parameters of Rayong 11, Rayong 5, Rayong 9, Rayong 72 and Kasetsart 50 obtained in yield trials conducted in 53 locations from 1995 to 2006.

Varieties	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)	Dry matter content (%)	Dry root yield (t/ha)
Rayong 11	27.75	26.1	7.31	42.8	11.88
Rayong 5	28.56	22.2	6.31	36.9	10.50
Rayong 9	29.19	24.7	7.19	42.9	12.50
Rayong 72	32.31	21.2	6.81	30.7	9.94
KU 50	28.81	22.9	6.56	37.8	10.88

Progress in Pest and Disease Protection

Cassava pests can be serious because they cause the loss of roots, loss of planting material and loss of leaves, which results in a reduction of the yield from the crop (James *et al*, 2000). During the 2009 planting season, mealybugs caused serious damage to cassava fields all over Thailand. The direct damage is due to their sucking feeding habits and the indirect damage by the build-up of sooty mold on the leaf surface due to the mealybugs' excrements, which reduced leaf photosynthesis (Lozano *et al*, 1981). Evaluations on mealybug tolerance or resistance of 78 cassava varieties under natural conditions were conducted. Four varieties, i.e. CMR48-53-48, CMR48-56-18, MVEN 156 and CMR49-22-240 showed less damage than others, and were considered to be potential sources of mealy-bug resistance.

Among the pathological constraints of cassava production, cassava bacterial blight (CBB), caused by *Xanthomonas axonopodis* pv. *manihotis* (Vauterin *et al*., 1995) is the most common. To identify sources of CBB resistance, the leaves of 348 clones were inoculated with *Xanthomonas axonopodis* pv. *manihotis* and evaluated under greenhouse conditions. Nine clones were identified as potential sources of cassava bacterial blight resistance. On the other hand, Banito *et al*. (2010) suggested that considering the differences in reaction of genotypes to leaf-inoculation, field testing in various ecozones is recommended for proper selection of resistant genotypes.

Recently, anthracnose disease has been observed more frequently in cassava in the country. Plant pathologists diagnosed the symptoms, and collected and tested the virulence of isolations of eight causal-agents from eight provinces. They concluded that they are all *Colletotrichum gloeosporioides* sp. *manihoti*, which has very high virulence. Hahn *et al*. (1989) reported that *Colletotrichum gloeosporioides* sp. *manihoti* is the most important fungal disease of cassava in the field. Inoculation under greenhouse conditions indicated that all released varieties, i.e. Rayong 5, Rayong 7, Rayong 9, Rayong 11, Rayong 72, Kasetsart 50, Huay Bong 60 and Huay Bong 80, are susceptible to anthracnose. It is recommended to urgently look for sources of resistance in the local germplasm collection or among introduced sources of resistance from other countries.

Problems of root rots in cassava can be found repeatedly in some areas. Cassava root rots are caused by a complex of soil-borne pathogens, which induce damages that eventually reduce the yield (Ambe, 1994). Cassava yield losses of up to 80% due to root rot diseases have been reported (Théberge, 1985). Results from a survey around the target areas revealed different causes and remedies. When root rot is caused by flooding, farmers need to avoid planting in low lands, or they need to either plant on high ridges or to harvest cassava before roots start to rot (should be harvested within seven days after flooding). Root rot also occurs due to waterlogging. In this case, farmers need to improve their soil drainage by occasionally breaking the hard pan, or by planting vetiver grass to let their roots penetrate into compacted layers in the soil. Problems of soft rot, caused by *Phytophtora dreschsleri* and *Pythium* sp., were frequently found in humid areas; and dry rot, caused by *Botryodiplodia* sp., which attack the root system, eventually cause decay of the root (Makambila, 1994). Farmers are advised to apply Metralaxyl 25 wp., 1 gm/10 liter of water to the soil around the infected areas. The infected plants must be eliminated in order to limit the infection. For root rots caused by white grubs or termites, farmers can use mechanical means or chemicals for their control. Fipronil 5% sc (suspension concentrate), 80 cc/20 liter of water is effective for treating stem cuttings and for spraying onto the infested soil.

Weeds are a major problem during the early growth stage of cassava. Planting cassava without weed control resulted in 90% yield reduction. It can be concluded that the most effective weed control is to use manual weeding twice during the first two months after planting cassava (**Table 3**). Two applications of Glyphosate at one and two months after planting, at the rate of 2.25 kg a.i./ha, can substitute for manual weeding in case of a labor shortage. However, yields were found to be reduced by 11% due to the adverse effect of Glyphosate on cassava. Application of chemicals must be done with care in order to prevent farmers and cassava plants from coming into contact with these toxic chemicals.

Table 3. Effect of different weeding techniques on cassava yields and income, 2009/10.

Weeding treatments	Fresh root yield (t/ha)	Gross income (Baht/ha.)	Weeding costs (Baht/ha.)	Net income (Baht/ha.)
No weeding	1.2[d]	2,275	0	2,275
Spraying Glyphosate at 1 month	15.8[c]	31,193	1,906	29,287
Spraying Glyphosate at 2 months	5.9[d]	11,543	1,906	9,637
Spraying Glyphosate at 3 months	6.2[d]	12,125	1,906	10,218
Spraying Glyphosate at 1 and 2 months	26.8[a]	52,918	3,812	49,106
Spraying Glyphosate at 1 and 3 months	21.0[b]	41,418	3,812	37,606
Manual weeding at 1 and 2 months	30.0[a]	59,156	5,625	53,531

Source*: Jaipala et al., 2010.*

Progress in Soil and Water Management

In 2010, the cassava planting area in Thailand was about 1.21 million ha. These cover various soil types. The yields of several cassava varieties were determined in some of the major soil series, and under various soil and water management conditions. The response of three varieties to NPK applications were studied in 11 soil series, i.e. Huay Pong and Sattahip series in Rayong province; Mab Bon, Hoob Krapong and Satuk series in Chonburi province; Kabinburi and Korat series in Prachinburi province; Warin and Nam Pong series in Nakhon Rachasima province; and Lad Yah and Korat series in Kanchanaburi province. It was concluded that the highest rate of nitrogen, applied as 200-50-100 kg/ha of N-P_2O_5-K_2O fertilizer, resulted in the highest yields in most trials, but the most economic rate under the current high price of chemical fertilizer is 100-50-100 kg/ha of N-P_2O_5-K_2O, which has been recommended to farmers during the past ten years.

A study of the yield potential of released varieties found that varieties performed differently in the various soil series. Rayong 9 performed well in loamy sands and sandy soils, i.e. in Huay Pong and Sattahip series in Rayong province, Mab Bon, Hoob Krapong and Satuk series in Chonburi province, Kabinburi and Korat series in Prachinburi province, Nam Pong series in Kalasin, Sri Kiew and Nam Pong series in Nakhon Rachasima, and in Lad Yah and Korat series in Kanchanaburi province. Rayong 11 performed well in loamy sand and clay loam soils, which are relatively high in organic matter (OM>1.5%), i.e. in the Wang Hai series in Loei province, Takli series in Nakhon Sawan province and in the Kampangsaen series in Supanburi province. This variety also performed better than other varieties in moderately calcareous soils. Rayong 5 performed well in the Korat series in Prachinburi province, Rayong 7 did well in the Korat series, which has shallow underground water, in Roi Et province, and Rayong 72 performed well in the Satuk soil series in Khon Kaen province.

Drip irrigation with its ability of small and frequent water applications have created interest in view of decreased water requirements, possible increased production, and better product quality (Mohamed *et al*., 2006). Drip-irrigation once a week during the dry periods in the early-rainy season and early-dry season planting trials in Sattahip soil series in Rayong province resulted in an increase in root yields of the tested cassava varieties (**Table 4**).

Table 4. Effect of irrigation on plant height, fresh root yield, starch content and harvest index (H.I.) of three cassava varieties planted in the early-rainy season (2007/08) and the early-dry season (2006/07) at Rayong Field Crops Research Center.

	Rayong 5				Rayong 9				Rayong 11			
	Early-rainy season		Early-dry season		Early-rainy season		Early-dry season		Early-rainy season		Early-dry season	
	No-irr	Irr	No-irr	Irr	No-irr	Irr	No-irr	Irr	No-irr	Irr	No-irr	Irr
Height (cm)	198	215	206	201	246	254	213	247	214	227	237	220
Yield (t/ha)	41.7	54.6	41.4	48.9	46.8	55.1	41.1	55.6	44.0	50.2	40.9	53.3
Starch (%)	27.2	27.3	22.3	25.5	30.2	31.6	30.9	31.4	31.4	31.1	29.1	31.4
H.I.	0.73	0.73	0.77	0.79	0.71	0.71	0.72	0.75	0.69	0.70	0.64	0.75

Fresh root yields of Rayong 5, Rayong 9 and Rayong 11 increased by this type of irrigation by 31, 17 and 14%, respectively, in the early rainy season trial; and by 18, 35 and 30%, respectively, in the early dry season trial. The yields of Rayong 5, Rayong 9 and

Rayong 11 increased from 41.7, 46.8 and 44.0 t/ha to 54.6, 55.1 and 50.2 t/ha, respectively, under early rainy season planting; and from 41.4, 41.1 and 40.9 t/ha to 48.9, 55.6 and 53.3 t/ha, respectively, in the early dry season planting.

Odubanjo *et al.* (2011) recommended that in areas with moderate water scarcity, drip irrigation with 50% of available water could be used for achieving higher yields of cassava. Also, in areas where water is very scarce, drip irrigation with 25% of available water can be applied to obtain yields higher than without irrigation. However, similar trials conducted in Ubon Rachathani and Kalasin provinces (using sprinkler and furrow irrigation, respectively) did not show a positive effect of irrigation on cassava yields. The reason for this is partly due to more weed competition in irrigated plots, but other reasons, such as soil-water salinity, excess soil moisture, water evaporation and plant transpiration-respiration changes due to the abundant water supply, as well as the efficiency of the various irrigation systems, should be studied in more detail.

Various organic and bio-fertilizers, plant hormones, growth regulators, and some minor element applications were introduced to cassava farmers by the private sector during the past five years. Most of these technologies will increase costs and require more labor, but promise to markedly increase yields. Others are implied to produce normal yields but at a lower costs. From our research it was concluded that:

1) Application of organic fertilizer at 3 t/ha before ridging combined with the application of chemical fertilizer 15-7-18, at 300 kg/ha at one month after planting (DOA's technology) was the most effective (soil testing before planting also recommended). However, bio-fertilizers, plant hormones, growth regulators and minor elements did not increase cassava yields in the tested areas (**Figure 1**).

2) Application of organic fertilizers or bio-fertilizers without chemical fertilizers may be effective in relatively fertile soils, but not in poor soil as in the tested areas.

3) The quality of organic- and bio-fertilizers is not under government control, so their quality and effectiveness is highly variable.

Progress in Post-harvest Management of Planting Material

Studies on planting material management revealed that to obtain high germination and survival rates of cuttings requires proper management. An application of either 100-50-100 kg/ha or 200-50-100 kg/ha of N-P_2O_5-K_2O to mother plants resulted in good quality stakes. However, applying the lower rate of 100-50-100 kg/ha of N-P_2O_5-K_2O is cheaper and provides a better return on investment (**Table 5**).

Selection of cuttings from the most appropriate parts of the stem, such as avoiding the use of the lower part of the stem of older plants (older than 18 months), as well as the upper parts of immature plants (younger than eight months) is strongly recommended (**Table 6**).

Storing stems for three days before cutting the stakes for planting is also beneficial. For stems stored for more than one month, sprouting can be accelerated by soaking the cuttings in water for two hours, followed by incubation in nylon mesh bags overnight before planting. This is similar to the report of Al-Mudaris and Jutzi (2001) that soaking seeds of sorghum in water before planting resulted in an increase in the final germination percentage of the seeds. Cuttings from fresh stems do not need this treatment.

Table 5. The effects of application of various NPK fertilizers to mother plants on the average percent sprouting/plant survival of cassava stakes of Rayong 9, Rayong 11 and CMR 42-48-98 planted at Khon Kaen Field Crops Research Center in 2010.

Fertilizers applied (kg/ha of N-P_2O_5-K_2O)	Plant sprouting/Plant survival (%)		
	15 days	30 days	60 days
0-50-100	29 d	61 c	61 c
50-50-100	45 cd	68 bc	69 bc
100-50-100	72 ab	86 a	86 a
200-50-100	78 a	86 a	86 a
100-50-0	54 bc	72 a-c	72 a-c
100-50-50	68 ab	80 ab	80 ab
100-50-200	64 ac	85 a	85 a
100-100-100	55 bc	73 a-c	74 a-c

Source: *Taweekoon et al., 2010.*

Table 6. The effect of using different parts of the stems of mother plants as planting material on the percent sprouting of cut stakes and plant survival, number of roots per plant, and fresh root yield of cassava planted at Rayong Field Crops Research Center in 2010.

Part of the stems of mother plants	Stake sprouting **(%)**				Plant survival (%)	Root no/plant	Fresh root yield (t/ha)
	1 week	2 weeks	3 weeks	4 weeks			
Basal part	0	52	99 a	100 a	90	10	28.77
Near basal part	1	62	100 a	100 a	91	11	25.17
Near middle-lower	1	64	99 a	100 a	91	10	24.75
Middle part	2	63	98 a	100 a	92	11	28.29
Near middle-upper	1	51	99 a	100 a	85	10	23.55
Near top part	1	60	98 ab	99 a	87	10	24.41
Top part	2	53	94 b	98 b	84	9	21.46
F-test	ns	ns	*	*	ns	ns	ns
CV (%)	72.4	17.1	2.8	1.1	6.8	11.4	24.5

Source: *Hansethasuk et al., 2010.*

Preparation of stakes by cutting the stems straight with a circular saw is recommended. In case of an ample supply of planting material, an increase in cutting length from 20 cm up to 50-80 cm is recommended for improved weed control, especially where herbicides are commonly used (**Table 7**).

Table 7. The effect of different methods of cutting stems into stakes on percent sprouting and plant survival , the number of roots per plant and fresh root yields of cassava at Rayong Field Crop Research Center, 2010.

Method of stem cutting	Stake sprouting (%)				Plant survival (%)	Root No/plant	Fresh root yield (t/ha)
	1 week	2 weeks	3 weeks	4 weeks			
Cutting straight by knife	1	78	98	100	92	11	22.81
Cutting slanted by knife	1	77	100	100	91	10	21.98
Cutting straight by saw	2	80	98	100	98	11	24.09
F-test	ns	ns	ns	ns	ns	ns	ns
CV (%)	67.4	8	1.8	0.6	4.8	8.4	14.6

Source: *Hansethasuk et al., 2010.*

CONCLUSIONS AND RECOMMENDATIONS

The objective of the cassava varietal improvement program in this project was to develop high starch yield varieties for industrial use. However, in the future, other aspects that affect cassava productivity may need to be considered. Especially, in recent years, the severity of damage from cassava pests and diseases has increased substantially. Therefore, we should be consciously aware of this situation and the cassava breeding strategy for pest and disease resistance will need to be more important in the future.

The scoring of cassava mealybugs under natural conditions is affected by several factors that cannot be controlled, and these need to be investigated more intensively. The focus of cassava research should be to develop cassava germplasm with greater mealybug resistance. In addition, more research should be conducted on the use of herbs and natural extracts, as well as the use of natural enemies to control mealybugs, while causing no harm to the user or to the environment, instead of using insecticides.

In addition to studying the more efficient use of NPK chemical fertilizer, the combination of chemical fertilizers with microorganism or organic waste materials from local agriculture may be useful for improving soil structure, increase utilization of organic residues and decrease the use of chemical fertilizers. As well, the effect of irrigation on cassava in various types of soils should be studied further.

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Figure 1: The effect of DOA's technology on the fresh root yield of Rayong 9 (a), as compared with the application of plant hormones+growth regulators+minor elements (b); and DOA's technology on Rayong 11 (c), as compared with the use of bio-fertilizers (d).

CASSAVA AGRONOMY RESEARCH AT THE CHINESE ACADEMY OF TROPICAL AGRICULTURAL SCIENCES (CATAS) IN CHINA

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ABSTRACT

This paper presents the main results of cassava agronomy research conducted from 2009 to 2011 by the Tropical Crops Genetic Resources Institute (TCGRI） of the Chinese Academy of Tropical Agricultural Sciences (CATAS) in Danzhou, Hainan Province of China PR. This research was mainly supported by the earmarked funds from the China Agriculture Research System (CARS-12-hnhj).

In horizontal planting, the placing of the stakes with the buds all facing in the same direction significantly increased the fresh root yield (16.0%), the dry root yield (19.3%) and the starch yield (23.0%), as compared to facing the buds in opposite directions (check). Highest yields of fresh roots, dry roots and starch were obtained when the buds all faced south, followed by facing west and north , while lowest yields were obtained when all the buds faced east.

Comparing the yield effects of plant density and fertilization, it was found that fertilization had a greater effect than planting density. Fertilization increased the fresh root yield and starch yield, but decreased the starch content and harvest index. Closer plant spacing increased the fresh root yield, starch yield and starch content, while wider plant spacing increased the harvest index. Applying the fertilizer close to the rooting end of the horizontally planted stakes, or in between the sides of two planted stakes, increased fresh root yields 10.2-17.3%, and starch yields 12.7-19.0%, as compared to placing the fertilizer nearby one side of the planted stake (check). Moreover, we found that placing the fertilizer at 0-9 cm depth was better than at 12 cm depth.

The return of shredded cassava stems to the field significantly improved fresh root yield by 15.6-26.3% as compared to the check without this mulch. Application of Mg fertilizer increased fresh root yields 14.3%, and starch yield 10.6% when the soil exchangeable Mg content was 12.2 mg/kg, which is considered very low.

Interplanting cassava in a stand of watermelon, pumpkin, muskmelon or hairy melon, or intercropping cassava with peanut or soybean, improved cassava fresh root yields 6.1-25.2%, increased total income 1.6-4.2 times, and net income 1.7-4.9 times, as compared to monocropped cassava. Interplanting with melons resulted in higher benefits than intercropping with peanut or soybean.

The research on photosynthetic characteristics of cassava leaves under water stress

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showed that the variety SC8 has a higher photosynthetic capacity, as well as a better utilization of strong illumination, than SC5. The research on physiological characteristics under water stress shows that the drought resistance of cassava could be improved by spraying 100 mg/L salicylic acid (SA) or 0.2 mg/L brassinolide (BR) solution on the cassava leaves. Among five varieties tested, SC8 had the highest water use efficiency (WUE), followed by SC205.

Concerning the damage caused by the red spider mite, *Tetranychus cinnabarinus*, there are two critical periods during the cassava growth cycle, i.e. July to August and November. The planting of cassava along plastic mulch and intercropping with a short-duration crop could reduce the damage. SC8 was found to be the most resistant variety. The evaluation of 531 cassava germplasm accessions for resistance to *Tetranychus cinnabarinus* indicates that SC8, C1115 and another 32 accessions can be used as sources of resistance in the breeding program.

Some research was also conducted on typhoon resistant technologies.

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INTRODUCTION

Most research conducted from 2009 to 2011 by the Tropical Crops Genetic Resources Institute (TCGRI) of the Chinese Academy of Tropical Agricultural Sciences (CATAS) was supported by the earmarked funds from the China Agriculture Research System (CARS-12-hnhj).

METHODOLOGY AND RESULTS

1. Planting Direction of Buds on the Stakes

1.1 Yield effects of buds facing in the same or in opposite directions

In 2010 an experiment was conducted on the effect on yield of having buds facing in the same or in opposite directions when cassava stakes are planted horizontally (**Figure 1**). The experiment had five replications and used a randomized block design; the test variety was South China 8 (SC8) (Fan Weifeng *et al*., 2011).

Figure 1. Same bud direction, all facing east (on left), or opposite bud direction, facing either east or west (on right).

The results, shown in **Table 1**, indicate that facing all the buds in the same direction significantly increased fresh root yield by 16.0%, dry root yield 19.3% and starch yield 23.0%, compared with facing the buds in opposite directions (check). So, we need to place stakes in such a way that all buds face in the same direction when cassava is planted horizontally.

Table 1. The effect of placing horizontally planted cassava stakes with buds either facing all in the same or in opposite directions.

Treatments (buds facing direction)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Starch yield (t/ha)	Dry matter content (%)	Starch content (%)	Harvest index	Root no. per plant
Same	47.1aA	16.7aA	10.7aA	35.4aA	22.8aA	0.46aA	7.0aA
Opposite	40.6bA	14.0bA	8.7bA	34.3aA	21.4aA	0.45aA	6.5aA

Note: Data in the same column followed by different small letters indicate significant differences at the 5% level, while data followed by different capital letters indicate highly significant differences at the 1% level.

1.2 Yield effects of buds facing in different geographic directions

An experiment was conducted in 2010 at TCGRI to see whether facing all the buds of horizontally planted stakes in four different geographical directions has any effect on various cassava yield parameters (Huang Jie *et al*., 2012a). The experiment used SC8 as the test variety; it had four replications and used a randomized block design. The results, shown in **Table 2**, indicate that highest yields of fresh roots, dry roots and starch were obtained in the order of buds all facing south > west > north > east. When buds were all facing towards the south, fresh root yields increased 38.8%, dry root yields 36.3%, and starch yields 34.8%, as compared with the check treatment of buds facing east. The higher yield of buds facing west increased fresh root yield 24.9%, dry root yield 24.5%, and starch yield 24.6%, as compared with the check treatment. So, we recommend that the horizontally planted stakes are placed with all buds facing south or in a southwestern direction when cassava is planted in Hainan, China. More research is needed to confirm these results in Hainan and in other parts of China.

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Table 2. The effect of placing horizontally planted stakes with buds facing in different geographical directions on various cassava yield parameters.

Treatments (buds facing directions)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Starch yield (t/ha)	Dry matter content (%)	Starch content (%)	Harvest index	Root no. per plant
East	27.3aA	10.2aA	6.9aA	37.2aA	25.2aA	0.42aA	7.1aA
West	34.1aA	12.7aA	8.6aA	37.1aA	25.1aA	0.43aA	7.7aA
South	37.9aA	13.9aA	9.3aA	36.6aA	24.5aA	0.47aA	7.2aA
North	29.8aA	10.6aA	7.0aA	35.5aA	23.5aA	0.41aA	7.6aA

See note under Table 1.

2. Fertilizer Application and Plant Density

2.1 Yield effects of fertilization and planting density

An experiment on the effects of planting density and fertilization on cassava yields was conducted in 2004 and 2005 at TCGRI using a split plot design with four replications (Huang Jie *et al*., 2009), using SC5 as the test variety. The main plots had five different planting densities, while the subplots had three different fertilizer levels. In general, fertilization was more effective in improving cassava growth and yields than changing the plant density, as shown in **Table 3**. The closer plant spacing at 0.6x0.6 m or 0.8x0.8 m were the most effective treatments in increasing fresh root yield, starch yield, and the starch content of fresh roots, with the spacing of 0.8x0.8 m resulting in the highest starch yields. The wider plant spacing at 1.2x1.2 m or 1.4x1.4 m was the most effective in increasing the number of roots per plant, the harvest index, and stem diameter.

Table 3. Effect of different plant spacings on various cassava yield parameters.

Plant spacing treatments	Fresh root yield (t/ha)	Starch yield (t/ha)	Starch content (%)	Root no. per plant	Harvest index	Stem diameter (cm)
1.4m×1.4m	17.1bB	4.3cB	24.2bcBC	7.8aA	0.66aA	2.4bAB
1.2m×1.2m	20.9abAB	5.4bcAB	24.7bcABC	7.6aA	0.63abA	2.5aA
1.0m×1.0m	23.4aA	5.7abAB	23.2cC	7.3aA	0.63abA	2.3bB
0.8m×0.8m	23.7aA	6.8aA	27.3aA	5.6bB	0.60abA	2.0cC
0.6m×0.6m	24.3aA	6.5abA	25.8abAB	4.7bB	0.53bA	1.9cC

See note under Table 1.

The data in **Table 4** indicate that fertilization had a major beneficial effect on fresh root yield, starch yield, root number per plant, stem diameter and plant height, but decreased the starch content of fresh roots as well as the harvest index. The data suggests that the low-branching variety SC5 should be planted at a close spacing of 0.6x0.6 m in a low fertility soil with a low rate of fertilizer application; at a slightly wider spacing of 0.8x0.8 m space in a moderately fertile soil or with a higher rate of fertilization; and at a still wider spacing of 1.0x1.0 m in a highly fertile soil and/or with a high rate of fertilization.

Table 4. Effect of different fertilizer levels on various cassava yield parameters.

$N:P_2O_5:K_2O$ (kg/ha)	Fresh root yield (t/ha)	Starch yield (t/ha)	Starch content (%)	Root no. per plant	Harvest index	Plant height (cm)	Stem diameter (cm)
0:0:0	13.4cC	3.7cC	27.0aA	5.2bB	0.64aA	116.9cC	1.8cC
75:25:75	23.1bB	6.1bB	25.2bA	7.0aA	0.61aAB	170.2bB	2.3bB
150:50:150	29.2aA	7.4aA	22.9cB	7.5aA	0.58bB	194.5aA	2.5aA

See note under Table 1.

2.2 Yield effects of fertilizer placement

An experiment on the effects of fertilizer placement on the yields of two cassava varieties was conducted in 2008 at TCGRI using a split-plot design with randomized blocks and four replications (Huang Jie *et al*., 2010). The main plots had two varieties, SC8 and SC10, while the subplots had five fertilizer placement treatments (**Figure 2** and **Table 5**).

Figure 2. Fertilizer placement possibilities around the stake.

Table 5. Experimental details of five fertilizer placement treatments.

Treatments	Fertilization placement
Along the side of the stake (check)	15-20 cm from the north side of the stake.
In between the sides of two stakes	40 cm (midway) between the sides of two stakes
Root end	15-20 cm from the root end
Bud end	15-20 cm from the bud end
In between the ends of two stakes	30 cm (midway) between the ends of two stakes

Note: Plant spacing was 0.8x0.8 m. Stake length was 20 cm. Fertilizers were applied in a small furrow of 20 cm length (East-West) and 5 cm width. The buds all faced East.

The results, shown in **Table 6**, indicate that placing the fertilizers at 15-20 cm from the root end of each stake, or midway in between the sides of two stakes, increased the fresh root yield 10.2-17.3% and the starch yield 12.7-19.0%, as compared with the placement of fertilizer at 15-20 cm from one side of the cassava planting stakes (check = traditional method).

Table 6. Effect of fertilizer placement locations on various cassava yield parameters.

Fertilizer placement treatments	Fresh root yield (t/ha)	Starch yield (t/ha)	Starch content (%)	Harvest index	Root no. per plant
Stake side (check)	31.3 a	7.9 a	25.1 a	0.39 a	8.7 a
Between 2 stake sides	34.8 a	8.9 a	25.6 a	0.40 a	9.8 a
Root end	36.7 a	9.4 a	25.7 a	0.41 a	9.5 a
Bud end	31.6 a	8.3 a	26.2 a	0.39 a	9.2 a
Between 2 stake ends	34.5 a	9.0 a	26.0 a	0.41 a	9.7 a

Note: Data in the same column followed by different letters indicate significant differences at the 5% level.

Obviously, the traditional fertilization method of applying fertilizers anywhere nearby the cassava stake is not the best practice. It is recommended to face all the buds on the stakes in the same direction, and then apply the fertilizers at 15-30 cm from the root end of the stake. This will increase the yield and reduce the cost. Applying the fertilizer in between the sides of the stakes may be better for the young cassava plants, as it will increase yields and reduce fertilization labor costs, avoid possible harmful effects on cassava roots due to the high concentration of the fertilizer or due to damage by the hoes used for making the furrows

2.3 Effect of depth of fertilizer placement

Another experiment on the effect of depth of fertilizer placement on cassava yield was conducted in 2010 at TCGRI (Zheng Yu *et al.,* 2011), using SC8 as the test variety. The experiment had five different fertilization depths, four replications and used a randomized block design. The results, shown in **Table 7**, indicate that the fertilizer placement at 6 cm depth resulted in the highest fresh and dry root yield and starch yield, but the effect of depth of placement was not statistically significant for any of the yield parameters. However, the placement at 6 cm depth increased the fresh root yield 7.5%, dry root yield 5.3% and starch yield 3.9% compared with the check treatment of leaving the fertilizer on the soil surface (0 cm depth). The deep application at 12 cm depth decreased the fresh root yield 15.1%, the dry root yield 18.6% and the starch yield 21.1%, compared with the check treatment (0 cm depth). So, we suggest that for cassava, fertilizers should be placed at 0-9 cm depth and that 6 cm depth is probably the best.

Table 7. Effect of different fertilizer placement depths on various cassava yield parameters.

Depth of fertilizer placement treatments	Fresh root yield t/ha)	Dry root yield (t/ha)	Starch yield (t/ha)	Dry matter content (%)	Starch content (%)	Harvest index	Root no. per plant
0 cm (check)	30.5a	11.3a	7.6a	37.1a	25.0a	40.9a	5.3a
3 cm	28.8a	10.5a	6.9a	36.4a	24.1a	42.9a	5.6a
6 cm	32.8a	11.9a	7.9a	36.4a	24.2a	44.9a	5.3a
9 cm	30.0a	11.0a	7.4a	36.7a	24.6a	42.9a	5.0a
12 cm	25.9a	9.2a	6.0a	35.7a	23.2a	40.6a	5.1a

See note under Table 6.

2.4 Effect of returning shredded cassava crop residues back to the soil

Another experiment was conducted in 2008 at TCGRI to study the effect of returning the shredded cassava crop residues, mainly stems, back to the soil on cassava yield, using SC8 as the test variety (Zheng Yongqing *et al.*, 2009). The experiment had four treatments, four replications and used a randomized block design. The shredded cassava residues were first heaped up for one month to become compost, after which this compost was applied at 0, 600, 900 and 1,200 kg/ha, with half of each level applied at 30 and at 60 days after planting.

The results, shown in **Table 8**, indicate that returning the compost of shredded cassava stems to the soil significantly increased cassava yields; application of the composted stems increased fresh root yields between 15.6 and 26.3% as compared to the check treatment without the compost. The application of 600 kg/ha of the compost resulted in the highest fresh and dry root yields, but all three levels of applied compost increased yields while decreasing the dry matter content of the roots.

Table 8. Effect of returning shredded and composted cassava crop residues to the field on various cassava yield parameters.

Dry compost application	Fresh root yield (t/ha)	Dry matter content (%)	Plant height (cm)	Stem diameter (cm)
0 (check)	34.6	39.1	235.8	2.7
600	43.7*	38.1	238.1	2.8
900	40.0*	37.2	241.4	2.9
1200	41.8*	37.4	239.2	3.0

Note: * means significant difference at 5% level.

2.5 Effect of application of Ca, Mg, Zn and Cu fertilizers

The effect of application of secondary- and micro-nutrient fertilizers on cassava yields was studied in an experiment conducted in 2008 at TCGRI, on a field that had been cropped continuously with cassava for 15 years (Huang Jie *et al*., 2011a). The test varieties were SC8 and SC9. The experiment had five fertilizer treatments, which were based on the nutritional requirements of cassava as determined by CIAT, four replications, and used a randomized block design.

The results, shown in **Table 9**, indicate that the application of 200 kg/ha of Mg-sulfate was most effective, increasing the fresh root yield 14.3% and starch yield 10.6%, as compared to the check treatment without fertilizer.

Table 9. Effect of the application of Ca, Mg, Zn and Cu fertilizers on various cassava yield parameters.

Fertilizer treatments (kg/ha)	Fresh root yield (t/ha)	Starch yield (t/ha)	Starch content (%)	Root no. per plant
0 (check)	18.2 a	6.06 a	33.3 a	6.45 a
600 $Ca(OH)_2$	17.3 a	5.66 a	32.7 a	6.33 a
200 $MgSO_4{\cdot}7H_2O$	20.8 a	6.70 a	32.2 a	6.39 a
45 $ZnSO_4{\cdot}7H_2O$	17.0 a	5.37 a	31.6 a	5.19 a
12 $CuSO_4{\cdot}5H_2O$	18.0 a	5.90 a	32.8 a	5.58 a

See note under Table 6.

However, the application of Ca, Zn and Cu did not increase the fresh root and starch yields in a soil with levels of these nutrients considered to be quite low: the level of exchangeable Mg was only 12.2 mg/kg, that of exchangeable Ca was 130.6 mg/kg, and available Zn and Cu were only 0.74 and 0.11 mg/kg, respectively, all considered to be in the low range, while Mg was very low (Howeler, 2012).

According to the soil survey in China, the levels of soil exchangeable Mg are very low in many traditional cassava producing areas of Hainan, Guangxi and Guangdong province, so there may be a need to apply Mg fertilizers to cassava. Moreover, the soil exchangeable Ca, available Zn, Mn, Cu and B were also considered low or very low in some cassava growing areas in the above mentioned provinces, so we need to pay attention to the possible need to apply these secondary- and micro-nutrient fertilizers.

3. Interplanting and Intercropping

3.1 Effects of interplanting or intercropping on cassava yields and economic benefits

TCGRI worked together with the Agricultural Bureau of Wuming County in Guangxi Province, to develop six demonstration bases to show various methods of cassava intercropping or interplanting in 2009 (Lu Kundian *et al*., 2011).

The results, shown in **Tables 10** and **11**, indicate that interplanting cassava with water melon, pumpkin, muskmelon or hairy melon, or intercropping cassava with peanut or soybean, increased the cassava fresh root yield 6.1%-25.2%, and increased the total income 1.6-4.2 times and the net income 1.7-4.9 times, as compared with the check treatment of cassava monoculture. The interplanting of cassava with different types of melons produced more financial benefits than the intercropping with peanut or soybean. The above model is now adopted in 16,800 ha, equivalent to 60% of the cassava growing area in all of Wuming County in 2009.

Table 10. Effects of cassava interplanting or intercropping on the yields of cassava and the associated crops, grown in demonstration plots in Wuming County of Guangxi Province of China PR.

Interplant or intercrop demonstration	Yield of cassava in monoculture (check) (t/ha)	Yield of cassava when interplanted or intercropped (t/ha)	Yield of the interplanted or intercropped crops (t/ha)
Water melon	38.6	44.8	26.4
Pumpkin	38.6	45.7	18.8
Muskmelon	29.8	37.3	9.8
Hairy melon	38.6	41.6	45.0
Peanut	37.4	39.7	1.5
Soybean	29.8	35.0	1.4

Note: peanut and soybean yields were dry weight, others were fresh weight.

Table 11. Economic benefits of growing cassava interplanted or intercropped.

Model	Cassava income (Yuan/ha)	Interplant or intercrop income (Yuan/ha)	Total income (Yuan/ha)	Total cost (Yuan/ha)	Net income (Yuan/ha)	Total income as % of mono-culture	Net income as % of mono-culture
C monoculture	17,370	—	17,370	7,350	10,020	-	-
C+water melon	20,160	37,500	57,660	27,060	30,600	332.0	305.4
C monoculture	17,370	—	17,370	7,350	10,020	-	-
C+pumpkin	20,565	31,960	52,525	26,880	25,645	302.4	255.9
C monoculture	13,410	—	13,410	8,220	5,190	-	-
C+muskmelon	16,785	29,400	46,185	21,825	24,360	344.4	469.4
C monoculture	17,370	—	17,370	7,350	10,020	-	-
C+hairy melon	18,720	54,000	72,720	23,295	49,425	418.7	493.3
C monoculture	16,830	—	16,830	7,593	9,237	-	-
C+peanut	17,865	9,000	26,865	11,343	15,522	159.6	168.0
C monocultue	13,410	—	13,410	8,220	5,190	-	-
C+soybean	15,750	5,600	21,350	9,420	11,930	159.2	229.9

Note: C=cassava; 1 US$ = 7.0 Chinese Yuan in 2009.

3.2 Cultivation model of water melon or pumpkin interplanted with cassava

According to Li Chunguang *et al*. (2011), cassava varieties most suitable for interplanting or intercropping are those that have few or no branches, such as SC205. Normally, in Wuming County water melon seeds are planted before March, and pumpkin seeds before January. Two layers of plastic film are used for increasing the temperature, one film for covering the planting bed, the other for making a low canopy cover over the seedlings. During the growth of water melon and pumpkin farmers should apply more water and fertilizer. Later, cassava is interplanted in March when the temperature is above 15°C. The planting arrangement is shown in **Figure 3**. Water melon is planted at a spacing of 4.0x1.5 m, pumpkin at 4.0x2.0 m and cassava at1.0x 0.9 or 1.0 m.

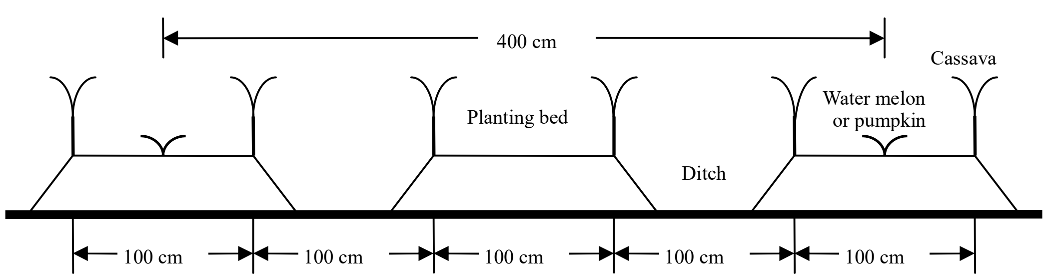

Figure 3. Planting arrangement of cassava interplanted with watermelon or pumpkin.

3.3 Cultivation model of muskmelon or hairy melon interplanted with cassava

Liao Haopei *et al*. (2011) described the method of planting muskmelon and hairy melon interplanted with cassava. This is basically the same as that used for water melon and pumpkin described above, except that hairy melons are planted before January and muskmelons before February. These melons are later interplanted with cassava in March, when the temperature is above 15°C. The planting arrangement is shown in **Figure 4**. Muskmelons are planted at a spacing of 2.0x0.6 m; hairy melon at 2.0x1.0 m, and cassava at 1.0 x0.9 or 1.0 m.

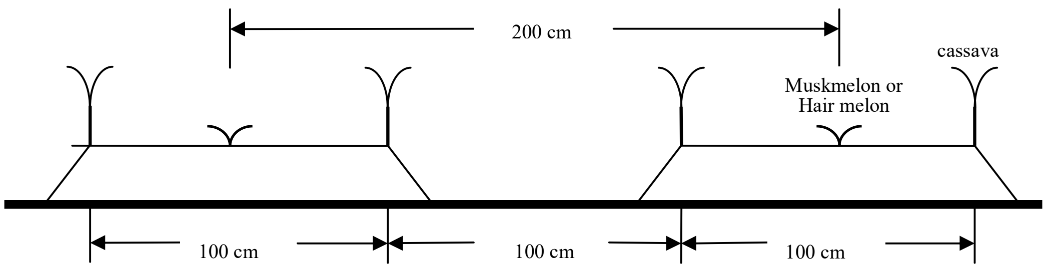

Figure 4. Planting arrangement of cassava interplanted with muskmelon or hairy melon.

3.4 Cassava intercropped with peanut or soybean

Wei Xiaozhen *et al.* (2011) described the method of intercropping cassava with peanut or soybean. It is best to plant a non-branching cassava variety and to select peanut and soybean varieties that grow upright and are early maturing. Cassava is planted at the same time as the intercrops, peanut or soybean, or within 7 days before or after the intercrops, usually in February or March when the temperature is close to 15°C. The planting arrangement of the crops is shown in **Figure 5**. The plant spacing of cassava is 1.0x0.8 or 0.9 m. The intercropped peanut or soybean are planted at a spacing of 30-35 x 20 cm with two rows or peanut or soybean between two rows of cassava.

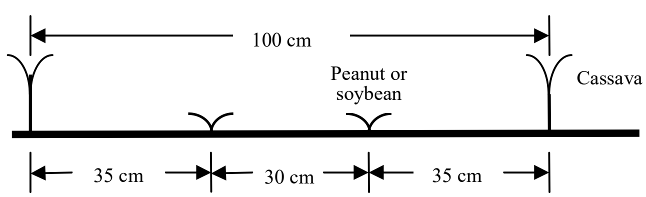

Figure 5. Planting arrangement of cassava intercropped with peanut or soybean.

4. Photosynthetic and Physiological Characteristics of Cassava Leaves

4.1 Photosynthetic characteristics under moderate water stress

Liu Zifan *et al*. (2011) reported on the use of cassava plantlets of SC8 and SC205 grown in pots in 2009 to study their leaf photosynthetic characteristics under moderate water stress using the LI-6400 portable photosynthesis system. The results showed that the net photosynthetic rate (*Pn*) and stomatal conductance (*Gs*) of SC8 and SC205 increased with enhanced intensity of illumination, but the intercellular CO_2 concentration (*Ci*) tended to decrease under both well-watered conditions and under water stress. The photosynthetic rate and stomatal conductance of SC8 were higher than those of SC205, but the CO_2 concentration of SC8 was lower than that of SC205. When the two cassava varieties were subjected to a moderate level of water stress, their apparent dark respiration (C_0) significantly increased, the maximum photosynthesis rate (*Pmax*) and apparent quantum yield (α) significantly decreased, while the light saturation point (*LSP*) decreased slightly and the light compensation point (*LCP*) increased slightly.

4.2 Physiological characteristics under different levels of water stress

Li Yiping *et al*. (2010) studied the effect of spraying the leaves of cassava plantlets of two pot grown cassava varieties, SC8 and SC201, with various concentrations of either salicitic acid or brassinolide on the content of proline (Pro) of the leaves and their activities of superoxide dismutase (SOD) and peroxidase (POD) when plants were subjected to five different levels of severity of water stress. The salicitic acid was applied at four concentrations, i.e. 0, 40, 60 and 100 mg/L, while the brassinolide was applied at 0.1, 0.2 and 0.5 mg/L. The water stress levels were induced by keeping the soil water content at 8.5−10.0, 11.5−13.0, 16.0−17.5 and 21.5−23.0%. Compared with the untreated check plants, all salicitic acid and brassinolide treatments were effective in increasing the proline content of the leaves, as well as the activities of superoxide dismutase and peroxidase. Some treatments increased the activity of these two enzymes significantly or very significantly, and the application of 100 mg/L salicitic acid and 0.2 mg/L brassinolide were the most effective in this respect. It can be concluded that the spraying of cassava leaves with solutions of 100 mg/L of salicitic acid or 0.2 mg/L of brassinolide could improve the plants' resistance to water stress.

4.3 Photosynthetic characteristic of cassava leaves of five cassava varieties

Zhang Zhenwen *et al*. (2009) reported the effect of changing light and CO_2 concentrations on the net photosynthesis of cassava leaves of five cassava varieties using a non-linear formula to fit a response curve using Sigmaplot software.

The results indicate that there was a change in net photosynthesis under the different light and CO_2 concentrations, but the response curves were nonlinear. Among the five varieties the lowest CO_2 Composition Point (CCP) (15.7 μl/L) and the highest

CO_2 Saturation Point (CSP) (2053.9 μl/L) were observed with the variety SC5. Meanwhile, the Light Composition Point (LCP) of SC7 was the highest (47.0 μmol/m^2/s) and the Light Saturation Point (LSP) was the lowest (895.6 μmol/m^2/s). The variety with the highest Water Use Efficiency (WUE) was SC8, followed by SC205, with values of 1.53 and 1.17 μmolCO_2/mmol of H_2O, respectively.

5. Control of Red Spider Mites (*Tetranychus cinnabarinus* (Boisduval)

5.1 Frequency of cassava red spider mite outbreaks

Pan Wenqin *et al*. (2011) reported the results of research on the frequency of red spider mite (*Tetranychus cinnabarinus* (Boisduval) outbreaks in Wuming County in Guangxi Province. Between 2009 and 2010 they conducted three experiments using different cassava varieties, different cultivation practices, and different intercropping or interplanting systems. They observed that there were two critical damage periods during the whole cassava growing period, the first one being from July to August, and the second period in November. Among three cassava cultivars, SC8 was the most resistant to *T. cinnabarinus*. Furthermore, the system of planting on beds covered with plastic mulch film and intercropping with short-duration crops could reduce the damage of *T. cinnabarinus* on cassava.

5.2 Evaluation of the resistance of 531 cassava germplasm accessions to red mites

In 2010 Huang Jie *et al*. (2011b) evaluated the resistance to the red spider mite, *Tetranychus cinnabarinus* (Boisduval), of 531 cassava germplasm accessions grown in the National Cassava Germplasm Garden of TCGRI. The results show that a few varieties had a high level of resistance to *T. cinnabarinus*, and that SC8 and C1115 among 32 accessions can be used as parents in the breeding program for high resistance to red spider mites. Other varieties like SC8013, SC7, Nanzhi 199, SC6, SC11, GR891, GuiRe 3, SC5 and GR911 also showed rather strong resistance. Eating varieties in general have weaker resistance, but SC9 has a relatively higher resistance.

6. Research on Agronomic Practices to Increase Resistance to Typhoons

The effectiveness of technologies to decrease the damage from typhoons in cassava fields was reported by Yu Changde *et al*. (2012) when an 8-9 level typhoon struck in the summer of 2011, and by Huang Jie *et al*. (2012b) when the fields were struck again by a 10-12 level typhoon in October of the same year. From these observations we recommend that: 1) Cassava be intercropped with low growing crops such as melons and gourds, or with grain legumes such as beans, peanut etc. Cassava should not be intercropped with tall crops such as maize; 2) The planting beds or ridges of cassava be covered with plastic film; 3) The planting density and the rate of fertilization should not be too high in typhoon areas, particularly not too much nitrogen; 4) Plant cassava in an area where strong winds can be avoided, or plant a typhoon resistant variety around the bigger cassava field; 5) There is no need to remove cassava leaves when the typhoon level is below nine, but cut plant tops off completely before a stronger typhoon; 6) Don't use typhoon damaged stems for replanting, and try to avoid any herbicide damage on the green stem; and 7) Make ditches to drain out the rain water in flat land. Varieties SC8, Nanzhi 199 and SC9 were found to resist 9-10 level typhoons.

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EFFECT OF CASSAVA STAKE PRIMING WITH NUTRIENT SOLUTION IN LAO PDR

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ABSTRACT

Cassava is an important food, feed and cash crop for smallholder farmers in Lao PDR. In cassava production, cuttings (also called "stakes") from mature stems of selected mother plants are used as planting material. However, since cassava is commonly grown by poor farmers on poor soils with minimum inputs, the crop not only produces low root yields, but planting stakes tend to be of low quality. The quality and nutrient content of cassava stakes are important factors that can affect cassava growth and productivity. This study evaluated means to overcome nutrient deficiencies in stakes of cassava varieties and cassava stakes from different sources.

The first experiment aimed to evaluate the effect of stake priming on the growth and yield of five cassava varieties. A field experiment was conducted using a randomized complete block design (RCBD) with four replications. The two factors were stake priming with a complete nutrient solution (two levels: priming and no-priming) and five cassava varieties (Rayong 5, Rayong 7, Rayong 9, Rayong 72 and Kasetsart 50 [KU 50]). The results showed that priming significantly increased root number, root starch content and root yield.

The second experiment aimed to evaluate the effect of priming of stakes cut from stems of KU 50 harvested in four different locations in Lao PDR. The stakes were planted in a field experiment using an RCBD with three replications. The experiment was harvested at four and at eight months after planting (MAP). The results showed that there were no significant effects of priming on root number and root yield, nor on starch content and starch yield at the first harvest at 4 MAP. However, at the final harvest at 8 MAP, fresh root and starch yields were increased by priming with plants grown from stakes from all four sources. Different stake sources had a significant effect on root yield.

It was concluded that cassava stake priming can overcome the problem of poor stake quality due to their low nutrient contents. It benefits farmers by not requiring expensive soil amendments with fertilizers. If mother plants produce stems with inadequate nutritional status, stake priming offers a simple and effective way to improve stake quality, which is likely to increase cassava yields.

Key words: Cassava, stake sources, stake priming, Lao PDR.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), also known as manioc in French and yuca in Spanish, is a perennial crop with its apparent center of origin in the southern rim of the Amazon Basin of Brazil (Olsen and Schaal, 2001). It is an important food, feed and cash crop for smallholder farmers in Lao PDR. Of the world's cassava production of 277 million tonnes in 2013, 57% was produced in Africa, 32% in Asia and 11% in South America (FAOSTAT, 2015).

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In cassava production, after the starchy roots are harvested, cuttings from the remaining stems, called stakes, are used as planting material. However, since cassava is commonly grown by poor farmers on poor soils with minimum inputs, the crop produces low root yields and stakes are often of poor nutritional quality (Cock, 1985; Howeler, 2002; Leihner, 2002). The poor quality and low nutrient content of cassava stakes is a significant factor that limits cassava growth and productivity (Eke-Okoro *et al.,* 2001). It has been suggested that stakes produced from mother plants grown on well-fertilized soils grow better because they have more reserves (Cock, 1985; López and El-Sharkawy, 1995). For about three weeks after planting cassava, growth depends exclusively on nutrient reserves stored in the stakes; sprouting of stakes is closely related to their starch content (CIAT, 1988). However, sprouting of the stakes is even more closely associated with their potassium (K) content than carbohydrate or sugar content (López and El-Sharkawy, 1995).

Priming plant propagules with nutrient solution can provide mineral nutrients to plant propagules, such as seed or cassava stakes, before planting to overcome nutrient deficiencies in the soil or in the propagules. For example, under nutrient deficiency conditions, priming barley, lentil, chickpea, wheat and rice seed with nutrient solution before sowing were reported to promote germination, seedling growth and root growth (Slaton *et al*., 2001; Ajouri *et al*., 2004; Johnson *et al.,* 2005). However, the conditions under which cassava stake priming is effective or ineffective are currently unclear.

RESEARCH OBJECTIVE

1) To evaluate the effect of stake priming in nutrient solution on growth and root yield of different cassava varieties.
2) To evaluate the effects of stakes of one cassava variety produced at four different locations, and how their performance was influenced by nutrient priming.

MATERIALS AND METHODS

This study was carried out by conducting two field experiments at two different locations:

Experiment 1: Effect of cassava stake priming with complete nutrient solution on the growth and yield of five cassava varieties

This experiment was conducted at the Mae Hia Research Station and Training Center, Chiang Mai University, Chiang Mai, Thailand from September 2010 to August 2011. The location has an annual rainfall of 1,685 mm and average daily temperature of 25.5 °C. The soil at the site had the following chemical characteristics: pH 5.8 (in water, 1:1), total N 0.07%, available P 15.5 µg/g (Bray II) and exchangeable K 15.5 meq/100 g (1N NH_4-acetate). The treatments were arranged in a factorial combination in a randomized complete block design (RCBD), with four replications. The combinations were two stake priming treatments (priming and no-priming) and five cassava varieties (Rayong 5, Rayong 7, Rayong 9, Rayong 72 and Kasetsart [KU] 50). Stakes of the five cassava varieties were obtained from the same source. i.e. Chiang Mai Field Crops Research Center, Sansai, Chiang Mai. Concentrations of N, P and K of the stakes were determined prior to initiating the experiment. Stakes of 20-cm length were primed by submerging in a complete nutrient solution (**Table 1**) for two hours.

Table 1. Elements and salts used in the complete nutrient solution.

Stock solution	Elements	Concentration needed (ppm)	Formula	Preparation of stock solution (g/L)	Priming solution (ml/10L)
1	N	25000	KNO_3	202.3	25
2	P	5000	KH_2PO_4	134.09	25
3	K	1250	K_2SO_4	87	25
4	Ca	5000	$CaCl_2. 2H_2O$	294.1	25
5	Fe	250	Fe-citrate	6.7	25
6	Mg	1250	$Mg_2SO_4. 7H_2O$	123.3	25
	Mn	5	$MnSO_4. H_2O$	0.338	
7	Zn	2.5	$ZnSO_4. H_2O$	0.288	25
8	Cu	0.1	$CuSO_4. 5H_2O$	0.1	25
	Co	0.5	$CoSO_4. 7H_2O$	0.056	
	Mo	0.5	$Na_2MoO_4.2H_2O$	0.048	
9	B	50	H_3BO_3	0.247	250

Source: *modified from Broughton and Dilworth, 1971.*

After priming the stakes were planted vertically at 1 m x 1 m spacing in plots of 4 m x 5 m. Weed control was done by hand. Six plants from the internal area of each plot were harvested at 12 months after planting. The number of roots, above-ground biomass, fresh and dry root weight, starch content and starch yield were measured. The starch content of fresh roots was calculated with the following formula:

Starch content (%) = 210.8 specific gravity – 213.4

where specific gravity = weight root sample in air/(weight sample in air – weight sample in water).

Experiment 2: The responses to nutrient priming of stakes of KU 50 from different locations in Lao PDR on cassava growth and root yield

This experiment was conducted at the Naphok Agricultural Research Center (ARC) of the National Agriculture and Forestry Research Institute (NAFRI), near Vientiane, Lao PDR (18° 08' 44" N; 102° 44' 05" E; 168 meters above sea level) from May 2010 to March 2011. The soil at the site had the following chemical characteristics: pH 4.5 (in water, 1:1), organic matter 1.8%, total N 0.1%, available P 6.3 µg/g (Bray II) and exchangeable K 0.1 meq/100 g (1N NH_4-acetate). The treatments were arranged in a factorial design of two combinations arranged in a RCBD, with three replications. The combinations were two levels of stake priming with complete nutrient solution for two hours before planting (priming and no-priming) using stakes of variety KU 50, a popular cassava variety in Lao PDR, collected in four different locations in the country, i.e. (i) Naphok, Xaithany District (18° 08' 44" N; 102° 44' 05" E; 168 meters above sea level), Vientiane capital; located in the middle region where cassava is mostly grown on lowland soils for starch factories; (ii) Peak District (19° 20' 35" N; 103° 09' 10" E; 1,102 meters above sea level); (iii) Phaxay District (19° 17' 44" N, 103° 04' 57", 1 121 meters above sea level). The latter two sites are in Xiengkhuoang Province in northeast Lao PDR where cassava is mostly grown on sloping land with high soil erosion, mostly for household consumption and animal feeding;

and (iv) Xay District (20° 41’ 57” N; 101° 59’ 29” E; 640 meters above sea level), Oudomxay Province; located in northwestern Lao PDR (**Figure 1**).

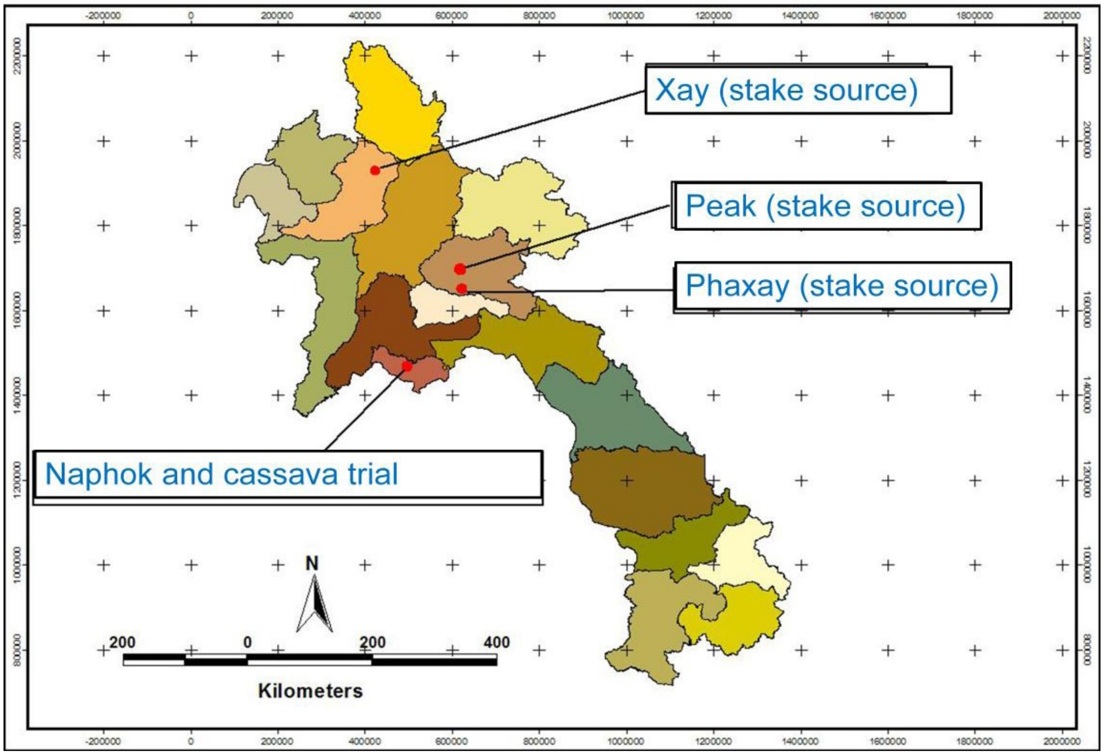

Figure 1. Locations where the four different stake sources were collected, and that of the site of Experiment 2 in Lao PDR.

The concentrations of N, P and K were determined in each batch of stakes prior to commencement of the experiment. Stake priming involved submerging the stakes in a complete nutrient solution (see **Table 1**) for two hours before planting at Naphok Experiment station. Stakes of 20-cm length were planted vertically at 1 m x 1 m spacing in plots of 6 m x 5 m. Weed control was done by hand. The experiment had two harvests, the first at four and the second at eight months after planting. Six plants were harvested at eight months after planting from the internal area of each plot. The number of roots, above-ground biomass, fresh and dry root weight, starch content and starch yield were measured. Starch content was measured and calculated using the same formula as in Experiment 1.

RESULTS

Experiment 1: Effect of cassava stake priming with complete nutrient solution on the growth and yield of five cassava varieties

Table 2 shows the nutritional status of the stakes of the five varieties before priming. Stakes of Rayong 9 tended to have lower levels of N, P and K than those of the four other varieties, except that stakes of KU 50 had still lower concentrations of P and K. Compared to the nutritional characteristics of planting stakes reported by López and El-Sharkawy (1995) the stakes used in this experiment were low in N, quite high in P and medium-high in K.

Table 2. Nutrient concentrations of the stakes used for Experiment 1 before priming.

Nutrient element	Variety				
	R5	R7	R9	R72	KU50
	Concentration (g/kg)				
N	4.5	4.2	3.6	4.9	4.8
P	2.6	3.0	2.8	3.1	1.0
K	5.6	6.2	4.6	4.9	3.9

Table 3 shows the fresh root yield response to priming of the five varieties at 12 months after planting at Mae Hia Experiment Station in Chiang Mai, Thailand, while **Figure 2** shows the dry root yield response and **Tables 4-7** show the response to priming in terms of above-ground dry weight, root number per plant, root starch content and starch yield, respectively.

Table 3. Effect of stake priming on fresh root yields of five cassava varieties at 12 months after planting at Mae Hia, Chiang Mai, Thailand in 2010/11.

Stake priming	Variety					Mean
	Rayong 5	Rayong 7	Rayong 9	Rayong 72	KU 50	
	Fresh root yield (t/ha)					
No-priming	56.8	37.8	49.5	60.6	61.8	**53.3^B**
Priming	73.8	51.5	56.2	75.7	58.2	**63.1^A**
Mean	**65.3^{ab}**	**44.6^c**	**52.8^{ab}**	**68.1^a**	**60.0^{ab}**	
F-test[1)]		SP*	V*	$VxSP^{NS}$		
$LSD_{0.05}$		8.7	13	-		

SP = stake priming; V = varieties; * = F-test significant at P < 0.05; NS = F-test not significant at P > 0.05. Values in the same column followed by different upper case letters are significantly different by LSD 0.05. Values in the same row followed by different lower case letters are significantly different by LSD 0.05.

Stake priming significantly increased the fresh root weight of all cassava varieties. The effects of stake priming (SP) and differences among varieties (V) in terms of fresh root yield were found to be significant (P<0.05), but their interaction (VxSP) was not significant (**Table 3**).

In terms of dry root yield, there was a significant interaction between priming and varieties (VxSP, P<0.05). Priming significantly increased the dry root yields of Rayong 9 and Rayong 72, but there was no significant effect in the other three varieties. Priming slightly decreased both the fresh and dry root yields of KU 50 **(Table 1** and **Figure 2).**

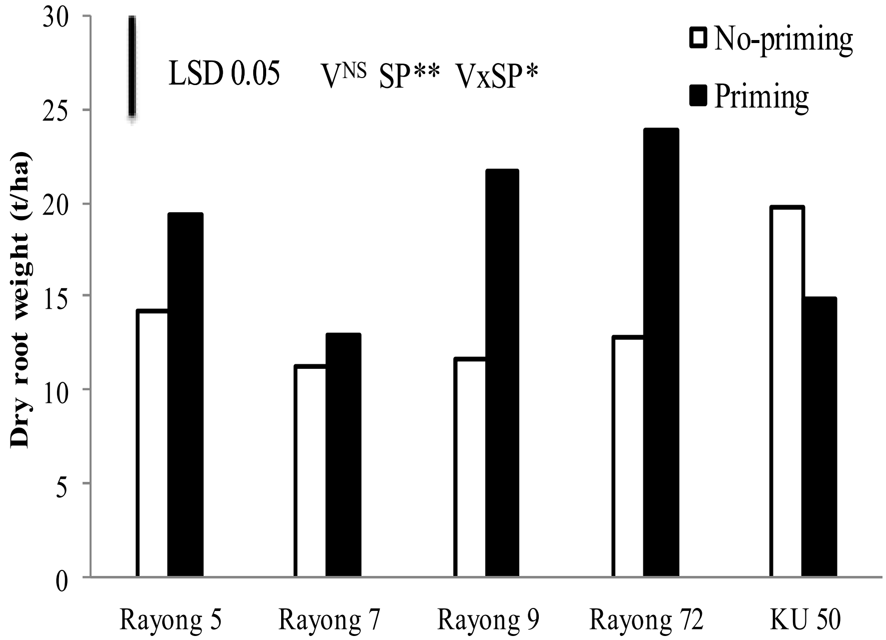

*Figure 2. Effect of stake priming on dry root weight of five cassava varieties at 12 months after planting. V = varieties, SP = stake priming, * = F-test significant as P < 0.05, ** = F-test significant as P < 0.01, and NS = F-test not significant as P > 0.05.*

The effect of priming on dry above-ground weight was not found. The dry above-ground weight only depended on cassava varieties **(Table 4).** On the other hand, the root number per plant was increased by priming, but the effect of varieties and the interaction between varieties and priming were not significant **(Table 5).**

Stake priming not only increased root yield and root number, but also increased the root starch content and starch yield **(Tables 6 and 7)**. Starch content depended on priming and cassava varieties, but the interaction between the two effects was not significant. Priming increased starch content by 8% compared with not-priming. On average, the starch content of Rayong 9 was the highest; while those of Rayong 7 and Rayong 72 were the lowest **(Table 6)**.

There was no interaction between priming and varieties on starch yield. Priming increased the starch yields of all cassava varieties. On average, priming increased the starch yield by 40%. Starch yields of Rayong 5, Rayong 9, Rayong 72 and KU 50 were about the same, and higher than that of Rayong 7 **(Table 7)**.

Table 4. Effect of stake priming on total dry above-ground weight of five cassava varieties at 12 months after planting.

Stake priming	Variety					Mean
	Rayong 5	Rayong 7	Rayong 9	Rayong 72	KU 50	
Dry above-ground weight (t/ha)						
No-priming	7.4	6.2	7.4	8.0	10.3	**7.2**
Priming	6.6	7.3	9.4	7.3	12.6	**7.7**
Mean	**7.0b^{c}**	**6.8^{c}**	**8.4^{ab}**	**7.7^{abc}**	**11.4^{a}**	
F-test		SP^{NS}	V*	$VxSP^{NS}$		
$LSD_{0.05}$		-	3.8	-		

SP = stake priming; V = varieties; * = F-test significant as P< 0.05; NS = F-test not significant as P > 0.05. Values in the same row followed by different lower case letters are significantly different by LSD 0.05.

Table 5. Effect of stake priming on root number per plant of five cassava varieties at 12 months after planting.

Stake priming	Variety					Mean
	Rayong 5	Rayong 7	Rayong 9	Rayong 72	KU 50	
Root number/plant						
No-priming	7.9	9.1	9.7	9.0	10.9	**9.3^{B}**
Priming	10.5	11.7	11.8	10.5	10.3	**11.0^{A}**
Mean	9.2	10.4	10.8	9.8	10.6	
F-test		SP*	V^{NS}	$VxSP^{NS}$		
$LSD_{0.05}$		1.5	-	-		

V = varieties, SP = stake priming, * = F-test significant as P < 0.05, and NS = F-test not significant as P > 0.05. Values in the same column followed by different upper case letters are significantly different by LSD 0.05.

Table 6. Effect of stake priming on the starch content of five cassava varieties at 12 months after planting.

Stake priming	Variety					Mean
	Rayong 5	Rayong 7	Rayong 9	Rayong 72	KU 50	
Starch content (%)						
No-priming	13.1	12.5	16.0	11.7	13.7	**13.4^{B}**
Priming	13.8	13.6	16.7	13.0	14.9	**14.4^{A}**
Mean	**13.5^{ab}**	**13.1^{cd}**	**16.2^{a}**	**12.4^{d}**	**14.3^{b}**	
F-test		SP**	V**	$VxSP^{NS}$		
$LSD_{0.05}$		0.7	1.1	-		

V = varieties, SP = stake priming, ** = F-test significant as P < 0.01, and NS = F-test not significant as P > 0.05. Values in the same column followed by different upper case letters are significantly different by LSD 0.05. Values in the same row followed by different lower case letters are significantly different by LSD 0.05.

Table 7. Effect of stake priming on starch yield of five cassava varieties at 12 months after planting.

Stake priming	Variety					**Mean**
	Rayong 5	Rayong 7	Rayong 9	Rayong 72	KU 50	
Starch yield (t/ha)						
No-priming	7.6	4.1	6.6	7.1	8.5	**6.3**^{B}
Priming	10.1	7.0	9.2	10.0	8.7	**9.1**^{A}
Mean	**8.8**^{a}	**5.5**^{b}	**7.9**^{a}	**8.6**^{a}	**8.6**^{a}	
F-test		SP**	V*	VxSP^{NS}		
$LSD_{0.05}$		1.4	2.3	-		

V = varieties, SP = stake priming, * = F-test significant as P < 0.05, ** = F-test highly significant as P < 0.01, and NS = F-test not significant as P > 0.05. Values in the same column followed by different upper case letters are significantly different by LSD 0.05. Values in the same row followed by different lower case letters are significantly different by LSD 0.05.

Experiment 2: The responses to nutrient priming of stakes of KU 50 from different locations in Lao PDR on cassava growth and root yield

Table 8 shows the concentrations of N, P and K in the stakes of KU 50 collected in the four different locations in Lao PDR. The variation in nutrient concentration is considerably greater among these different stake sources then among the five varieties shown in **Table 2**. In general, the stakes from Peak and Phaxay districts, both in Xhieng Khouang Province, have a lower nutrient content than the stakes from Naphok or Xay. Compared with information on the nutrient status of planting stakes reported by López and El-Sharkawy (1995) the stakes used in this experiment had a very wide range of N, P and K concentrations, with the N and P concentrations ranging from low to very low, while the K concentrations ranged from low (in Peak) to quite high (in Naphok). Soil analyses of these two districts indicate that most soils in Peak are extremely low in both P and K, while the soils in Naphok are medium in P and quite high in K (Howeler, 2007).

Table 8. Nutrient concentrations of the stakes used for Experiment 2 before priming.

Nutrient element	Stakes sources			
	Naphok	Peak	Phaxay	Xay
Concentration (g/kg)				
N	7.5	7.1	3.8	7.3
P	0.7	0.6	0.9	1.0
K	7.2	1.6	4.2	5.7

First harvest at four months after planting

Table 9 shows that stake priming (SP, P > 0.05), stake sources (SS, P > 0.05) and the interaction between stake priming and stake sources (SP x SS, P > 0.05) had no significant effect on fresh root yield. The same is true for the above-ground fresh weight

(**Table 10**), the starch content (**Table 11**) and starch yield **(Table 12)**. However, the effect of stake sources on root number per plant was significant (SS, P < 0.05) while the effects of stake priming and the interaction between stake priming and sources was again not significant (SP, P > 0.05 and SP x SS, P > 0.05). Plants grown from stakes from Naphok and Phaxay produced higher root numbers per plant than plants grown from stakes from Peak and Xay **(Table 13)**.

Table 9. Effect of stake priming in KU 50 from different sources on fresh root yield at four months after planting.

Stake priming	Stake sources				**Mean**
	Naphok	Peak	Phaxay	Xay	
Fresh root yield (t/ha)					
No-priming	3.0	3.4	2.8	3.0	**3.1**
Priming	3.9	3.3	2.7	3.1	**3.2**
Mean	**3.5**	**3.4**	**2.8**	3.0	
F-test		SP^{NS}	SS^{NS}	SP x SS^{NS}	
$LSD_{0.05}$		-	-	-	

SP = stake priming, SS = stake sources and NS = F-test not significant as P > 0.05.

Table 10. Effect of stake priming in KU 50 from different sources on fresh above-ground weight at four months after planting.

Stake priming	Stake sources				**Mean**
	Naphok	Peak	Phaxay	Xay	
Fresh above-ground weight (t/ha)					
No-priming	0.9	0.6	0.9	0.8	**0.8**
Priming	0.7	0.7	0.7	0.9	**0.7**
Mean	**0.8**	**0.6**	**0.8**	**0.8**	
F-test		SP^{NS}	SS^{NS}	SP x SS^{NS}	
$LSD_{0.05}$		-	-	-	

SP = stake priming, SS = stake sources and NS = F-test not significant as P > 0.05.

Table 11. Effect of stake priming in KU 50 from different sources on starch content at four months after planting.

Stake priming	Stake sources				Mean
	Naphok	Peak	Phaxay	Xay	
	Starch content (%)				
No-priming	13.3	11.5	14.4	13.0	**13.1**
Priming	13.0	11.1	14.3	14.7	**13.3**
Mean	**13.2**	**11.3**	**14.4**	**13.9**	
F-test		SP^{NS}	SS^{NS}	SP x SS^{NS}	
$LSD_{0.05}$		-	-	-	

SP = stake priming, SS = stake sources and NS = F-test not significant as P > 0.05.

Table 12. Effect of stake priming in KU 50 from different sources on starch yield at four months after planting.

Stake priming	Stake sources				Mean
	Naphok	Peak	Phaxay	Xay	
	Starch yield (t/ha)				
No-priming	0.4	0.4	0.4	0.4	**0.4**
Priming	0.5	0.4	0.4	0.5	**0.6**
Mean	**0.6**	**0.4**	**0.4**	**0.6**	
F-test		SP^{NS}	SS^{NS}	SP x SS^{NS}	
$LSD_{0.05}$		-	-	-	

SP = stake priming, SS = stake sources and NS = F-test not significant as P > 0.05.

Table 13. Effect of stake priming in KU 50 from different sources on root number per plant at four months after planting.

Stake priming	Stake sources				Mean
	Naphok	Peak	Phaxay	Xay	
	Root number/plant				
No-priming	13.8	9.1	10.6	11.0	**11.1**
Priming	13.9	9.5	12.2	11.5	**11.8**
Mean	**13.8**[a]	**9.3**[b]	**11.4**[ab]	**11.2**[b]	
F-test		SP^{NS}	SS^{*}	SP x SS^{NS}	
$LSD_{0.05}$		-	2.5	-	

SP = stake priming, SS = stake sources, * = F-test significant as P < 0.05 and NS = F-test not significant as P > 0.05. Values in the same row followed by different lower case letters are significantly different by $LSD_{0.05}$.

Final harvest at eight months after planting

Table 14 shows that there was a significant effect of both stake priming and stake sources (SP and SS, P < 0.05) on fresh root yield. Stake priming increased the average fresh root yield by 20%. The greatest positive effect of stake priming was observed with stakes from Peak and Phaxay, which had the lowest nutrient concentrations (**Table 8**). Stakes from Phaxay produced the highest fresh root yield, followed by stakes from Peak, Xay and Naphok, respectively. But there was no significant interaction between stake priming and stake sources (SP x SS, P > 0.05).

The effect of stake priming on root number per plant depended on stake sources (SP x SS, P < 0.05). The root number was increased by priming in plants grown from stakes from Naphok and Phaxay but not with plants grown from stakes from the other two sources **(Figure 3)**.

Table 14. Effect of stake priming in KU 50 from different sources on the fresh root yield at 12 months after planting.

Stake priming	Stake sources				Mean
	Naphok	Peak	Phaxay	Xay	**Mean**
Fresh root yield (t/ha)					
No-priming	14.7	15.4	19.6	18.4	**17.0^{B}**
Priming	16.8	21.6	26.5	18.5	**20.9^{A}**
Mean	**15.8^{b}**	**18.5^{ab}**	**23.0^{a}**	**18.5^{ab}**	
F-test		SP^{*}	SS^{*}	SP x SS^{NS}	
$LSD_{0.05}$		3.4	4.9	-	

SP = stake priming, SS = stake sources, * = F-test significant at P < 0.05 and NS = F-test not significant at P > 0.05. Values in the same row followed by different lower case letters are significantly different by LSD 0.05. Values in the same column followed by different upper case letters are significantly different by LSD 0.05.

For fresh above-ground weight, the effect of stake priming also depended on stake sources (SP x SS, P < 0.01). The fresh above-ground weight was increased by priming in plants grown from stakes from Phaxay, but not with plants grown from the other three sources **(Figure 4)**.

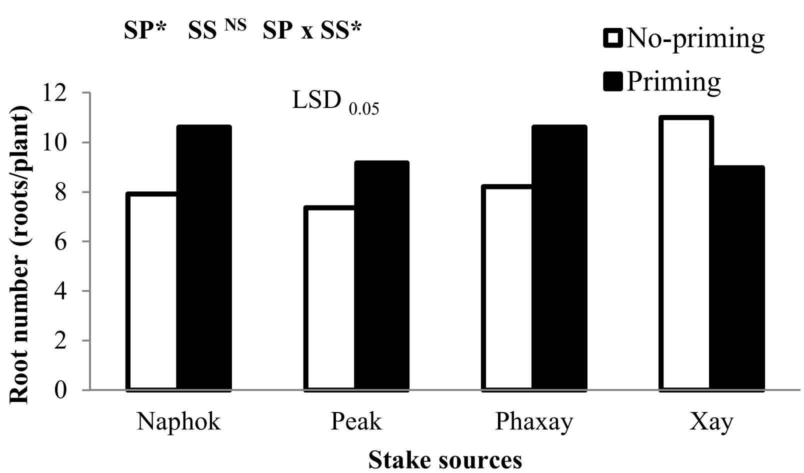

*Figure 3. Effects of stake priming on root number per plant in KU 50 from different sources. SP = stake priming, SS = stake sources, * = F-test significant at P < 0.05 and NS = F-test not significant at P > 0.05*

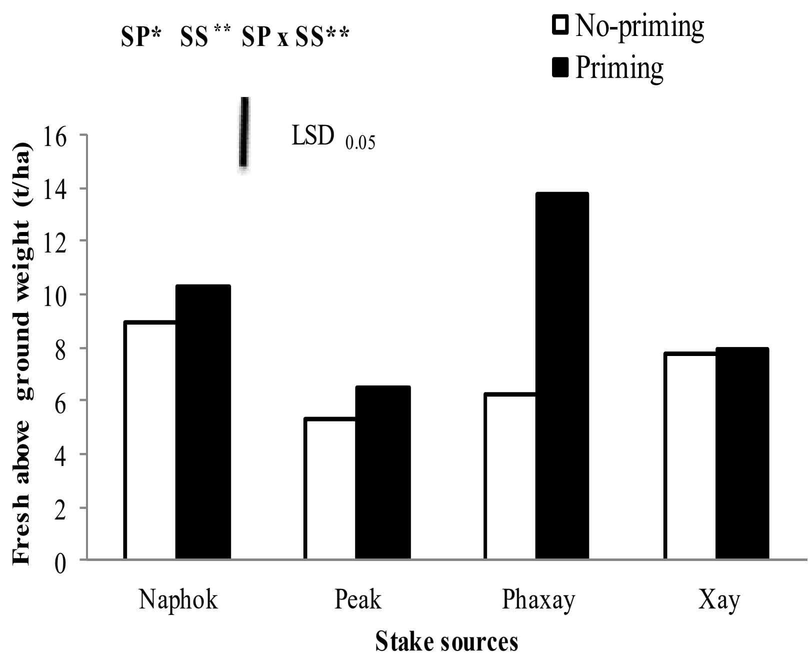

*Figure 4. Effects of stake priming in KU 50 from different sources on fresh above-ground weight. SP = stake priming, SS = stake sources, ** = F-test highly significant (P <0.01) and NS = F-test not significant as P > 0.05.*

The effects of stake priming, stake sources and the interaction between stake priming and stake sources on starch content were not significant (SP, SS and SP x SS, P > 0.05) **(Table 15)**. However, the average starch yield was increased 25% by priming (SP, P < 0.05), but the effect of stake sources and the interaction between stake priming and stake sources on starch yield was not significant (SS and SP x SS, P > 0.05) **(Table 16)**.

Table 15. Effect of stake priming in KU 50 from different sources on starch content at 12 months after planting.

Stake priming	Stake sources				Mean
	Naphok	Peak	Phaxay	Xay	
Starch content (%)					
No-priming	28.8	27.8	27.7	28.1	**28.1**
Priming	28.5	29.8	28.1	27.1	**28.5**
Mean	**28.7**	**28.8**	**27.9**	**28.0**	
F-test		SP^{NS}	SS^{NS}	SP x SS^{NS}	
$LSD_{0.05}$		-	-	-	

SP = stake priming, SS = stake sources and NS = F-test not significant at P > 0.05.

Table 16. Effect of stake priming in KU 50 from different sources on starch yield at 12 months after planting.

Stake priming	Stake sources				Mean
	Naphok	Peak	Phaxay	Xay	**Mean**
Starch yield (t/ha)					
No-priming	4.3	4.3	5.4	5.2	**4.8**[B]
Priming	4.9	6.5	7.4	5.2	**6.0**[A]
Mean	**4.6**	**5.4**	**6.4**	**5.2**	
F-test		SP^{*}	SS^{NS}	SP x SS^{NS}	
$LSD_{0.05}$		1.0	-	-	

SP = stake priming, SS = stake sources, * = F-test significant at P < 0.05 and NS = F-test not significant at P > 0.05. Values in the same column followed by different upper case letters are significantly different by LSD 0.05.

CONCLUSIONS

Nutrient deficiency is a limiting factor for root yield and biomass in cassava production. Stakes produced on soils with low fertility with low input show low nutrient content of stakes. Cassava stake priming provides a means to overcome the problem of poor quality stakes. Compared to the cost of application of soil amendments, such as fertilizers, with the aim to produce good quality stakes through adequate nutrition of the mother plants, stake priming offers a simple and effective way to improve stake quality.

However, further studies into how stake quality is influenced by the nutritional status of the mother plant should contribute towards more precision in the formulation of the priming nutrient solutions in order to obtain more consistent responses to stake priming.

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NUTRIENT BALANCES AND FARMERS' PERCEPTIONS ON CASSAVA CULTIVATION IN KAMPONG CHAM PROVINCE OF CAMBODIA

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ABSTRACT

In Cambodia, cassava is the most important upland crop, but the crop is mostly grown without fertilizer for many years. The magnitudes of nutrient balances are not known. While improved technologies are needed for sustainable crop production, their adoption depends on how farmers view cassava against other crops. The objective of this study was to assess nutrient balances for cassava cultivation, and the perception of farmers on growing cassava relative to other crops.

The study was conducted in Kampong Cham province, which has the largest and longest history of cassava production in the country. Forty five households in four zones were selected for the study. A farm survey employing a semi-structured interview combined with a field visit was used to collect data on cassava farmers' cultural practices, crop residue management and their perceptions on cassava and other potential crops. Crop cutting was done in 45 cassava fields of the sampled households to obtain root yields and weights of component plant parts, and a composite soil sample was taken from each field for analysis. Data were analyzed for nutrient balances and for farmers' perception on growing cassava against other upland crops. Nutrient balances were calculated for the individual fields based on the nutrient contents of the component sources obtained from the literature.

The results show that the balances of all the nutrients evaluated were negative. The losses were most serious for N, K and Ca with the averages of -59.65 kg N, -53.08 kg K and -10.93 kg Ca/ha, but were less serious for P and Mg with the averages of -4.82 kg P and -6.16 kg Mg/ha. These negative balances were the consequence of low nutrient inputs in current practices where only a few farmers applied chemical fertilizers or manure, and only at low rates.

With respect to farmers' perception, farmers in this area regard rice and cassava as their top priority crops, and have a greater preference for growing them than other crops. However, rice is grown for home consumption, while cassava is grown as a source of cash income. The marketing aspects of the crop, i.e. "good price" and "easy to sell", were the most important considerations for farmers' strong preference for cassava. Recently, production of cassava has increased substantially, reflecting increased market demand and prices. With the current trend of favorable marketing conditions, farmers will continue to have a strong preference for cassava, and are also likely to adopt improved technologies that will sustain or improve its yield, even if this entails extra input costs.

Key words: Soil nutrients, soil fertility management, long-term productivity, farmers' preference, farmers' attitude, technology adoption, Cambodia.

INTRODUCTION

Cassava and maize are the two most important upland crops of Cambodia. The production of cassava has increased substantially over the past five years because of high demand for domestic use and for exports, resulting in a high price. The area planted to cassava has increased dramatically from 15,380 ha in 2000 to 350,000 ha in

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2013. Production and yield increased from 147,763 tonnes and 9.61 t/ha in 2000 to 8 million tonnes and 22.86 t/ha in 2013 (FAOSTAT, 2015). In terms of production areas, cassava has become the second most important crop, after rice. Its role has changed from being a food crop to being more an industrial crop with multiple end-uses. It has become the most important source of cash income for many poor farmers (Ung Sopheap *et al.,* 2008). The market opportunities in Thailand, Vietnam and China are the major driving forces for these increases (Seng *et al*., 2009; Men Sarom *et al.,* 2015).

The production area and yield of cassava increased mainly due to the introduction of some new high-yielding varieties and by the expansion of the crop into new production areas where the soils are still fertile. Cassava is mostly grown without fertilizer inputs in Cambodia (Ung Sopheap *et al.*, 2008) and the crop has been grown in some of these areas for many years. However, the crop yields are expected to decrease as the high yield would be difficult to maintain without the adoption of improved technologies. Like all crops, cassava extracts nutrients from the soil and the amount of nutrients removed from the soil depends on the yield level (Howeler, 2001). Like, other crops, when cassava is grown continuously without fertilization, soil fertility will decline and yields are likely to decrease (Howeler, 2000; 2012b).

The soil's nutrient balance can be defined as the difference between nutrient inputs to and nutrient outputs from the system (Janssen, 1999). This has been used as an indicator of soil quality changes in agricultural systems (Bindraban *et al*., 2000). Nutrient balance analyses have been used as a tool for assessing the sustainability of land use systems (Patanothai, 1998; Smaling *et al.*, 1999). A number of studies on nutrient balances have been conducted in different countries around the world, including in Africa and Europe (Smaling *et al*., 1999; Janssen, 1999; Oenema and Heinen, 1999); in Asia (Patanothai, 1998; Vien, 1998; Manaligod and Cuevas, 1998; Poltanee *et al*., 1998); and in America (Jordan, 1985). These studies have provided useful information, not only for the improvement of soil fertility management, but also for determining the most appropriate management strategies for different soil types and land use systems in those countries. There is considerable data on cassava nutrient concentrations and contents in various cassava plant tissues, as well as on nutrient balances (Howeler and Cadavid 1983: Putthacharoen *et al*., 1998; Howeler, 1991; 2002; 2004; 2012a), but there is little known about the nutrient balance under the cassava cropping conditions of Cambodia.

In Cambodia, farmers do not grow only cassava but also grow other upland crops. These crops include mungbean, soybean, peanut, maize and rice, while rubber has also become a priority crop in recent years and has gained popularity among Cambodian farmers. It is not known how farmers view cassava relative to other upland crops. Future production of cassava in Cambodia, both in terms of area expansion and adoption of improved technologies, will depend on the decision making of the farmers. Knowledge on the perception of farmers on cassava against these crops, and a nutrient balance analysis are, therefore, important for determining appropriate strategies for promotion of the crop and certain improved production technologies for long-term sustainability of cassava-based production systems in Cambodia. The objective of this study was to assess nutrient balances for cassava cultivation and to determine the farmers' perception on growing cassava relative to other upland crops in Kampong Cham province in northeast Cambodia.

MATERIAL AND METHODS

Site Description

Kampong Cham province was selected for the study area because it has the largest planted area of cassava (MAFF, 2008), and it also has the longest history of cassava production in the country. In addition to cassava, farmers in this area also grow a wide range of other crops including rice, mungbean, soybean, maize, peanut, sesame, fruits and rubber. A preliminary survey was conducted and secondary data were collected on the areas planted to cassava, on cultural practices used, on crop residue management, yields obtained, as well as information on other crops grown, on climate, topography, soil type and history of cassava production. Based on this information, cassava areas in this study area were divided into four zones **(Figure 1).**

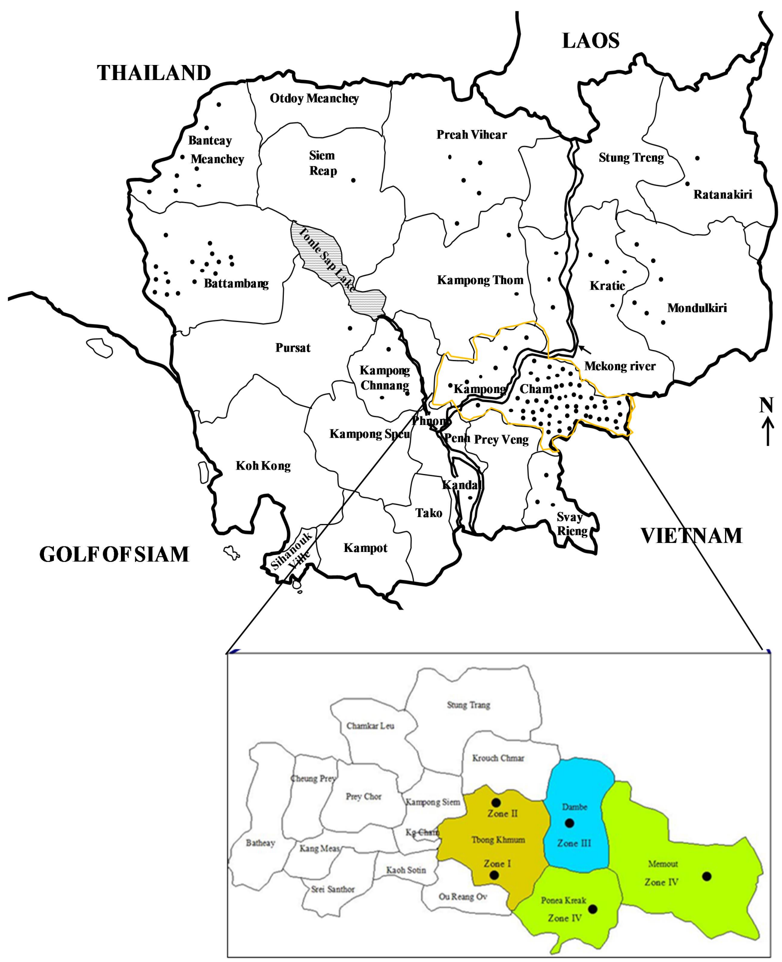

Figure 1. Distribution of cassava growing areas in Cambodia in 2007 (each dot represents 1,000 ha), and locations of Kampong Cham province and cassava production zones in the province.

Zone I and II are located in Tbong Khmum district, Zone III in Dambe district and Zone IV in Ponhea Krek district. Villages with the largest area of cassava cultivation in each zone, and about 70-80% of cassava growers in these villages, were selected for the detailed study.

Data Collection and Analysis

Secondary data on production areas, prices of crops, marketing and other crops grown in the study areas were collected using a formal survey with questionnaires to provide background information on farmers' perception of cassava cultivation relative to other crops. A total of 45 households were selected from all four zones. The questionnaires were used to collect data on type of crops grown in the area, periods of growing each crop, reasons for growing the crop and the type of crops grown in the event that the price of cassava becomes too low. Data obtained from these questionnaires were analyzed by comparative frequencies of households. Besides conducting farmer surveys, crop cuttings were made in 45 cassava fields of all the sampled households to determine the fresh weights of roots and other plant parts for each field in order to calculate nutrient balances in each of the four production zones.

Determination of Nutrient Inputs and Outputs

Nutrient balances were calculated for the individual cassava fields of the sample households in all zones. The concept and methodologies for nutrient balances analysis were described by Bindraban *et al.* (2000), Roy *et al*. (2003) and Phong *et al*. (2010). Conceptually, there are six inputs and five outputs of nutrients in a crop production system. The inputs include: (1) chemical fertilizers, (2) manure, (3) atmospheric deposition, (4) biological nitrogen fixation, (5) sedimentation and irrigation, and (6) planting material. The outputs include: (1) the harvested products, (2) removal of crop residues, (3) leaching, (4) gaseous loss, and (5) erosion.

To determine the sources and amounts of nutrient inputs and outputs with respect to cassava cultivation, a farm survey was conducted to collect information on farmers' cassava production practices as related to fertilizer use and crop residue management. Crop cutting was used to determine the fresh weights of roots and other plant parts for each field.

In Kampong Cham province, farmers plant cassava horizontally by placing the stakes in shallow furrows and then covering the stakes with soil. Some farmers may apply chemical fertilizers or manure after planting, but many do not. Weeding is done 1-3 times, and the weed biomass is usually left in the field. At harvest, the plants are uprooted and roots are cut and then taken from the field as the harvested product. The stumps are also cut from the plant tops, with some being taken from the field for use as firewood. Stems that are of good size and maturity are sometimes cut and stored for use as planting material for the next season. However, when planting material is not needed, these stems are also left in the field. The remaining residues, which include plant tops, stems, leaves and small branches, are left in the field. The nutrients in these crop residues and weeds are recycled back into the soil.

Based on these farmers' practices, the nutrient inputs were identified as: (1) chemical fertilizers, (2) manure, (3) planting materials (stakes), and (4) deposition from rain (wet deposition). Deposition from dust (dry deposition) was expected to be small, as there was very little burning in the area; biological fixation was also regarded as being small, as few leguminous weeds were observed in the cassava fields. No sedimentation was anticipated, as the cassava fields are in the uplands. Therefore, in this study, dry deposition, biological nitrogen fixation and sedimentation were excluded from the sources of nutrient inputs. Likewise, leaching, gaseous losses and erosion, were not considered as outputs, as their measurement would be difficult and costly, although some loss of nutrients by these pathways was anticipated. Soil erosion and related potential nutrient loss, was expected to be small as the study areas where cassava was grown is classified as gently undulating land. Thus, the harvested product (cassava roots) and crop residues removed (i.e. the stumps) were the only two sources of nutrient outputs included in the nutrient balance analyses.

Measurement of Individual Input and Output Parameters

Nutrient inputs such as applied chemical fertilizers and manure were obtained from the farmers interviews. The amounts of individual nutrient elements (N, P and K) applied per ha were calculated from the nutrient composition of the specific fertilizer used and the application rates. The manure used was mainly wet cattle manure. When averaged over 10 data sources cited by Howeler (2004), wet cattle manure has a moisture content of about 68% (32% DM) and contains 1.85% N, 0.81% P, 1.69% K, 1.54% Ca and 0.62% Mg on a dry weight basis. These figures were used for estimating the inputs of the individual nutrient elements in the form of cattle manure applied to each cassava field.

The input from planting material was calculated from the number of planting stakes used per ha, based on the information of plant spacing provided by individual farmers during the interview phase. The derived number was then multiplied by the average weight of a stake to get the fresh weight of planting stakes used per ha, which was then converted into dry weight. The inputs of individual nutrients were then calculated from the stake nutrient contents, estimated on a dry weight basis. The average fresh weight of the stakes used was 150 gm. This figure was derived from weighing sample stakes that were made from 10 stalks by cutting the stalks into pieces which approximated the normal length of cassava planting stakes (about 20-25 cm). The dry matter percentage of planting stakes and their nutrient concentrations were obtained from published (Lopez and El-Sharkawy, 1995) and unpublished experiments (R. Howeler, personal communication) in Colombia. The dry matter content averaged 34%, while the nutrient concentration of stakes on a dry weight basis averaged 0.73% N, 0.09% P, 0.30% K, 0.49% Ca and 0.19% Mg. These estimates were used in calculating the input of individual nutrients from the planting stakes (see **Appendix**).

The nutrient inputs from rain was based on estimates from Poltanee *et al.* (1998), which were derived from actual measurements of rainfall in Khon Kaen province in northeast Thailand throughout 1992, which were multiplied with the weekly analysis data of the nutrient contents of the rainfall. Total rainfall in Khon Kaen in that year was 793 mm, with concentrations of nutrients averaging 0.225, 0.123 and 0.163 ppm for N, P and K, respectively. This amounted to 1.78 kg N, 0.97 P and 1.29 K/ha/year.

Two major sources of nutrient outputs were considered in this study: the harvested products (i.e. cassava roots), and removed crop residue in the form of stumps. Fresh weight yields of both were obtained from crop cutting in individual farmers' fields in the four zones. For each field, four plots, each of 5x5 m^2, were harvested. Roots and stumps were separated from other plant parts (stems and leaves), and the fresh weights of roots, stumps and the other plant parts were measured. The dry matter percentage of fresh roots and their nutrient concentrations (on a dry weight basis) were based on the average of many data sources provided by Howeler (personal communication) (see **Appendix**). On this basis, the cassava roots in the study area were assumed to have 38% dry matter content, and average contents of 0.75% N, 0.10% P, 0.66% K, 0.12% Ca and 0.07% Mg, on a dry weight basis. The dry matter percentage and content of individual elements of the stumps was assumed to be the same as those of the planting stakes, i.e., 34% dry matter and 0.73% N, 0.09% P, 0.30% K, 0.49% Ca and 0.19% Mg on a dry weight basis (Howeler, personal communication). These dry matter and nutrient content estimates were used in calculating the quantities of outputs of individual nutrients in the roots and stumps that were removed from the fields.

RESULTS AND DISCUSSION

Average Nutrient Balances over Four Zones

The nutrient input from chemical fertilizer was small as only 10 out of 45 households (22%) used fertilizer, and only at low rates. Di-ammonium phosphate (18-46-0) was applied at an average rate of 51.0 kg/ha for the ten households and only 11.33 kg/ha over all 45 households, providing nutrient inputs of only 2.04 kg N and 2.28 kg P/ha (**Table 1**). Cattle manure also provided little nutrient inputs as only three households (7%) applied cow manure and only at a low average rate of 3,033 kg/ha for the three households and only 202.22 kg/ha over all 45 households, providing nutrient inputs of 1.20 kg N, 0.52 kg P, 1.09 kg K, 1.00 kg Ca and 0.40 kg Mg/ha.

Table 1. Average nutrient inputs, outputs, nutrient balance and recycled nutrients, for cassava cultivation in four production zones in Kampong Cham province in Cambodia.

Input /Output	Quantity (kg/ha)	Nutrient content (kg/ha)				
		N	P	K	Ca	Mg
Chemical fertilizer	11.333	2.04	2.28	0	0	0
Cattle manure (moist)	202.222	1.20	0.52	1.09	1.00	0.40
Planting material (fresh)	2,324	5.77	0.71	2.37	3.87	1.50
Rainfall		1.78	0.97	1.29	-	-
Total inputs		**10.79**	**4.48**	**4.75**	**4.87**	**1.90**
Cassava roots (fresh)	21,607	61.58	8.21	54.19	9.85	5.75
Cassava stumps (fresh)	3,570	8.86	1.09	3.64	5.95	2.31
Total outputs		**70.44**	**9.30**	**57.83**	**15.80**	**8.06**
Balance		-59.65	-4.82	-53.08	-10.93	-6.16
Recycled (stems and leaves)[2]	10,704	56.74	4.98	24.56	27.54	7.63

[1] At an average planting distance of about 0.8x0.8 m; [2] Stems and leaves were left in the field; thus, the nutrients were considered recycled back to the field.

The nutrient inputs from wet deposition were also small, being only 1.78 kg N, 0.97 P and 1.29 K/ha. Among the four input sources, the planting material (cassava stakes) provided the largest quantities of nutrient inputs into the system, with the averages over all 45 households being 5.77 kg N, 0.71 kg P, 2.37 kg K, 3.87 kg Ca and 1.50 kg Mg/ha. In total, the nutrient inputs amounted to 10.79 kg N, 4.48 kg P, 4.75 kg K, 4.87 kg Ca, and 1.90 kg Mg/ha (**Table 1**).

The nutrient output is mainly the harvested products (cassava roots and stumps), which were both removed from the field. The average fresh root yield of cassava over the 45 households was 21.61 t/ha. The amounts of nutrients removed in the form of roots were 61.58 kg N, 8.21 kg P, 54.19 kg K, 9.85 kg Ca and 5.75 kg Mg/ha. On average, 3.57 t/ha of fresh stumps were also removed from the fields, resulting in the removal of 8.86 kg N, 1.09 kg P, 3.64 kg K, 5.95 kg Ca and 2.31 kg Mg/ha. Total nutrients removed by both sources amounted to 70.44 kg N, 9.30 kg P, 57.83 kg K, 15.80 kg Ca and 8.06 kg Mg/ha (**Table 1**).

As the quantities of nutrient outputs were much greater than the inputs, the balances for all nutrients were negative and considerable, being **-**59.65 kg N, **-**4.82 kg P, -53.08 kg K, **-**10.93 kg Ca and **-**6.16 kg Mg/ha. The quantity of nutrients in stems and leaves that were recycled back into the soils were quite considerable, averaging 56.74 kg N, 4.98 kg P, 24.56 kg K, 27.54 kg Ca and 7.63 kg Mg/ha (**Table 1**).

Serious losses were shown for N, K and Ca, both in terms of large average amounts being lost (-59.65 kg N, -53.08 kg K and -10.93 kg Ca/ha) and the frequency of fields with large negative balances. The losses of P and Mg were less, averaging -4.82 kg P and -6.16 kg Mg/ha, with most fields having small negative balances for these two nutrients.

Nutrient losses from cassava production in the Cambodian soils covered by this study were considerably greater than those reported for the Central Highlands of Vietnam (-38, -3.4 and -28 kg/ha for N, P and K, respectively) where farmers apply very little manure and almost no chemical fertilizer to cassava, and were also much greater than the losses reported in Thailand (–19.5 kg N, 1.1 kg P, and –11.3 kg K/ha) where farmers mostly apply 15-15-15 (N-P_2O_5-K_2O) compound fertilizer to cassava at a rate of 70 kg/ha, with a yield level of 15 t/ha (Howeler, 2004). This result is probably related to the higher root yield of cassava in the Kampong Cham province in this study (21.6 t/ha), and the fact that some of the nutrient losses in cassava growing areas of Thailand are compensated for by considerable fertilizer inputs.

In this study, the average nutrients in stems and leaves that were recycled back to the soils were estimated at 56.74 kg N, 4.98 kg P, 24.56 kg K, 27.54 kg Ca and 7.63 kg Mg/ha. These amounts are quite significant when compared with other sources of nutrient inputs or nutrient outputs. If these crop residues are also removed from the field, the consequence would be substantially greater negative balances for all the nutrients presented in **Table 1**. The practice of keeping or returning the plant residues should therefore be maintained. Evidence from long-term NPK trials conducted on a very poor soil in Khon Kaen province in Thailand has shown that, without fertilizer application but with incorporation of plant tops, yields of about 12 t/ha could be maintained for more than 15 years of continuous cropping, but when the tops were also removed from the field, yields declined to between 5 and 7 t/ha (Howeler, 1995). In some fields, however, the mature stems are used for planting other fields, and are thus removed from the fields. This is unavoidable since planting material is needed for the next crop. In these fields, nutrient losses would be substantially greater than for fields where the planting material is not needed. Quite often, the planting stakes used are from cassava plants in the same fields. In this situation, the nutrients from planting stakes are not brought in as input, but are recycled nutrients. This would make the negative nutrient balances even greater than those indicated in **Tables 1** and **2**, with the averages of all the sites being increased to -65.42 kg N, -5.53 kg P, -55.45 kg K, -14.80 kg Ca and -7.66 kg Mg/ha.

Variations in Nutrient Balances among Zones

Negative balances were shown for all nutrients in all four cassava production zones in Kampong Cham province (**Table 2**).

However, the magnitudes of the balances for the individual nutrients varied to some extent among the four zones. Zones 2 and 3 appeared to have greater negative balances than Zones 1 and 4 for all nutrients except P, for which Zones 3 and 4 had greater negative balances than Zones 1 and 2 (**Table 2**). Among the three major nutrients (N, P and K), the magnitude of the negative balances for N and K were large, ranging from -51.02 to -67.95 kg/ha for N and -44.77 to -62.41 kg/ha for K; the balances for P were much smaller, ranging from -2.16 to -8.27 kg/ha. For Ca and Mg, although the negative balances were much lower than those for N and K, being -8.90 to -13.91 kg/ha for Ca and -5.07 to -7.40 kg/ha for Mg, these amounts were considered significant as these are secondary nutrients.

Differences in nutrient inputs among the four zones were also observed. Zones 1 and 2 had greater levels of inputs than Zones 3 and 4 for all the nutrients (**Table 2**). This reflected the fact that some households in Zones 1 and 2 applied chemical fertilizer or manure to their cassava fields, but no households in Zones 3 and 4 fertilized their cassava. Although the average rates of fertilizer and manure application in Zones 1 and 2 were low, being 18 and 29 kg/ha for chemical fertilizer (DAP = 18-46-0) and 525 and 280 kg/ha for cattle manure, respectively, they still provided some nutrient inputs, resulting in the levels of nutrient inputs for Zones 1 and 2 being greater than for Zones 3 and 4, where the nutrient inputs came only from the planting material and wet deposition from rainfall.

The levels of nutrient outputs in the four zones did not show the same trends as nutrient inputs, but closely reflected crop yields in the respective zones. Average crop yield in Zone 2 was the highest (25.61 t/ha), followed by Zone 3 (22.57 t/ha), Zone 1 (20.41 t/ha), and Zone 4 (18.22 t/ha). The amounts of nutrient outputs, thus, were highest for Zone 2, followed by Zones 3, 1 and 4, sequentially. However, the amounts of nutrients removed by the harvested products in Zones 1 and 2 were offset to some extent by higher inputs from chemical fertilizer and manure, making the nutrient balances in Zone 2 slightly lower than those for Zone 3 (**Table 2**).

Table 2. Average nutrient inputs, outputs and nutrient balances, for cassava cultivation in the individual zones in Kampong Cham province in Cambodia.

Input /Output	Quantity (kg/ha)	Nutrient (kg/ha)				
		N	P	K	Ca	Mg
Zone 1						
Chemical fertilizer	18.333	3.30	3.68	0	0	0
Organic fertilizer	525	3.11	1.36	2.84	2.59	1.04
Planting material	2,258	5.60	0.69	2.30	3.76	1.46
Rainfall	-	1.78	0.97	1.29	-	-
Total input	**-**	**13.80**	**6.70**	**6.43**	**6.35**	**2.50**
Cassava roots	20,405	58.15	7.75	51.18	9.31	5.43
Stumps	3,642	9.04	1.11	3.71	6.07	2.31
Total output	**-**	**67.19**	**8.86**	**54.89**	**15.38**	**7.74**
Balance	**-**	***-53.39***	***-2.16***	***-48.46***	***-9.03***	***-5.24***
Zone 2						
Chemical fertilizer	29.000	5.22	5.83	0	0	0
Organic fertilizer	280	1.66	0.73	1.51	1.38	0.56
Planting material	2,822	7.01	0.86	2.88	4.70	1.82
Rainfall	-	1.78	0.97	1.29	-	-
Total input	**-**	**15.67**	**8.39**	**5.68**	**6.08**	**2.38**
Cassava roots	25,615	73.00	9.73	64.24	11.68	6.81
Stumps	3,770	9.36	1.15	3.85	6.28	2.43
Total output	**-**	**82.36**	**10.88**	**68.09**	**17.96**	**9.24**
Balance	**-**	***-66.69***	***-2.49***	***-62.41***	***-11.88***	***-6.86***
Zone 3						
Chemical fertilizer	-	0	0	0	0	0
Organic fertilizer	-	0	0	0	0	0
Planting material	1,528	3.79	0.47	1.56	2.55	0.99
Rainfall	-	1.78	0.97	1.29	-	-
Total input	**-**	**5.57**	**1.44**	**2.85**	**2.55**	**0.99**
Cassava roots	22,571	64.33	8.58	56.61	10.29	6.00
Stumps	3,704	9.19	1.13	3.78	6.17	2.39
Total output	**-**	**73.52**	**9.71**	**60.39**	**16.46**	**8.39**
Balance	**-**	***-67.95***	***-8.27***	***-57.54***	***-13.91***	***-7.40***
Zone 4						
Chemical fertilizer	-	0	0	0	0	0
Organic fertilizer	-	0	0	0	0	0
Planting material	2,812	6.98	0.86	2.87	4.68	1.82
Rainfall	-	1.78	0.97	1.29	-	-
Total input	**-**	**8.76**	**1.83**	**4.16**	**4.68**	**1.82**
Cassava roots	18,223	51.93	6.93	45.70	8.31	4.85
Stumps	3,164	7.85	0.97	3.23	5.27	2.04
Total output	**-**	**59.78**	**7.90**	**48.93**	**13.58**	**6.89**
Balance	**-**	***-51.02***	***-6.07***	***-44.77***	***-8.90***	***-5.07***

Farmers' Perceptions of Cassava Cultivation

The results of the farmer survey on the farmers' reasons for growing cassava listed the following in decreasing order of priority: (1) ease of growing the crop; (2) good market prices; (3) ease of selling the crop; and (4) ability to grow the crop on poor soils. The average frequencies that these factors were listed for Zones 1 to 4 were 89, 80, 59 and 26% of sampled households, respectively (**Table 3**). No farmers indicated that the basis of their selection of cassava was on account of a low labor input requirement. It was also noted that in the old cassava production areas (Zones 1 and 2), the frequency that farmers listed its ability to be grown on poor soils was much higher than for the new production areas (Zones 3 and 4). The relative frequencies for the 'ability to grow cassava on poor soils' as a reason for growing the crop were 25, 60, 8 and 9% of households in Zones 1, 2, 3 and 4, respectively. For all farmer respondents in all zones, aspects of growing the crop (easy to grow and can be grown on poor soils) and marketing issues (good prices and easy to sell) appeared to be equally important in influencing farmers' decisions to grow cassava.

Table 3. Length of time that cassava has been grown and reasons for growing cassava for individual households surveyed in the four cassava production zones in Kampong Cham province of Cambodia.

Zone	No. of HH	Years of cassava cropping	Reasons for growing cassava (% of HH)*				
			Can grow in poor soil	Easy to grow	Easy to sell	Good price	Requires less labor
Zone 1	12	6-28	25	83	83	92	0
Zone 2	10	6-20	60	90	40	80	0
Zone 3	12	1-10	8	92	58	67	0
Zone 4	11	2-7	9	91	55	82	0
Average			26	89	59	80	0

* Each household gave more than one reason

In the survey interviews, farmers were asked to rank the crops they grew based on their preferences. The results (**Table 4**) showed that cassava and rice were the two most preferred crops, overwhelmingly outranking other crops grown in the area. Over all households in the four zones, 46.7% ranked cassava, 46.7% ranked rice, and the remaining 6.7% ranked rubber as their most preferred crop. For the crop of second choice, 46.7% selected cassava, 35.6% selected rice, and the remaining households selected either rubber or cashew nut or vegetables or mungbean, with frequencies ranging from 2.2 to 6.7%.

When asked what crop farmers would grow in place of cassava if cassava prices became too low to be acceptable, rubber was the farmers' choice in all households in Zone 1, 40% of households in Zone 2, 83% of households in Zone 3 and 91% of households in Zone 4 (**Table 5**). It was noted that in Zone 2 the number of farmers who chose legumes (mungbean, soybean and peanut) to replace cassava, was the same as the number who chose rubber, while some farmers in Zones 2 and 3 indicated that they would continue to grow cassava even if the price was low. Overall, the results clearly indicate that, if the price became unfavorable, rubber would be its potential competitor for agricultural land.

Table 4. Preference ranking of crops by cassava growers in all production zones in Kampong Cham, Cambodia.

Crop	First choice		Second choice		Third choice	
	No. of HH	%*	No. of HH	%*	No. of HH	%*
Cassava	21	46.7	21	46.7	3	6.7
Rice	21	46.7	16	35.6	2	4.4
Rubber	3	6.7	2	4.4	2	4.4
Mungbean	0	0.0	2	4.4	8	17.8
Vegetables	0	0.0	2	4.4	6	13.3
Cashew nut	0	0.0	1	2.2	0	0.0
Soybean	0	0.0	0	0.0	1	2.2

*Percent of 45 total households surveyed.

The results also show that cassava growers in Kampong Cham province in Northeast Cambodia consider rice and cassava as their priority crops, which are grown primarily for home consumption and for cash income, respectively. Farmers' preferences for these two crops are much higher than other crops, including maize, soybean, mungbean, peanut, sesame and rubber.

Table 5. Preferred alternative crops if cassava prices became too low.

Crop	Zone 1		Zone 2		Zone 3		Zone 4	
	No. of HH	%	No. of HH	%	No. of HH	%	No. of HH	%
Rubber	12	100.0	4	40.0	10	83.3	10	90.9
Legume	0	0.0	4	40.0	1	8.3	0	0.0
Cassava	0	0.0	2	20.0	1	8.3	0	0.0
Maize	0	0.0	0	0.0	0	0.0	1	9.1
Total	12	100.0	10	100.0	12	100.0	11	100.0

Although the farmers' responses for their reasons for growing cassava appeared to indicate equal importance of aspects of growing the crop (easy to grow, can be grown on poor soils) and crop marketing (good prices, easy to sell) in determining their preference for cassava, their rating of priorities indicates that aspects of marketing the crop were the most important considerations. Their responses to this question for other crops also suggest that Cambodian farmers are highly commercially oriented in relation to their choice of upland crops. The rapid increases in market demand and associated good price of cassava in Cambodia in recent years, clearly explains why Cambodian farmers rate cassava highly when compared with other upland crops. The future demand for cassava in Cambodia is expected to continue to increase, reflecting an increasing domestic demand by cassava processing industries and for export. Good ongoing prices for the crop can be anticipated. Rubber appears to be the only crop that has the potential to compete with cassava. However, the growing of rubber requires a high level of investment and it takes a considerable time to get returns on the initial investment. Only well-off farmers will be able to consider growing rubber. With the current trends in market demands for cassava, it is believed that rubber will not be a serious competitor in the near to medium term.

It is anticipated that cassava cultivation in Cambodia will continue, with a further expansion in the area planted to the crop. Currently, most cassava cultivation in Cambodia is done with little or no fertilizer inputs (Ung Sopheap, 2008). Like other crops, continuous planting of cassava without fertilization will result in a decline in soil fertility and an associated reduction in crop yields (Howeler, 2000; 2012b). Without improved agronomic practices, soil erosion can also potentially be a serious problem when farmers grow cassava on sloping lands (Howeler, 2002; 2012d). To sustain cassava production, improved technologies, particularly relating to soil fertility management and conservation, are needed, some of which will require extra inputs.

CONCLUSIONS

The results of this study clearly show that, under the current low-input practices, cassava fields in Kampong Cham province of Cambodia are losing nutrients that are essential for plant growth, particularly N, K and Ca. If such practices are continued for an extended period, soil fertility will decline and future crop yields will also decrease. Cassava production in Cambodia is, therefore, unsustainable under current use of low-input practices. Soil nutrient depletion and exhaustion can be prevented by the application of adequate amounts of chemical fertilizers, organic manures or compost, and by the incorporation of plant tops, green manures or prunings of hedgerows (Howeler and Thai Phien, 2000; Howeler, 2012c). The large negative balances for N and K suggest that chemical fertilizers high in these two elements should be used, and that the current use of diammonium phosphate (DAP) is not very appropriate for cassava. Lime could also be applied to compensate for the loss of Ca, but the use of single- or triple superphosphate would also add considerable amounts of Ca. Organic manures can provide secondary nutrients and micro-nutrients, and help improve soil physical properties. If available, the organic manures should be applied together with lime and chemical fertilizers high in N and K for long-term productivity of cassava cropping systems. With respect to farmer perception, farmers view cassava highly when compared with other potential upland crops. With the expectation of continuing favorable marketing conditions for cassava, farmers are likely to adopt improved technologies capable of sustaining or even further improving their production of cassava, even if this would entail extra input costs.

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Appendix. Dry matter content and nutrient concentrations in various parts of the cassava plant as obtained from published and unpublished data.

Plant part	DM (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Description	Source
Roots	37	1.28	0.08	0.42	0.13	0.10	Branca SC, fertilized	Paula *et al*., 1983
	37	0.97	0.08	1.04	0.15	0.13	Riqueza, fertilized	Paula *et al*., 1983
	37	1.18	0.05	0.30	0.14	0.09	Riqueza, unfertilized	Paula *et al*., 1983
	48	0.83	0.12	0.46	0.04	0.03	CM523-7, fertilized	Cadavid, 1988
	48	0.71	0.09	0.37	0.04	0.05	CM523-7, unfertilized	Cadavid, 1988
	30	0.58	0.07	0.63	0.09	0.07	Rayong 1, fertilized	Sittibusaya,unpublished
	42	0.70	0.10	0.75	0.09	0.05	MCol22, '78/79, fertilized	Howeler, 2012
	37	0.80	0.08	0.71	-	-	MCol 22, '78/79, unfertil.	Howeler, 1985a
		0.81	0.09	0.48	0.20	0.07	MCol 22, '82/83, fertilized	Howeler, 2012
		0.48	0.12	0.73	0.11	0.06	MVen77, '83/84, fertilized	Howeler, 2012
	41	0.28	0.07	0.51	0.05	0.07	MVen77, '83/84, unfertil.	Howeler, 2012
		0.40	0.13	0.79	0.08	0.05	MVen77, '84/85, fertilized	Howeler, 2012
		0.27	0.08	0.49	0.04	0.05	MVen77, '84/85, unfertil.	Howeler, 2012
		1.17	0.14	1.00	0.29	0.10	Rayong 1, '89/90, fertiliz.	Putthacharoen *et al*., 1998
	23	0.82	0.13	1.23	0.25	0.12	Rayong 1, '90/91, fertiliz.	Putthacharoen *et al*., 1998
Av. Roots	**38**	**0.75**	**0.10**	**0.66**	**0.12**	**0.07**		
Tops		2.03	0.13	0.56	0.87	0.22	Branca SC, fertilized	Paula *et al*., 1983
		2.73	0.17	0.72	1.27	0.27	Riqueza, fertilized	Paula *et al*., 1983
		2.60	0.11	0.87	1.83	0.30	Riqueza, unfertilized	Paula *et al*., 1983
		1.20	0.16	0.79	0.52	0.21	CM523-7, fertilized	Cadavid, 1988
		1.21	0.12	0.46	0.43	0.21	CM523-7, unfertilized	Cadavid, 1988
		1.81	0.18	0.86	0.92	0.32	Rayong 1, fertilized	Sittibusaya,unpublished
		1.49	0.13	0.63	0.79	0.29	MCol 22, '82/83, fertilized	Howeler, 2012
		1.46	0.16	0.99	0.80	0.22	MVen77, '83/84, fertilized	Howeler, 2012
		1.17	0.16	0.73	0.34	0.15	MVen77, '84/85, fertilized	Howeler, 2012
		1.43	0.14	0.80	0.50	0.16	MVen77, '84/85, unfertil.	Howeler, 2012
Av. Tops	**~31**	**1.71**	**0.15**	**0.74**	**0.83**	**0.23**		
Stems		0.47	0.12	1.46	0.71	0.16	SãoPedro Preto,	Nijholt, 1935
		0.60	0.36	1.92	0.88	0.07		Krochmal&Samuels, '70
		0.61	0.49	1.13	0.52	0.36		Kanapathy, 1974
	24	1.51	0.17	0.80	0.67	0.25	MCol22, '78/79, fertilized	Howeler&Cadavid, 1983
		1.87	0.35	1.29	1.46	0.61	Rayong 1, '89/90, fertiliz.	Putthacharoen *et al*., 1998
		1.15	0.29	1.08	1.62	0.31	Rayong 1, '90/91, fertiliz.	Putthacharoen *et al*., 1998
Av. Stems	**24**	**1.03**	**0.30**	**1.28**	**0.98**	**0.31**		
Stakes		0.78	0.13	0.27				Lopez&El-Sharkawy,'95
	37	0.54	0.06	0.15	0.26	0.16	Carimagua '81, Average 3 fertilizer treatments	Howeler, unpublished
		1.07	0.10	0.47	0.72	0.19	Quilichao '78, Average 3 fertilizer treatments	Howeler, unpublished
	32	0.54	0.06	0.31	0.50	0.21	Quilichao '79, Average 3 fertilizer treatments	Howeler, unpublished
Av. Stakes	**34**	**0.73**	**0.09**	**0.30**	**0.49**	**0.19**		

SUSTAINABLE CASSAVA PRODUCTION AND SOIL PRODUCTIVITY THROUGH SOIL-BASED NUTRIENT MANAGEMENT: EXPERIENCE FROM A LONG TERM FERTILIZER EXPERIMENT AND FIELD VALIDATION TRIAL IN AN ULTISOL OF KERALA, INDIA

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ABSTRACT

Fertilizer recommendations based on soil nutrient availability and crop needs is one of the methods to increase the fertilizer use and economic efficiency. Soil nutrient availability is usually determined through soil testing, which provides information on the fertilizer requirement of a crop for that nutrient to achieve the crop production goal in addition to maintaining environmental quality.

Cassava is a crop grown by resource-poor farmers with low inputs and the traditional practice of continuous application of manures and fertilizers, which has resulted in a considerable build-up of nutrients like P without significant increases in yield and quality of roots. An effort was therefore made to study the effect of application of manures and fertilizers based on the actual soil nutrient status under the long-term fertilizer experiment underway at ICAR-CTCRI since 1977. In the third phase of this long-term experiment, which was initiated in 2004, a soil test-based fertilizer recommendation (STBF) treatment was included. In this treatment, manure and fertilizer applications varied yearly as their requirements were based on the status of organic carbon and available N, P and K to determine the requirement of N, P and K fertilizers and FYM (farmyard manure). The recommendation of FYM and NPK were evolved based on the above criteria, and in this paper the effect of this treatment for six consecutive years on root yield, root quality parameters, such as starch, cyanogenic glucosides and total dry matter production, as well as soil nutrient status, this is pH, organic carbon, available N, P, K, Ca, Mg, Fe, Cu, Mn and Zn and total plant uptake for the above nutrients were studied by following standard analytical procedures.

The long-term fertilizer experiment was conducted in a typic kandiustult (laterite) with a pH of 4.5-5, medium in organic carbon, while available N and K were low and P was high. For this paper, the STBF treatment was compared with the current standard recommendation known as the Package of Practices (POP), in which NPK was applied at the rate of 100:50:100 kg N, P_2O_5 and K_2O/ha, along with FYM at 12.5 t/ha. The STBF treatment varied from year to year as it was based on soil test data for each of the six years (2005-2010), but on average it consisted of the application of FYM at 8.3 t/ha and NPK at 89:0:67 kg/ha.

The scientific information generated on the superiority of STBF over POP was validated in farmers' fields in two districts of Kerala at 13 locations involving 17 farmers with a mean level of NPK of 80:7:70 kg/ha and FYM at 7 t/ha. The root yield data clearly indicated that, STBF was as effective in increasing yields as POP during all years except in 2007. Due to the lower levels of fertilizers and manures used, the benefit cost ratio was found higher for STBF compared to other treatments. In the case of quality attributes and total plant nutrient uptake, no significant difference was seen, but the quality traits, such as cyanogenic glucosides and starch were found improved by

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the use of STBF. The nutrient status of the soil also followed the same trend with organic carbon and available P registering a significantly lower level without a significant reduction in root yield, suggesting the need to apply fertilizers and manures based on soil nutrient availability.

Hence, the present study will be of immense application from the farmers' point of view to sustain yield, to maintain quality of the produce, to improve the nutrient use efficiency, to increase the farmers' income and to safeguard the environmental quality. Since fertilizer is one of the principle means to achieve global food security, the underlying principles of fertilizer management to use it efficiently and responsibly need to be practiced in all crops and cropping systems to optimize crop productivity as well as to maintain environmental quality

Key words: Root yield, root quality, soil test-based fertilizer recommendation, B:C ratio, secondary and micronutrients

INTRODUCTION

Root and tubers constitute the third most important food crops of man after cereals and grain legumes. They form either the staple or subsidiary food for about one fifth of the world population. They have a higher biological efficiency, and yield as much as 15-50 t/ha. They also have the ability to withstand adverse weather conditions and capacity to yield rather well in poor and marginal soils. These attributes make these crops ideal for cultivation in the less developed and developing countries of Asia, Africa and Latin America. In these countries, they are increasingly valued as a source of income and employment, besides being a food security crop. Globally, cassava is cultivated in an area of 20.73 million ha with a production of 276.72 million tonnes with an average yield of 13.35 t/ha. In India, the crop is grown in an area of 0.21 million ha with a production of 7.24 million tonnes and an average yield of 34.96 t/ha (FAO, 2013). In Kerala, cassava is the secondary staple with an annual production of 2.547 million tonnes from an area of 74,000 ha with a productivity of 34.42 t/ha (Farm Guide, 2014). As the world average cassava yield is only 13.5 t/ha, it is important to develop more effective cultivation technologies for increasing the productivity. Low soil fertility is one of the main constraints in cassava production and the elimination of all soil fertility constraints was estimated to increase cassava yields by 22% in Asia and 21% globally (Henry and Gottret, 1996). There is considerable scope for increasing cassava yields through better nutrient management since it is a crop that responds well to the application of manures and fertilizers.

The primary aim of agriculture is to maximize food production while maintaining the quality of our soil, water and environmental resources. Soil quality, and especially soil fertility is the key component which can be assessed through soil testing. Fertilizer recommendations based on soil nutrient availability and crop needs is one of the methods to enhance nutrient use efficiency. Colwell (1967) emphasized the importance of soil analyses to provide information on fertilizer requirements. As such, an attempt was made to develop manure and fertilizer recommendations for the major cassava growing soils of Kerala based on the fertility status of these soils and to demonstrate to the farmers the environmental and economic benefits of soil test-based fertilizer recommendations (STBFR) over the existing blanket recommendation known as the Package of Practices (POP).

MATERIALS AND METHODS

In order to develop the fertilizer recommendation based on soil and plant test data, the following methodologies/activities were undertaken:

1. Evaluation of the nutrient status of the soil

The fertilizer and manure recommendation based on soil test and plant tissue analysis data was arrived at based on the evaluation of the status of organic carbon, available P, K, Mg and Zn of the soils of the major cassava growing districts of Kerala State. They are briefly summarized below.

a. Rapid appraisal of the nutrient status of cassava growing soils of Kerala

The Central Tuber Crops Research Institute (CTCRI) in Thiruvananthapuram, Kerala, under the Indian Council of Agricultural Research (ICAR), conducted a random survey to evaluate the nutrient status of the major cassava growing soils of Kerala in order to develop fertilizer and manure recommendations based on soil data. Hence, districts having more than 5000 ha of cassava cultivation were selected for the study. In each selected district, the major blocks (sub districts) growing cassava and in each selected block, the main panchayats (villages) where cassava is a main crop were identified. In each panchayat, the agricultural officers were contacted and farmers were chosen. A total of 226 soil samples were collected at a depth of 0-20 cm representing 104 uplands/garden lands and 122 lowlands/wet lands.

b. Evaluation of the nutrient status of the soil used for growing cassava and the nutrient concentration in the cassava plants

CTCRI, in collaboration with Kerala State Land Use Board (KSLUB), evaluated the soil fertility status of the nine major cassava growing districts of Kerala. Soil samples were collected from the identified farmers' fields by KSLUB. Similarly, cassava tissue samples were also collected from the index leaf tissue, which is the youngest fully expanded leaf (YFEL) blade at 3-4 months after planting (MAP).

c. Long-term fertilizer experiment at CTCRI

A long-term fertilizer experiment had been initiated at ICAR-CTCRI in 1977 and the third phase of this experiment was started in 2004. In this phase, a soil test-based fertilizer recommendation (STBFR) treatment was included based on the annual collection and analyses of soil samples taken from the respective plots at a depth of 0-20 cm.

The soil samples collected from the selected farmers' fields and experimental plots were analyzed for pH using 1:2.5 soil:water suspension (Jackson, 1973). Available nitrogen (N) and phosphorus (P) were estimated by the alkaline permanganate method (Subbiah and Asija, 1956), and the molybdenum blue color method (Bray No.1) extract (Bray and Kurtz, 1945), respectively. Available potassium (K), calcium (Ca) and magnesium (Mg) were determined by extraction with neutral 1N ammonium acetate and direct reading in a flame photometer (Hanway and Heidal, 1952). Available sulfur (S) was determined by calcium chloride ($CaCl_2$) extraction followed by turbidimetric estimation (Tabatai, 1982). Of the micronutrients, iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) were determined by diethylene triamine-penta-acetic acid (DTPA) extraction (Lindsay and Norvell, 1978) followed by reading in an atomic absorption spectrophotometer (Analyst 100). The nutrient contents of the index leaf tissue were determined by di-acid digestion followed by standard procedures (Piper, 1970).

2. Criteria for categorization of the soil based on soil and plant analysis data

The soil samples collected were categorized based on different approaches:

a. General rating

For classification of soil into different fertility classes, the general rating proposed by Dev (1997) and Motsara (2002) were adopted and is given in **Table 1**.

Table 1. General rating of soils based on nutrient status as determined by the methods described above.

Nutrient	Low	Medium	High	Deficient	Sufficient	Reference
Organic carbon (%)	<0.5	0.5-0.75	>0.75	-	-	Dev (1997)
Available N (kg/ha)	<280	280-560	>560			Dev (1997)
Available P (kg/ha)	<10	10-25	>25	-	-	Dev (1997)
Available K (kg/ha)	<110	110-280	>280	-	-	Dev (1997)
Exchang. Ca (meq/100 g)	-	-	-	<1.5	≥1.5	Dev (1997)
Exchang. Mg (meq/100 g)	-	-	-	<1.0	≥1.0	Dev (1997)
Available Fe (ppm)	-	-	-	<4.0	4-6	Motsara (2002)
Available Cu (ppm)	-	-	-	<0.2	≥0.2	Motsara (2002)
Available Mn (ppm)	-	-	-	<3.00	≥3.00	Motsara (2002)
Available Zn (ppm)	-	-	-	<0.6	≥0.6	Motsara (2002)

b. Computation of soil nutrient index

The soil nutrient index (SNI), as suggested by Parker *et al*. (1951), was calculated by giving weights to the number of samples falling in low, medium and high fertility classes following the formula:

$$SNI = \frac{(Nl \times 1) + (Nm \times 2) + (Nh \times 3)}{Nt}$$

where Nl, Nm, Nh and Nt are the number of samples in low, medium, high fertility classes and total number of samples, respectively. Based on the SNI computation, organic carbon, available N, P and K status were rated as low (<1.67), medium (1.67-2.33) and high (>2.33). The available N is based on the organic C status.

c. Classification based on soil nutritional requirements of cassava

According to Howeler (1996), the soils can also be classified based on the soil nutritional requirement for cassava as shown in **Table 2**.

Table 2. Approximate classification of soil chemical characteristics according to the nutritional requirements of cassava.

Soil parameter	Very low	Low	Medium	High	Very high
pH[1)]	<3.5	3.5-4.5	4.5-7	7-8	>8
Organic matter (%)[2)]	<1.0	1.0-2.0	2.0-4.0	>4.0	-
P (ppm)[3)]	<2	2-4	4-15	>15	-
K (meq/100 g)[3)]	<0.10	0.10-0.15	0.15-0.25	>0.25	-
Ca (meq/100 g)[3)]	<0.25	0.25-1.0	1.0-5.0	>5.0	-
Mg (meq/100 g)[3)]	<0.2	0.2-0.4	0.4-1.0	>1.0	-
S (ppm)[3)]	<20	20-40	40-70	>70	-
Cu (ppm)[4)]	<0.1	0.1-0.3	0.3-1.0	1-5	>5
Mn (ppm)[4)]	<5	5-10	10-100	100-250	>250
Fe (ppm)[4)]	<1	1-10	10-100	>100	
Zn (ppm)[4)]	<0.5	0.5-1.0	1.0-5.0	5-50	>50

[1)] pH in H_2O. 1:1
[2)] OM = Walkley and Black method.
[3)] P in Bray II; K, Ca and Mg in 1N NH_4-acetate; S in Ca phosphate.
[4)] Cu, Mn, Fe and Zn in 0.05 N HCl+0.025 N H_2SO_4.

d. Classification based on plant nutritional requirements of cassava

The nutrient concentration in the indicator tissue, that is the youngest fully-expanded leaf (YFEL) blades at 3-4 months after planting, was taken as the criteria to evaluate the nutritional status of the cassava plants according to the classification of Howeler (1996), which is shown in **Table 3**.

Table 3. Nutrient concentrations in YFEL blades of cassava at 3-4 months after planting.

	Nutritional status					
Nutrient	Very deficient	Deficient	Low	Sufficient	High	Toxic
N (%)	<4.0	4.1-4.8	4.8-5.1	5.1-5.8	>5.8	-
P (%)	<0.25	0.25-0.36	0.36-0.38	0.38-0.50	>0.50	-
K (%)	<0.85	0.85-1.26	1.26-1.42	1.42-1.88	1.88-2.40	>2.40
Ca (%)	<0.25	0.25-0.41	0.41-0.50	0.50-0.72	0.72-0.88	>0.88
Mg (%)	<0.15	0.15-0.22	0.22-0.24	0.24-0.29	>0.29	-
S (ppm)	<0.20	0.20-0.27	0.27-0.30	0.30-0.36	>0.36	-
Cu (ppm)	<1.5	1.5-4.8	4.8-6.0	6-10	10-15	>15
Fe (ppm)	<100	100-110	110-120	120-140	140-200	>200
Mn (ppm)	<30	30-40	40-50	50-150	150-250	>250
Zn (ppm)	<25	25-32	32-35	35 -57	57-120	>120

3. Development of fertilizer recommendation based on soil test and plant tissue analysis

a. Major nutrients (N, P and K)

The blanket recommendation according to the Package of Practices (POP) for cassava is NPK at 100:50:100 kg/ha plus FYM at 12.5 t/ha. In the case of fertilizer recommendations based on soil test data in Kerala, the methodology proposed by Aiyer and Nair (1985) is followed for all crops and is given in **Table 4**.

Table 4. Soil fertility classes and N, P, K recommendation for each class as per cent of the general recommendation.

Soil fertility class	Organic carbon (clayey/loamy soil) (%)	Recommendation of N as % of general (POP) recommendation	Available P (kg/ha)	Exchangeable K (kg/ha)	Recommendation of P and K as % of general (POP) recommendation
0	0.00-0.16	128	0.0-3.0	0-35	128
1	0.17-0.33	117	3.1-6.5	36-75	117
2	0.34-0.50	106	6.6-10.0	76-115	106
3	0.51-0.75	97	10.1-13.5	116-155	94
4	0.76-1.00	91	13.6-17.0	156-195	83
5	1.01-1.25	84	17.1-20.5	196-235	71
6	1.26-1.50	78	20.6-24.0	236-275	60
7	1.51-1.83	71	24.1-27.5	276-315	48
8	1.84-2.16	63	27.6-31.0	316-355	37
9	2.17-2.50	54	31.1-34.5	356-395	25

b. *Organic manure (FYM), secondary nutrient (Mg) and micronutrient (Zn) recommendations based on soil test data*

Based on the results obtained in the long-term fertilizer trial conducted at ICAR-CTCRI since 1990, the rate of application of Mg as magnesium sulfate ($MgSO_4$), Zn as zinc sulfate ($ZnSO_4$), and organic manure as farm yard manure (FYM), were standardized based on the data on root yield, soil nutrient status, plant nutrient concentration, their critical levels and nutritional requirements (Susan John *et al*., 2010) as shown in **Table 5**.

Table 5. Rate of application of FYM, Mg and Zn for cassava based on soil nutrient status.

Organic carbon (%)	Rate of application of FYM (t/ha)	Soil status of Mg (meq/100 g)	Rate of application of $MgSO_4$ (kg/ha)	Soil status of Zn (ppm)	Rate of application of $ZnSO_4$ (kg/ha)
<0.50	12.50	0-0.25	20	<0.2	12.5
0.5-0.75	10.00	0.25-0.50	15	0.2-0.3	10
0.75-1.00	7.50	0.50-0.75	10	0.3-0.4	7.5
1.00-1.50	5.00	0.75-1.00	5	0.4-0.6	5
>1.50	2.50	>1.00	2.5	>0.6	2.5

4. Field validation of the soil test-based fertilizer recommendation

The validation and demonstration of soil test-based fertilizer recommendations was undertaken through a State Horticulture Mission (SHM) funded project during 2007-2009 in 13 locations of the two selected districts of Kerala, this is Kollam and Pathanamthitta involving 17 farmers in an area of 5.28 ha. Soil samples collected before laying out the trial from these locations were analyzed for organic carbon, available P, K, Mg and Zn following standard analytical procedures (Jackson, 1973). The rate of application of N, P and K was determined following the earlier procedure of Aiyer and Nair (1985) and in the case of FYM, Mg and Zn as per Susan John *et al*. (2010) shown in **Tables 4** and **5**, respectively. The validation trials consisted of five treatments as follows:

T1- Farmer's practice
T2- Package of Practices (POP) recommendation for cassava (NPK at 100:50:100 kg/ha plus FYM at 12.5 t/ha)
T3- Application of FYM+ NPK and Mg based on soil test data
T4- Application of FYM+ NPK and Zn based on soil test data
T5- Application of FYM+ NPK based on soil test data

Root yields and root quality parameters, that is cyanogenic glucosides (Indira and Sinha, 1969), root starch (Chopra and Kanwar, 1976) and dry matter contents were determined. The economics of STBFR with and without the application of Mg and Zn was also computed by calculating parameters like gross income, production costs, net income and B/C ratios.

RESULTS AND DISCUSSION

The results obtained under the different activities on nutrient requirements, that is the assessment of the fertility status of the soil, the recommendation arrived at based on soil and plant analytical data, and the impact of STBFR in comparison to POP on yield in the on-station replicated long-term fertilizer experiment at CTCRI, and in the validation trials in different farmers' fields are briefly discussed below.

1. Evaluation of the nutritional status of cassava growing soils of Kerala

The rapid appraisal of the nutrient status of nine major cassava growing districts, conducted by ICAR-CTCRI, indicated wide variation in all the soil chemical characteristics including primary, secondary and micronutrient status, although there was not much difference between the upland and lowland soils within the same district. Both upland and lowland soils were acidic in soil reaction with mean pH values of 4.65 and 4.76, respectively. There are several reports indicating that, the soils of Kerala are acidic belonging to laterite soil type where cassava is a suitable crop as it is tolerant to high levels of aluminium (Al) and Mn and low levels of Ca, N and K (Nair *et al*., 2007; Natarajan *et al*., 2005; Soil Survey Organization, 2007).

With respect to the general rating, the evaluation of the nutrient status of the soils indicate that, the soil organic carbon status of the different districts ranged from low to high with a mean high status for the State, and the available N status was low to medium in the different districts with a mean low status for the State. The available P was high in 90-95% of the surveyed area indicating a very high content for the State as a whole, while the exchangeable K of the soils in the different districts ranged from low to high with a mean medium status for the State as a whole (Susan John *et al.,* 2009a). The exchangeable Ca content of the surveyed districts ranged from 0.52-2.06 meq/100 g with a mean value of 1.12 meq/100 g. However, in 75% of the appraised districts based on the general soil critical level (1.5 meq/100 g), the status was not sufficient. As regards to the exchangeable Mg status, the content ranged from 0.23-1.96 meq/100 g with a mean value of 0.90 meq/100 g, which was slightly below the critical level of 1 meq/100g. The status was sufficient in 50% of the surveyed districts according to the general critical level of 1 meq/100 g for Indian soils. In the case of micronutrients, that is Fe, Cu, Mn and Zn, based on the general critical levels, they were sufficient in 100% of the surveyed districts (Susan John *et al*., 2009b).

In the case of soil samples collected by KSLUB in collaboration with ICAR-CTCRI, the general rating indicated that, the nine districts belonged to the moderately acidic class (4.5-5.5) with organic carbon ranging from medium to high in 90% of the districts. The available N status of all the nine districts was low, but the P status was found high. Though the available K status of the cassava growing soils of Kerala in general was medium, the districts ranged from low to medium in available K except in a few districts where it was high, in a range of 0.35-0.62 meq/100 g. The exchangeable Ca status in all the districts was sufficient having values above the critical level. The available Mg status of the soils in all the districts was low. The S status was also found high in all these districts, with values well above the general critical level of 5 ppm for Indian soils, as determined with $CaCl_2$, which is different from the methods used in the classification shown in **Table 2**. The micronutrient status of the soils of all these districts was satisfactory with their status well above their respective critical levels (**Table 6**).

Regarding the computed Soil Nutrient Index (SNI), the cassava growing soils of Kerala were found to be medium in organic carbon (2.02) and K (2.12), low in N (1.37) and high in P (2.41). The SNI for organic carbon ranged from 1.17-3.00 with a mean value of 2.02, indicating that 56% of the surveyed area was considered high, 33% medium and 11% low. The SNI for available N was in the range of 1-2 for the uplands and lowlands of the different districts with 72% of the surveyed area belonging to low and 28% of the area in the medium category. In the case of available P, the SNI indicated a range of 2-3 with a mean value of 2.41, with 61% of the surveyed area considered to be in the high and 39% in the medium category. The SNI for exchangeable K had a value of 1-3 for the different districts with a mean value of 2.12, with 11, 50 and 39% of the surveyed area found to be in the low, medium and high classes, respectively (Susan John *et al.,* 2009a). In the case of all these nutrients, the high status was encountered mainly in the high altitude areas of Kerala, like in the districts of Kottayam, Idukki, Palakkad and Pathanamthitta, which can be attributed to their cropping history of rubber plantations. The shedding of their leaves may have contributed to the high nutrient status of the soils, which in turn may have favored cassava growth and productivity (Joseph *et al.,* 1990; Karthikakuttyamma *et al*., 1991). Since cassava requires soils rich in organic matter with high contents of basic cations for both root yield and quality, the soils of Kottayam, Idukki, Palakkad and Pathanamthitta were found to be the best for growing cassava (Susan John *et al.,* 2009a).

ICAR-CTCRI in collaboration with the Kerala State Land Use Board evaluated the soil fertility status of the nine major cassava growing districts of Kerala and these were categorized based on the soil and plant nutritional requirements for cassava as suggested by Howeler (1996). The results are presented in **Tables 6** and **7**. The nutritional status of the soils in these nine districts ranged from very low to high with respect to all nutrients. In all these districts, the soils were medium in soil pH while the organic carbon status ranged from very low to medium, and the available P content was high. In the case of available K, the levels ranged from low to high. Among the secondary nutrients, the exchangeable Ca was medium in all districts, except in three districts, where it was low. The exchangeable Mg status was also in the medium range in all the districts except in two districts where it was low, while the S status of these soils was found very low in all districts, except in one where it was low. As regards to the micronutrient status, Fe was medium, Cu was high, Mn was very low to medium, and Zn was also low to medium. As regards to the overall status of these nutrients for Kerala, the soil pH, available Ca, Mg, Fe, Mn and Zn were medium; organic carbon was low; and P, K and Cu were high.

Table 6. Nutrient contents of the soils in the major cassava growing districts of Kerala.

	pH	OC	N	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn
Districts		%	kg/ha		me/100 g			ppm				
Trivandrum	4.57	0.93	266	35.3	0.24	1.24	0.38	7.65	57.9	3.77	9.2	1.16
Kollam	5.26	1.42	114	58.3	0.15	1.52	0.42	8.22	70.1	2.65	5.7	1.04
Kottayam	5.24	1.49	210	41.5	0.39	2.79	0.53	9.09	37.6	3.70	10.6	2.16
Pathanamthitta	4.51	1.23	226	30.0	0.21	1.01	0.39	6.75	49.8	5.07	14.7	1.04
Alapuzha	5.00	0.55	195	92.3	0.29	0.98	0.80	6.59	56.3	0.99	4.8	0.90
Ernakulam	4.49	1.50	245	67.5	0.13	1.66	0.44	20.16	70.8	3.63	11.9	0.95
Thrissur	5.09	0.66	137	65.5	0.35	1.87	0.76	8.88	46.1	4.38	30.6	1.23
Kozhikode	5.20	0.40	51	93.9	0.15	2.00	0.42	5.65	25.3	1.38	16.6	2.34
Malappuram	5.65	1.68	206	65.5	0.62	2.95	0.84	8.88	48.4	3.30	17.9	2.73
Mean	**5.00**	**1.09**	**183**	**61.1**	**0.28**	**1.78**	**0.55**	**9.10**	**51.4**	**3.21**	**13.6**	**1.50**

Table 7. Nutrient concentrations in the youngest fully expanded leaf blades of cassava at 3-4 months after planting.

	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn
Districts	(%)					(ppm)				
Trivandrum	4.79	0.462	1.91	0.33	0.311	0.098	19.06	56.03	643.03	490.00
Kollam	3.70	0.370	1.90	1.16	0.309	0.090	14.10	55.43	208.80	269.50
Kottayam	3.96	0.502	1.76	0.93	0.183	0.096	13.71	57.26	316.17	166.40
Pathanamthitta	4.18	0.448	2.14	0.59	0.287	0.091	12.94	70.06	192.06	340.91
Alapuzha	3.33	0.361	1.65	0.64	0.370	0.087	14.28	44.72	261.03	816.00
Ernakulam	5.13	0.502	2.05	0.48	0.293	0.089	15.65	56.85	218.85	184.35
Thrissur	5.22	0.427	1.99	0.28	0.290	0.089	8.30	57.45	173.55	325.40
Kozhikode	3.49	0.451	1.90	0.40	0.355	0.096	13.00	51.60	217.20	604.80
Malappuram	3.23	0.325	2.68	1.10	0.466	0.130	22.20	58.20	458.39	215.30
Mean	**4.11**	**0.428**	**2.00**	**0.66**	**0.318**	**0.096**	**14.80**	**56.40**	**298.79**	**379.18**

Based on the classification made by Howeler (1996) (**Table 3**), the analyses of the indicator tissue at 3-4 months after planting (**Table 7**), indicates that, in general the concentrations of N and Ca were deficient; P, K, Mg, Cu and Zn were sufficient, and Fe and Mn concentrations were very high or toxic. The unusually low concentrations of S, as compared to the values shown in **Table 3**, may be due to the use of a different analytical procedure. No symptoms of S deficiency have been observed.

2. Soil test and plant tissue analysis based fertilizer recommendation for the major cassava growing districts of Kerala

The usefulness of soil test data as a guide in making fertilizer recommendations was suggested by many researchers (Goswami *et al*., 1971). But Baker (2008) was of the opinion that, as there is a great variability among soils of different areas, it has not been possible to formulate uniform recommendations for a given soil and crop. Hence, an attempt was made to formulate fertilizer recommendations for the above districts for cassava comprising of farmyard manure, N, P, K and Mg and Zn using the procedures indicated earlier and as shown in **Table 8**.

Table 8. Fertilizer recommendations for nine major cassava growing districts in Kerala State based on soil tests and plant tissue analysis.

Districts	Organic manure	N	P_2O_5	K_2O	$ZnSO_4$	$MgSO_4$
	(t/ha)	(kg/ha)				
Trivandrum	12.0	107	25.0	79	5.0	5.7
Kollam	10.5	125	26.0	104	6.2	10.0
Kottayam	11.5	117	21.0	35	9.0	5.7
Pathanamthitta	12.0	115	28.0	85	3.4	12
Alapuzha	12.0	117	7.0	76	3.6	3.6
Ernakulam	12.5	113	5.0	99	8.0	0
Kozhikode	12.5	125	0	95	0	0
Malappuram	10.0	130	17.5	0	0	0
Thrissur	12.5	110	12.0	48	3.0	5
Mean	**12.0**	**118**	**16.0**	**69**	**4.35**	**4.70**

Compared to the POP recommendation for cassava (FYM at 12.5 t/ha along with chemical NPK fertilizers at the rate of 100:50:100 kg/ha, Mg at 3.2 kg/ha, Zn at 2.5 kg/ha), the STBFR-based recommendation included on average, the application of only 12 t/ha of manure, together with a slightly higher application of 118 kg N/ha, whereas the P, K, Mg and Zn recommendations were lower compared to the blanket POP recommendation. The recommendation indicated that, though the organic carbon status of the soils of the different districts are medium to high, resulting in not much reduction in FYM application, a comparatively high N requirement compared to POP was due to the low inherent status of N in these soils, as evidenced from the results of samples collected from the nine districts both by ICAR-CTCRI and also in collaboration with KSLUB (**Table 6**) as well as the low N content noticed in the indicator leaf tissues. The medium to high available P status in 90% of the surveyed districts suggested the possibility of reducing the application of P as indicated in **Table 8**. This is in conformity with the reports of Nambiar (1994) and Singh *et* *al.* (1998) that, in many long-term fertilizer trials the build-up of P reached a level where no more phosphate application was needed for the next few seasons. The high K content noticed in the soil as well as in the plant tissues resulted also in a lower recommended rate of application of K.

Though the Ca status of these soils were found deficient in more than 50% of the surveyed districts, as the response of cassava to lime application tend to be small due to the fact that, cassava is Al tolerant and Ca efficient (Edwards and Kang, 1978), there is no need to apply lime (Susan John and Venugopal, 2006). In the case of Mg, Howeler (1996) reported 0.2-1.0 meq/100 g to be the adequate range of soil Mg, which makes it likely that in many districts there will be a response to its application. Hence, the data on Mg status of both the soils and plant tissues of the different districts clearly indicated the need to apply $MgSO_4$ in these soils at the rate of 4-12 kg/ha, considerably below the general recommended application of $MgSO_4$ at 20 kg/ha. Susan John *et al.* (2005) reported that cassava absorbs 25-35 kg/ha Mg from the soil, which may cause depletion of both native and applied Mg through plant uptake and leaching.

In the case of Zn, based on the results from the long-term fertilizer experiment, it was recommended to apply $ZnSO_4$ at the rate of 12.5 kg/ha (Susan John *et al*., 2005). The Zn status in the lowland and upland soils of the districts surveyed showed that, these soils contain sufficient Zn, based on the soil critical level of 0.6 ppm as reported by Dev (1997). Hence, the Zn status of the soil indicates that, there is no need for its application. However, taking into account the Zn uptake by cassava at1-2 kg/ha (Susan John *et al*., 2005) and the additional yield gain as well as root quality improvement observed, the recommended rates of Zn application were calculated (**Table 8**). According to Howeler (1996), Zn has to be applied when the soil Zn status ranges from 0.5-5.0 ppm. In this case, based on both soil Zn status and plant Zn concentration, the rate of application of $ZnSO_4$ ranged from 3-9 kg/ha. In a fertilizer recommendation comprising organic manure, major, secondary and micronutrients, the significance of secondary and micronutrients was highlighted by Portch and Stauffer (2005). They suggested that, basing fertilizer recommendations on incomplete analyses, ignoring micro- and secondary-nutrients, may lead to low yields.

3. A comparison of STBFR with POP

In the long-term fertilizer experiment at CTCRI, one treatment using a soil test-based fertilizer recommendation (STBFR) for organic manure, N, P and K has been included since 2004, using the same procedure as in Kerala (Aiyer and Nair, 1985). During the following six years, the organic carbon content of the soil was found to be high (>0.5%), so the recommendation for FYM was reduced to the level of 7.5-10 t/ha with an overall mean value of 8 t/ha. In the case of N and K, the overall average STBFR of 92 and 67 kg/ha, respectively, was lower during all these years compared to POP. Also, the available P status of the soil remained very high, hence its application was completely omitted (**Table 9**).

Comparing the root yields of treatments using POP, STBFR and the absolute control (AC), it is seen that, during all these years, with 100% savings in P fertilizer, 3-9% savings in N, 6-75% savings in K fertilizer and 25% savings in organic manure, the yields obtained using POP or STBF were not statistically different, indicating the need to make fertilizer recommendations for cassava based on the soil's nutrient status. There are several reports showing the significance of balanced fertilizer application including FYM in maintaining high root yields and root quality (Asokan *et al.,* 1988; Susan John *et al*., 1998).

Table 9. Comparison of fertilizer application based on Soil Test-Based Fertilizer Recommendation (STBFR) with the application based on the previously recommended Package of Practices (POP) in the long-term fertilizer experiment at ICAR- CTCRI in Thiruvananthapuram, Kerala.

	Soil test results in the STBF treatment			Soil test-based fertilizer and manure recommendation				Root yield			
Year	Or.C	P	K	FYM	N	P_2O_5	K_2O	POP	STBF	AC	CD
	(%)	kg/ha		t/ha	kg/ha			t/ha			0.05
2004-05	0.706	56.3	145.6	10	97	0	94	22.81	20.41	16.19	2.52
2005-06	0.897	158.1	206.1	7.5	91	0	71	23.80	23.55	17.02	3.09
2006-07	0.915	139.9	233.0	7.5	91	0	71	12.62	15.85	6.58	2.00
2007-08	0.778	80.8	192.6	7.5	91	0	83	30.96	31.06	18.00	3.20
2008-09	0.939	56.5	267.5	7.5	91	0	60	31.02	26.16	13.08	7.93
2009-10	0.931	82.5	400.3	7.5	91	0	25	29.23	26.24	15.93	8.09
Mean	**0.861**	**95.7**	**240.8**	**8.0**	**92**	**0**	**67**	**25.07**	**23.88**	**14.47**	**4.47**

FYM=farmyard manure; POP=Package of Practices, STBF=Soil Test-Based Fertilizer Recommendation, AC=Absolute Control (no fertilizers and manures); CD=coefficient of determination

The change of the soil nutrient status with respect to organic carbon, available N, P and K using either POP or STBFR are shown in **Figures 1, 2, 3** and **4**. It can be seen that, there was a slight to drastic decline in the level of all these nutrients except in the case of available N during two years.

4. Validation and popularization trial for STBFR in cassava

In this demonstration trial, the organic manure and fertilizer recommendations were made based on the initial nutrient status of the soil with respect to organic carbon, available P, K, Mg and Zn. The location and nutrient status of these sites, as well as the soil test-based fertilizer recommendation are presented in **Table 10**.

In general, the soil organic carbon and P levels in these locations of the two districts were found to be very high, whereas the K, Mg and Zn levels were low indicating a recommendation comprising of a comparatively lower rate of application of organic manure and N at about 6 t/ha and 80 kg/ha, respectively, and P at only 7 kg/ha. Since the content of Mg and Zn were found to be very low in these locations (well below their critical levels of 1 meq/100 g and 0.6 ppm for Mg and Zn, respectively), all these locations needed their application at 2.5-20 and 2.5-12.5 kg/ha of Mg- and Zn-sulfates, respectively.

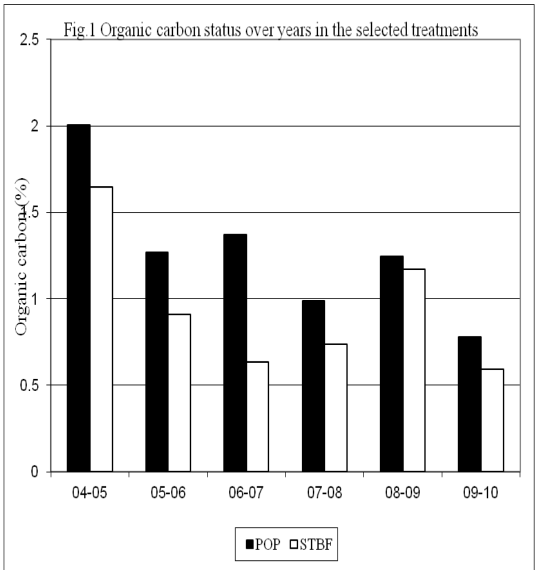

Fig.1 Organic carbon status over years in the selected treatments

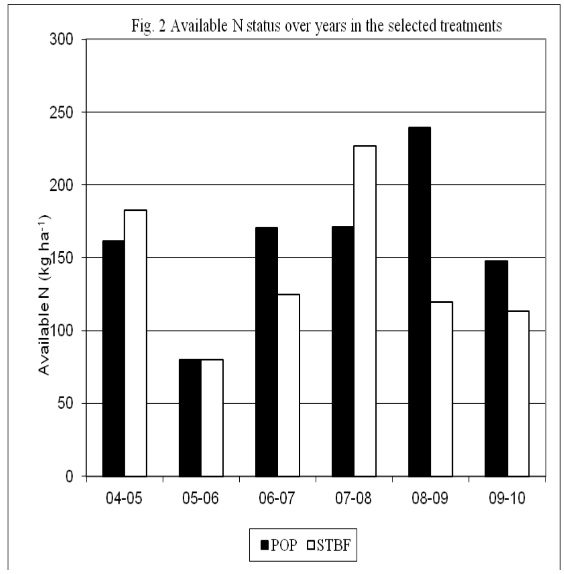

Fig. 2 Available N status over years in the selected treatments

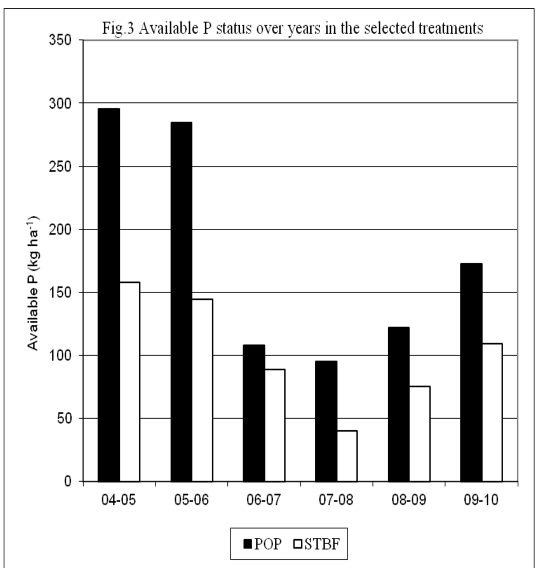

Fig.3 Available P status over years in the selected treatments

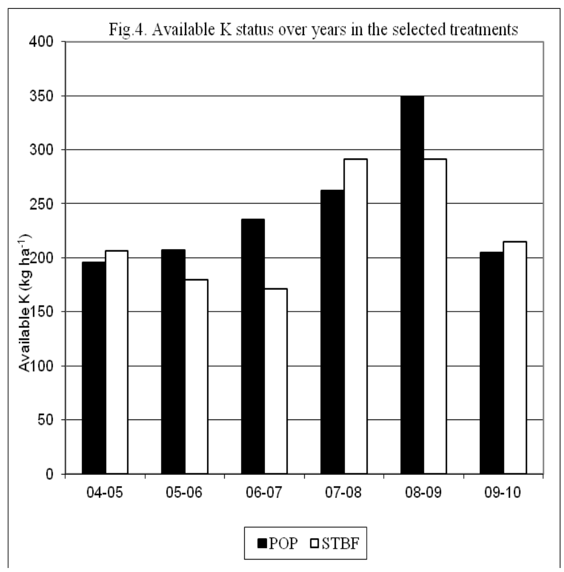

Fig.4. Available K status over years in the selected treatments

The effect of these treatments on cassava root yield and quality parameters, i.e. dry matter, starch and cyanogenic glucosides contents, and economic parameters such as gross income, production costs, net income and B/C ratio were also studied and the average results are shown in **Table 11.**

Table 10. Nutrient status of selected locations and soil test-based fertilizer recommendations.

	Locations	Soil test results					Soil test-based fertilizer recommendations					
I	**Kollam**	OC	P	K	Mg	Zn	FYM	N	P	K	Mg	Zn
1	Sakthikulangara	0.46	58.9	191.2	0.66	0.66	12.5	91	0	83	10	2.5
2	Chadayamangalam	1.92	24.9	212.8	0.62	0.24	5	63	24	71	10	10
3	Kadakkal	1.02	216.2	349.4	0.35	0.57	5	84	0	37	15	5
4	Anchal	1.29	133.4	439.0	0.29	0.37	5	78	0	25	15	7.5
5	Ezhukone	2.40	39.2	78.4	0.48	0.85	5	54	0	106	15	2.5
6	Kalayapuram	1.18	203.2	268.8	0.20	0.24	5	84	0	60	20	10
7	Panaveli	1.14	110.2	185.9	0.36	0.55	5	84	0	83	15	5
8	Pallickal	1.08	123.7	145.4	0.26	0.19	5	84	0	83	15	12.5
II	**Pathanamthitta**											
9	Adoor	1.44	83.0	206.1	2.21	0.25	5	78	0	71	2.5	10
10	Thumpamon	1.02	27.5	199.4	0.51	0.26	5	84	24	71	10	10
11	Thumpamon	1.08	51.2	190.4	0.34	0.58	5	84	0	83	15	5
12	Elanthur	1.56	200.4	306.9	0.49	0.37	5	71	0	48	15	7.5
13	Adoor	0.72	12.6	165.8	0.20	0.86	10	97	47	83	20	2.5
	Mean	**1.26**	**98.8**	**226.1**	**0.54**	**0.46**	**6**	**80**	**7**	**70**	**13.65**	**7.0**

The data in **Table 11** showed that, the soil test-based fertilizer treatment (T4) applied as FYM at the rate of 6 t/ha, NPK fertilizers at 80:7:70 kg/ha, and $ZnSO_4$ at 7 kg/ha resulted in the highest root yield of 42.19 t/ha. This was not significantly different from the soil test-based application of organic manure and NPK fertilizers along with Mg as $MgSO_4$ at 13.65 kg/ha (T3). The soil test based application of FYM at 6 t/ha together with NPK at 80:7:70 kg/ha (T5) resulted in a root yield of 34.63 t/ha, which in turn was statistically equivalent to the POP treatment in which FYM was applied at 12.5 t/ha along with NPK at 100:50:100 kg/ha (T2), which resulted in a yield of 33.18 t/ha. Among the five treatments, the farmers' practice, using mostly organic manures in the form of FYM, bone meal and ash along with chemical fertilizers like Factomphos (NPKS at 20:20:0:15) and potassium chloride, applied in comparatively large quantities, equivalent to NPK of about 125:100:150 kg/ha (T1), resulted in the lowest root yield of 28.95 t/ha. Kamaraj *et al.* (2008) also reported cassava root yield increases by 23-34% through the application of major, secondary and micro-nutrients based on soil test data in two villages of Tamil Nadu. Moreover, balanced nutrient application in pulses – mainly green gram and black gram −

with the required quantity of micronutrients along with macronutrients was found to be an effective way for getting higher grain yields of these crops in red and lateritic soils (Bhattacharya *et al*., 2004), and in rainfed rice in West Bengal (Mukhopadhyay *et al*., 2008), and in sugarcane in Uttar Pradesh (Singh *et al*., 2008). According to Sharma and Biswas (2007), the investments in macronutrients alone will not give the desired results unless the micronutrient deficiencies are corrected. Ghosh *et al*., (2008) in West Bengal also reported the importance of soil test-based nutrient management in a rice-based cropping sequence to attain targeted yields, and they confirmed that compared to state recommended rates, the approach based on soil testing did lead to higher crop yields, net returns and relative agronomic efficiencies.

Table 11. Influence of various soil test-based nutrient management treatments on cassava root yield, root quality and economic parameters.

Treat-ments[1)]	Root yield (t/ha)	Root quality			Economic parameters			
		Dry matter (%)	Starch content (%)	Cyanogenic glucosides (ppm)	Gross income (Rs/ha)	Production costs (Rs/ha)	Net income (Rs/ha)	B:C ratio
T1	28.95	35.53	21.48	56.12	72,365	66,451	5,914	1.09
T2	33.18	35.41	22.96	53.58	89,960	65,512	17,448	1.27
T3	38.84	37.88	23.08	37.88	97,110	60,011	37,099	1.62
T4	42.19	38.03	21.16	34.08	1,05,468	60,343	45,125	1.75
T5	34.63	35.28	21.16	43.62	86,563	59,692	26,871	1.45
CD (0.05)	4.21	0.60	1.11	3.75	-	-	-	-

1) T1 = Farmer's Practice: FYM, bone meal and wood ash plus ~125:100:150 kg/ha of $N:P_2O_5:K_20$
T2 = POP: 12.5 t/ha of FYM plus 100:50:100 kg/ha of $N:P_2O_5:K_20$
T3 = STBFR: 6 t/ha of FYM plus 80:7:70 kg/ha of $N:P_2O_5:K_20$ plus 13.65 kg/ha of $MgSO_4$
T4 = STBFR: 6 t/ha of FYM plus 80:7:70 kg/ha of $N:P_2O_5:K_20$ plus 7 kg/ha of $ZnSO_4$
T5 = STBFR: 6 t/ha of FYM plus 80:7:70 kg/ha of $N:P_2O_5:K_20$

As regards to the quality attributes, the root dry matter content was highest with Zn application, which in turn was on par with the additional application of Mg. In the case of the other three treatments, they were on par with respect to dry matter production. Starch content of the roots was highest with Mg (23.08%), which in turn was on par with the POP treatment (22.96%). The effect of all other treatments was similar with respect to starch yield. Application of Zn resulted in the lowest cyanogenic glucoside content of 34.08 ppm followed by the Mg treatment (37.88 ppm). The farmer's practice and POP treatments resulted in the highest levels of cyanogenic glucosides, while this was significantly lower (43.62 ppm) in the roots in the STBFR treatment. This is in agreement with the reports by Yadav (1993) that sugar recovery was higher due to balanced and judicious application of manures and fertilizers based on soil test data in sugarcane.

The economic parameters, such as gross income, total production costs, net income and B:C ratio indicate that, the highest gross income, net income and B:C ratio were obtained with the additional application of Zn (T4) followed by the treatment with Mg (T3). Treatment T5, having a lower level of organic manure and NPK than the POP treatment (T2), resulted in a higher B:C ratio of 1.45 compared to 1.27 in the case of T2 (Susan John *et al*., 2011). All these parameters thus clearly point out the need for changing the present blanket POP fertilizer recommendation to a more need-based recommendation based on soil tests and plant analytical data.

5. Nutrient management plan for agro ecosystems of Kerala

The Department of Agriculture of the Government of Kerala, in collaboration with 14 agricultural governmental institutions involving 27 soil testing laboratories are involved in developing a soil test-based nutrient management plan for 23 agro-ecological units of Kerala. Under this program, analysis of around 150,000 soil samples, out of a total of 225,000 soil samples collected, indicated the deficiencies of secondary nutrients, Ca and Mg, and the micronutrient B. The very high level of organic carbon, P, S and other micronutrients such as Fe, Cu, Mn and Zn was reflected in their respective recommendations indicating the need either to reduce their dose or to omit their use entirely. The nutrient management plan being prepared for the different panchayats, blocks and districts indicated the need to rationalize the existing fertilizer recommendation based on soil and plant analyses. The present nutrient management plan preparation based on soil test data is a web-based agricultural information system with facilities to get information on independent farmer details including the rate, time, type and method of application of soil amendments, organic manures and fertilizers including primary, secondary and micronutrients. The demonstration trials conducted to validate this information supported the need to resort to a soil test-based fertilizer recommendation for cassava so as to avoid the present indiscriminate use of fertilizers so as to minimize the cost of cultivation as well as to maintain soil health.

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SITE-SPECIFIC NUTRIENT MANAGEMENT FOR CASSAVA IN INDIA

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Cassava (*Manihot esculenta* Crantz) is an important secondary staple as well as raw material for industrial production of many starch-based products such as sago in India. The crop is cultivated over an area of 0.28 million hectares, of which about 85 percent is in the three southern states of Kerala, Tamil Nadu and Andhra Pradesh. In Kerala, cassava is grown mainly for human consumption in the form of different cooked items, whereas in Tamil Nadu and Andhra Pradesh it is cultivated for the industrial production of sago, starch and other products. The total production in India is 9.6 million tonnes with average productivity of 34.4 tonnes/hectare, which is the highest in the world.

Over the past 45 years or so, research conducted in India has resulted in developing different nutrient management strategies that include a blanket recommendation, soil test-based fertilizer recommendations, soil test crop response studies and site-specific nutrient management (SSNM). The present blanket recommendation of N, P_2O_5 and K_2O for cassava in India is 100:50:100 kg/ha. Studies conducted in major cassava production domains of India clearly showed that there is wider spatial and temporal variability of soil and canopy properties in these areas and further yield increases with improvement in soil quality is possible only through developing SSNM technologies. Studies conducted by CTCRI, India for the past nine years have clearly demonstrated the superiority of the SSNM technology over other nutrient management techniques. We used the calibrated QUEFTS model for developing SSNM for cassava in India.

The results of the studies showed that there was a significant increase in the yield of tuberous roots and agronomic efficiency of applied fertilizer nutrients in SSNM treatment compared to the farmers' practice. The gross return above fertilizer cost (GRF) was also significantly higher for SSNM treatment compared to the farmer's practice. Minimum and maximum internal efficiencies of N, P and K were estimated as 35 and 80 for N, 250 and 750 for P and 32 and 102 for K. A linear increase in tuberous root yield with N, P and K uptakes of 17.6, 2.2 and 15.6 kg N, P and K per 1,000 kilogram tuberous root yield was also observed. Relationships between soil supply and soil chemical properties, and fertilizer nutrient recovery efficiencies with their rates of application were developed for major cassava production domains of India. Good agreement between measured and predicted yields was observed while calibrating the model, which showed that the model can be used for making site-specific NPK recommendations for cassava in major cassava production domains of India. Geographic information system (GIS)-based studies are also done to develop site-specific nutrient recommendation maps of major cassava production domains of India.

The paper also discusses the Nutrient Decision Support System (NuDSS) software called Cassava Site Specific Nutrient Management (CASSNUM) that has been developed for taking decisions on SSNM of cassava. There are three important modules in CASSNUM software, namely a cassava site-specific nutrient calculator (CASSNUT), cassava site-specific nutrient disorders (CASSNUD) and GIS-based cassava site-specific nutrient management (GISCASS).

Key words: Cassava, site-specific nutrient management, CASSNUM software, India.

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FARMYARD MANURE BIOCHAR FOR SUSTAINABLE CASSAVA PRODUCTION ON DEGRADED LANDS OF EAST JAVA, INDONESIA

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ABSTRACT

A cassava (*Manihot esculenta* Crantz) experiment was conducted for three consecutive years at Ringinrejo village of Blitar district in East Java, Indonesia, using the following five treatments: (1) No organic manure; (2) farmyard manure (FYM) applied once at the start of the experiment; (3) FYM applied every planting year; (4) biochar made from FYM applied only once; and (5) biochar made from cassava stems applied only once. Treatments were arranged in a randomized block design with four replications. The data collected included total dry cassava biomass, root yield and soil fertility status (soil organic matter, total N, available P and available K).

The experimental results show that both the application of FYM and biochar increased cassava growth and yield when planted on degraded land. The first year yield of cassava without organic manure was 24.67 t/ha, whereas the yield of cassava applied with FYM, FYM biochar and cassava stem biochar were 29.48, 32.64 and 25.37 t/ha, respectively. Planting cassava continuously on the soil without organic manure application to the soil, or when FYM was applied only once at the beginning of the experiment, the yields of cassava decreased. To obtain a positive effect of FYM, it should be applied in every planting season. During three years of planting cassava, the application of biochar could stabilize or even increase cassava yields. Planting cassava continuously on the same soil, even with the application of inorganic fertilizers the fertility status of the soil decreased, especially the soil organic matter (OM) and the N content. The same phenomenon occurred when FYM was applied only once at the beginning of the experiment. Application of FYM in every planting season built up the soil OM and N contents. The application of either FYM biochar or cassava stem biochar increased soil OM, and it remained relatively stable during three years after their application. Application of cassava stem biochar also increased the available K in the first year, but during the third year after application the available soil K in this treatment was not different from that in the other treatments.

Key words: Farmyard manure, sustainable production, soil organic matter, biochar, Indonesia.

INTRODUCTION

In Indonesia, cassava (*Manihot esculenta* Crantz) is the most important root crop and the third most important food crop after rice (*Oryza sativa* L.) and maize (*Zea mays* L.). However, both the government and the private sector in Indonesia have paid little attention to cassava and this even decreased from year to year. For example, there was a decrease in harvested area from 1.25 million ha in 2004 to 1.17 million ha in 2009, and this is now less than in Thailand, which had 1.32 million ha of harvested area in 2009 (FAO, 2010). In terms of harvested area, until 2007, Indonesia was the largest cassava

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producer in Asia. Between 2004 and 2009 the average cassava yield in Indonesia increased from 15.46 t/ha to 18.74 t/ha, but this yield is still much lower than the average cassava yield in Asia of 20.13 t/ha, or in Thailand (22.67 t/ha) and India (34.36 t/ha).

Of the 1.17 million ha of cassava harvested area, 55% is in Java, where cassava is planted on degraded or nearly degraded land (Islami *et al*., 2011a)**,** which usually have a low soil fertility status with an effective soil depth of less than 30 cm. The soils tend to be stony or gravelly and are characterized by very low OM content, and low contents of N, P, K and micronutrients such as Zn and Fe (Howeler, 2008). This is probably one of the main factors responsible for the low yield of cassava in Indonesia. Indeed, application of inorganic fertilizer will increase cassava yields, but this is expensive and may not be capable of maintaining yield stability (Islami *et al*., 2011a)

The main reason for the low soil fertility status of degraded land is caused by their low soil OM contents. Therefore, the simplest technology to improve soil productivity and stabilize crop yield on these lands is by applying organic amendments. There is no doubt that the application of organic fertilizers, such as manure, will increase soil productivity and cassava yields (Amanullah *et al*., 2007; Islami *et al.*, 2011b). However, it is now known that under the wet tropical conditions, this organic fertilizer will decompose rapidly, and its application should therefore be repeated every planting season. With the limitation of organic material resources, this practice is considered impractical to many farmers.

In consideration of these problems, it is worthwhile to search for alternative organic material resources that are more resistant to decomposition. Some research results indicate the ability of more resistant organic materials, such as "biochars", to improve soil properties and soil productivity (Glaser *et al*., 2002; Lehman *et al*., 2003; Liang *et al.*, 2006). An increase in crop yield with biochar application has also been shown with many other crops, such as maize (Islami *et al.*, 2011c; Sukartono *et al*., 2011b; Yamato *et al*., 2006), soybean (Tagoe *et al*., 2008), and rice (Asai *et al*., 2009). It seems that no research has been reported on the use of biochar with cassava. Therefore, the objective of this study was to evaluate the potential of biochar for improving the fertility status of soil planted with cassava. The study was also directed to understand its effect on crop yield and yield stability.

MATERIALS AND METHODS

The experiments were carried out on an upland farmers' field at Ringinrejo village in Blitar district, about 60 km southwest of Malang, East Java, Indonesia. The soils have an effective depth of less than 25 cm, and the surface soil has about 10% stones or gravel. Some properties of the soil are presented in **Table 1**.

The location has a distinct wet and dry season with an average annual rainfall of about 2000 mm with the rainy season starting in about November and ending in March of the following year. However, during the time of this experiment, there was an unusual rainfall distribution which extended throughout the year

The experimental treatments tested in this experiment were: (1) No organic manure; (2) Farmyard manure (FYM) applied and incorporated once at the start of the first year of the experiment; (3) FYM applied at the start of every planting season; (4) biochar made from FYM, applied once at the start of the first year; and (5) biochar made from cassava stems, also applied once at the start of the first year.. These treatments were arranged in a randomized block design with four replications.

The cassava cultivar used was Faroka, a high yielding bitter cassava variety. It was planted in plots of 6.0x5.0 m at a planting distance of 1.0x1.0 m. Each year of planting, all treatments were fertilized with 300 kg urea, 100 SP36 (36% $P_2O_{5)}$, and 100 KCl/ha, equivalent to 135 kg N, 36 P_2O_5 and 60 K_2O/ha. All P and K fertilizers were applied at planting time and N fertilizer was applied three times, at planting, and at 30 and 90 days after planting. In the first year, cassava was planted on January 15, 2009 and harvested on October 10, 2009, the second year cassava was planted on October 30, 2009 and harvested on August 25, 2010, and the third year cassava was planted on September 15, 2010 and harvested on July 10, 2011. In the second year, each FYM plot was split into two subplots, each measuring 3x5 m. Hence the plant sample in the first year was nine plants, whereas for the second and third year it was only three plants.

Farmyard manure (cow manure) was collected from a local farmer. Farmyard manure biochar was made by a simple method, as described by Sukartono *et al*. (2011b), and cassava stem biochar was made by a traditional self-combustion method as described by Islami *et al*. (2011b). To make biochar from FYM, the manure was sun-dried until its water content reached 15%. Ten kg of sun-dried FYM was put in a stainless steel heating drum with size of 50 cm height and 40 cm diameter. The drum was then sealed, and heated on a simple brick stove with sawdust as the combusting material. The temperature during combustion, fluctuated between 240-300 ºC, and the FYM was burned in the stove for 8-10 hours. Cassava stem biochar was prepared by the traditional method of auto-thermal combustion in a pit of about 1.5 x 1.5 x1.0 m. During combustion, the temperature varied between 200-370 ºC, and the combustion lasted for about 48 hours. The biochar from those processes was cooled, dried, and then ground to pass through 1.0 mm sieve for field application. Some properties of these organic amendments and the soil used for the experiment are shown in **Table 1.**

The amendments were applied at time of land preparation; they were incorporated to a depth of about 20 cm, at a rate of 15 t/ha (air dried).

Table 1. Characteristics of the soil, farm yard manure (FYM), and the two biochars used in the experiment.

Soil or organic amendments (DM basis)	pH	Org C (%)	Total N (%)	P (%)	K (%)	CEC (cmol/kg)
Soil*	7.1	0.84	0.05	7.6*	0.18*	11.6
Farmyard manure (FYM)	6.5	19.28	1.43	0.39	0.42	-
FYM biochar	7.9	25.55	0.78	0.82	0.79	17.7
Cassava stem biochar	8.1	40.42	0.09	0.21	0.94	12.5

- The soil was oven dried before analysis, and the amendments were air dried (water content of about 15%). P and K in the soil is expressed in ppm available P and cmol/kg of exchangeable K; for the three soil amendments this is total P and K..

The data collected were the total fresh above-ground biomass at the time of the cassava harvest, the fresh root yield, and soil properties before the experiment started and at time of each cassava harvest. Two soil samples of about 0.5 kg each were taken to a depth of 20 cm from each plot and then mixed, after which a sub-sample of about 0.5 kg was again mixed with the other plots (replication 1 mixed with 2, and replication 3 mixed with 4). Then a 0.5 kg sample of each was processed for laboratory analysis. To monitor soil organic C dynamics, soil organic-C was determined at a depth of 5-10 cm, and at 15-20 cm at 4, 8, 16, 30, 60, 120, 300, 660 (at the harvest of the second year cassava), and at 980 (at the harvest of the third year cassava) days after planting cassava the first year.

The soil parameters analyzed were pH (H_2O), organic carbon, total N, available P, exchangeable K, soil bulk density (ρb), percentage sand and clay content, soil aggregate stability, and soil water content. Soil pH was measured with a pH meter (Jenway 3305), organic carbon by the Walkley and Black method (Soil Survey Laboratory Staff, 1992), and total N by the Kjeldahl method (Bremner, and Mulvaney, 1982). Available P was extracted with Bray II solution and the concentration was measured with a spectrophotometer (Vitatron). Exchangeable K was extracted with NH_4OAc 1N at pH 7 and the concentration was measured with an atomic absorption spectrophotometer (Shimatzu). An undisturbed soil sample was used to determine soil bulk density, ρb (Blake and Hartge, 1986), sand and clay content were determined with the pipette method (Soil Survey Laboratory Staff, 1992). Aggregate water stability was measured with the modified wet sieving method of Kemper and Rosenau (1986). To do this, 50 g of dry soil aggregates with diameter of 0.20-4.0 mm were wetted to water content of about field capacity (matric potential of -330 kPa). These soil aggregates were then put on a series of sieves with diameter ranging from 0.5 mm to 2.0 mm, after which the sieves were raised and lowered in water 1.3 cm, at 35 times/minute for three minutes. The results were expressed as the "Mean Weight Diameter" (MWD).

The MWD was calculated by equation (1):

$$MWD = \Sigma (w \times d) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which: d is the diameter (in mm) of a soil aggregate left on the sieve; w is the weight of that same soil aggregate (expressed as a percentage of its initial weight).

The data were analyzed with ANOVA, and if there was a significant difference a further LSD test (P= 5%) was performed.

RESULTS AND DISCUSSION

The experimental results, presented in **Table 2,** show that the cassava yields in the FYM-biochar and FYM treatments (32.64 and 29.48 t/ha, respectively) in the first year were significantly higher compared to the yield obtained without any organic manure (24.67 t/ha). For a comparison, the yield of non-fertilized cassava in border plots was only 17.25 t/ha. It seems that in this degraded soil, the plant nutrients from the applied chemical fertilizer were not enough, so that the addition of nutrients from FYM and biochar still had a significant effect on the growth and yield of cassava.

Some researchers have shown that if biochar was applied without N fertilizer there was a suppression of plant growth (Wisnubroto *et al.*, 2010). It has been shown that biochar application increases the population and activity of soil microorganism (Rondon *et al.*, 2007)**.** Therefore, with the limitation of N availability it is suggested that biochar application will cause competition for N between plants and soil microorganism, and will thus result in reduced plant growth. But this may not be the case with cassava plants. It seems that in long maturity crops such as cassava, the competition only occurred in the early growth stages, and hence the growth restraint in the early part of the growth cycle could be compensated for in the following growth stage.

Table 2. The effect of the application of two types of biochar and farmyard manure (FYM) on the above ground biomass and on cassava root yield.

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Treatments	1st year		2nd year		3rd year	
	Dry total biomass (t/ha)	Fresh root yield (t/ha)	Dry total biomass (t/ha)	Fresh root yield (t/ha)	Dry total biomass (t/ha)	Fresh root yield (t/ha)
No organic manure	6.04 a	24.67 a A	4.62 a	18.26 a B	4.05 a	14.85 a C
FYM applied once at the first year cassava	7.95 ab	29.48 b A	7.17 b	31.55 bc A	5.07 a	23.42 b B
FYM applied at every cassava planting	7.95 ab	29.48 b A	7.85 b	34.27 c A	8.06 b	32.28 c A
FYM-biochar applied once	9.47 b	32.64 b B	9.07 b	33.26 c AB	7.06 b	29.74 c A
Cassava stem-biochar applied once	7.67 ab	25.37 ab A	7.97 b	29.35 b A	7.85 b	29.04 c A

1) means followed by the same letters in the same column (small letters) or in the same row (capital letters) are not significantly different ($p=0.05$).

2) as a comparison, the yield of non-fertilized cassava was only 17.25 t/ha in the first year.

The results in **Table 2** show that unlike biochar treated cassava, the third year yield of cassava treated only once with FYM was much lower compared to the second and first year cassava yields. The yield of this treatment was also lower compared to those obtained in the biochar treatments, and when FYM was applied every planting year. The higher yield of biochar treated cassava could be explained from the soil data shown in **Tables 3** and **4**.

Although biochar only increased the organic-C and CEC of the soil, it would have a great effect on the plant nutrient availability and uptake. The increase in CEC (**Table 3**), together with the ability of biochar to retain N released from urea fertilizer in the form of NH_4-N; this would decrease N losses due to leaching (Ding *et al.*, 2010; Widowati *et al.,* 2011). This will increase the efficiency of N utilization by cassava plants.

Another way that biochar application increased cassava yield was thought to be due to the increase of P availability. As discussed above, biochar application has been shown to increase the population and activity of some soil microorganism, such as rhyzobium (Rondon *et al.*, 2007) and mycorrhiza (Warnock *et al.*, 2007). It is understood that mycorrhizal fungi contribute to an increase in the uptake of P by plants. The particular importance of mycorrhiza in the uptake of P by cassava has been reported by Howeler *et al*. (1987).

Table 3. Effect of the application of two types of biochar and FYM on some soil chemical properties after the harvest of the first and third year cassava.

Treatments	Chemical properties after the first cassava (2009)					Chemical properties after the third cassava (2011)				
	C (%)	N (%)	P (ppm)	CEC (cmol /kg)	K (cmol /kg)	C (%)	N (%)	P (ppm)	CEC (cmol /kg)	K (cmol /kg)
No organic manure	0.94 a	0.07	8.56 a	11.15 a	0.33 a	0.91 a	0.08	8.04 a	10.73 a	0.28 a
FYM applied once at the first year cassava	1.11 a	0.11	10.05 b	14.74 b	0.39 a	1.10 a	0.09	10.20 ab	11.92 a	0.37 a
FYM applied at every cassava planting	-	-	-	-	-	1.25 b	0.10	12.06 b	14.64 b	1.19 b
FYM-biochar applied once	1.89 b	0.09	10.75 b	14.67 b	0.55 ab	1.90 a	0.11	10.47 ab	14.30 b	0.52 ab
Cassava stem- biochar applied once	1.94 b	0.10 NS	8.15 a	14.28 b	0.89 b	2.12 a	0.09	9.12 ab	14.12 b	0.96 b

1) means followed by the same letters in the same column are not significantly different (P=0.05); NS: not significantly different (P=0.05)
2) soil properties before experiment: C = 0.84%; N= 0.05%; P= 7.6 ppm; K = 1.21 cmol /kg; CEC= 11.60 cmol/kg

The results in **Table 4** show that after the harvest of the first year cassava the soil physical properties had not been influenced significantly by the applied organic amendments. However, after the harvest of the third year cassava, the application of biochar had decreased the soil bulk density and increased soil aggregation. Only the treatment with the FYM applied every year had a similar effect. This might be related to the soil organic matter content in the soil. After harvesting the first year cassava organic-C in FYM treated soil was not significantly different from that in the treatment without organic amendment application. The increase in soil aggregation with biochar and with FYM applied every year was a logical consequence of the increase in soil organic-C (**Table 3**), which is very important for soil aggregate formation and stabilization. The possible increase of soil micro-organisms with biochar application, as suggested by Rondon *et al.* (2007), would also contribute to this better soil aggregate formation and stabilization.

In addition to the increase in plant nutrient availability, as discussed above, the decreased in soil bulk density and increase in soil porosity (**Table 4**) with the application of biochar application, as well as with the yearly application of FYM would also contribute to the higher yields of cassava, as the low soil bulk density and high soil porosity would improve root growth and root development.

The low organic matter content of the soil when the FYM was applied only once indicates that farmyard manure had almost completely been decomposed within one year. The increases of organic-C in the biochar treated soil, on the other hand, still continued until the harvest of the third year cassava. This result indicates that the biochar utilized, as produced by the method described by Sukartono *et al.* (2011a), had a longer lasting beneficial effect, as suggested by some researchers (e.g. Lehman *et al.,* 2003).

Table 4. Effect of the application of two types of biochar and FYM on some soil physical properties after the harvest of the first and third year cassava.

Treatments	Physical properties after the first cassava (2009)			Physical properties after the third cassava (2011)		
	Bulk density (t/m^3)	Porosity (%)	Mean weight diameter (mm)	Bulk density (t/m^3)	Porosity (%)	Mean weight diameter (mm)
No organic manure	1.26	52.45	1.55	1.20 b	54.71 a	1.55 a
FYM applied once at the first year cassava	1.22	53.96	1.56	1.16 ab	56.22 ab	1.60 a
FYM applied at every cassava planting	-	-	-	1.11 a	58.11 c	2.42 b
FYM biochar applied once	1.20	54.71	1.74	1.12 a	57.73 b	2.45 b
Cassava stem biochar applied once	1.18 NS	55.47 NS	1.78 NS	1.12 a	57.73 b	2.40 b

1) means followed by the same letters in the same column are not significantly different (P=0.05).
2) soil properties before experiment: Bulk density= 1.22 t/m^3; soil porosity = 53.96 %; MWD = 1.6 mm

The decomposition patterns of biochar and FYM follow the following decay equation (2):

$$C = a + b \ln(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

in which: C is soil organic-C, t is time after organic amendment application (days) and b is a constant, indicating the rate of decomposition.

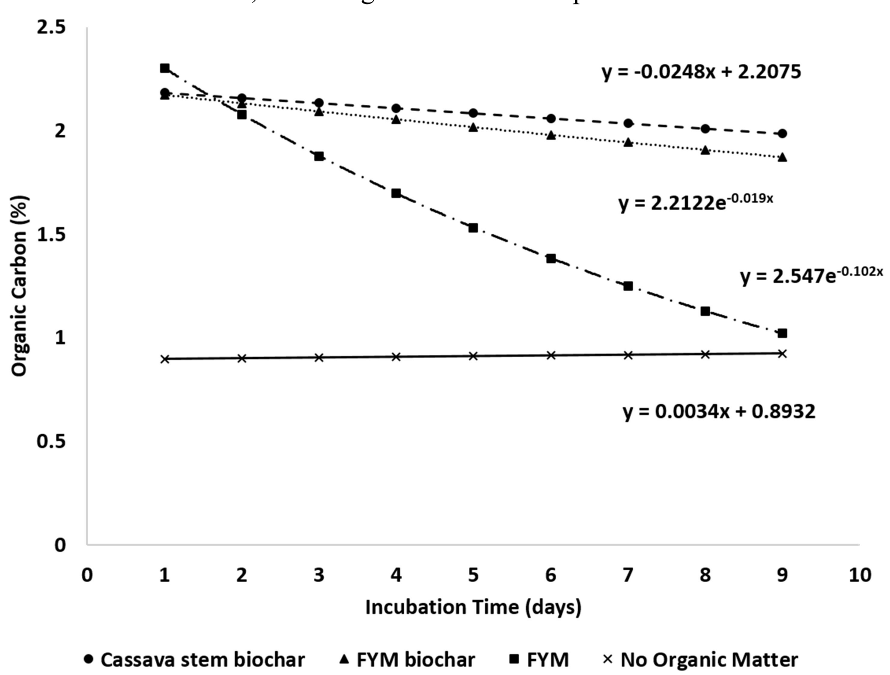

Figure 1. The model of soil organic C decomposition in soil applied with various soil organic amendments.

The results presented in **Figure 1** show that the b coefficient of the biochar treated soil in formula (2) above was very low and much lower compared to that of FYM. This indicates that the rate of decomposition of biochar is very low. The high b coefficient of the FYM treated soil indicates the high decomposition rate of FYM.

CONCLUSION

The experimental results presented and discussed above, show that on a degraded upland soil in East Java, Indonesia, the application of organic amendments improved the soil's fertility status and increased cassava yields. However, the positive effect of farmyard manure (FYM) application lasted only for one year. When this FYM was converted to biochar, its positive effect continued until at least the third year of cassava. One could argue that the rate of biochar applied here was very high and it would be almost impossible for farmers to apply such a high rate. Therefore, an additional experiment should be conducted using lower rates or other methods of application that could lower the rate. Since biochar is quite resistant to decomposition, its application could be done little by little each year.

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EARLY DETECTION AND MONITORING OF EMERGING CASSAVA PESTS IN ASIA: TOWARDS A COORDINATED EFFORT

Soroush Parsa[1]

Cassava production in the Asian region is facing an unprecedented challenge: the progressive invasion of several pests and pathogens from the Americas. Fortunately, many technologies are available to manage them. Best results, however, can only be achieved by swift, coordinated, region-wide action. This talk proposes a way forward. First, national regulations may need to be revised to prevent further introductions. Second, a region-wide surveillance system must be implemented for early detection and rapid response to new introductions. Finally, capacities to adapt and propagate technologies to manage pests already naturalized in the region must be strengthened. The presentation will emphasize promising tools to establish a region-wide surveillance system for emerging pests. The recent invasion of cassava mealybugs will illustrate the proposed response paradigm.

Key words: Cassava pests, surveillance, Asia.

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CASSAVA PESTS IN CHINA

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ABSTRACT

To contribute to the healthy, rapid and sustainable development of the cassava (*Manihot esculenta* Crantz) industry in China, a survey on the distribution and damage of cassava pests and mites in southern China was conducted from 2008 to 2014. In addition, research projects on the best system for the mass rearing of mites, the effect of host plant and high temperatures resistance, the potential geographic distribution of invasive cassava green mites in Hainan and Yunnan, as well as the control of the most important cassava insect and mite pests, were conducted. It was found that there are at least 60 cassava pests in China, including 56 insects and 4 mites: the green mite (*Mononychellus mcgregori*), the Africa red mite (*Eutetranychus africanus*), the spiraling whitefly (*Aleurodicus dispersus*) and two mealybugs (*Phenacoccus madeirensis and Paracoccus marginatus*) were reported for the first time in China; the red spider mite (*Tetranychus cinnabarinus*), the spot mite (*Tetranychus urticae*), the longhorn beetle (*Dorysthenes granulosus*), grubs(*Anomala corpulenta, Lepidiota stigma and Anomala exoleta*) and noctuids (*Helicoverpa armigera* and *Spodoptera litura*) were among the most serious pests, causing considerable damage during the past five years.

A system was developed for the mass rearing of the red and green spider mites. Rubber trees were found to be another host plant of the cassava green mite, *M. mcgregori*. Preliminary studies indicate the reason why *M. mcgregori* cannot survive at high temperatures. A preliminary estimate was made of the potential geographic distribution of the green mite *M. tanajoa* in Hainan and Yunnan Provinces of China. In addition, the effect of spider mites on cassava yield was determined, four cultivars with resistance to spider mites were identified and the mechanism of resistance was postulated. Also, the occurrence of *D. granulosus* and various grubs was confirmed and a strategy for integrated pest management was developed and applied in the field.

Key words: Cassava pests, mites, geographic distribution, high temperature, mite resistance, occurrence of *Dorysthenes granulosus* and grubs

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is of high value, both as a food and feed crop, as well as an energy crop for industrial processing into starch, bio-fuel and a host of other products. In tropical regions, cassava plays an extremely important role in supporting farmers' income. In China, research on the prevention and control of cassava pests had been of low priority, but recent serious pest outbreaks have led to major problems of raw material supply for the healthy development of the cassava processing industry. With the rapid development of China's international commodity exchange and tourism, combined with the existence of several host plants and suitable temperatures and humidity, many invasive pests can easily be introduced into the country, colonize, develop populations and cause serious damage; this has become one of the important limiting factors for the sustainable development of the cassava industry. Therefore, a survey was conducted from 2008 to 2014 to determine the distribution and damage of cassava pests and mites in

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southern China. In addition, a system was developed for the mass rearing of the red and green mites, and research was conducted on identifying other host plants, to determine high temperature adaptability, the potential geographic distribution of invasive cassava green mites in Hainan and Yunnan, and on the control of the most important cassava insect and mite pests. The result obtained will provide important technical support for the cassava industry's development in the country.

RESULTS

1. The Status of Cassava Pests in China

Before 2006, few people paid attention to cassava pests, and only three pests species were reported in south China, including the red spider mite, *Tetranychus cinnabarinus*, and two insects, *Araecerus fasciculatus* and the peanut cricket, *Tarbinskiellus portentosus*. After a serious outbreak and heavy damage from various cassava pests in 2007, the government realized the importance of cassava pests and started to pay more attention to developing effective cassava pest control measures. Since then, cassava pest research has been supported with special funding from the Chinese Cassava Agro-technology Research System (CCARS). This includes a survey of the distribution and damage caused by cassava pest problems in the main cassava growing areas in southern China from 2008 to 2014. As a result, in 2014, 60 cassava pests had been reported, including 55 insect and 4 mite species. The green mite, *Mononychellus mcgregori,* in 2008, the Africa red mite, *Eutetranychus africanus*, in 2014, the spiraling whitefly, *Aleurodicus dispersus,* in 2006, and two mealybugs, *Phenacoccus madeirensis* in 2011 *and Paracoccus marginatus* in 2014; these were reported for the first time in China. In addition, the red spider mite, *Tetranychus cinnabarinus*, two spot mites, *Tetranychus usurticae*, the longhorn beetle, *Dorysthenes granulosus*, three grubs, *Anomala corpulenta, Lepidiota stigma and Anomala exoleta*, and the noctuids, *Helicoverpa armigera* and *Spodoptera litura,* were found to be widespread and causing serious damage.

M. mcgregori was first found in Danzhou, Hainan in 2008, but has now spread to most of Yunnan, Beihai and Nanning of Guangxi, and Suixi of Guangdong. *P. madeirensis* was also first discovered in Danzhou, Hainan in 2011, but has now spread to most of Yunnan and to Suixi of Guangdong. *A. dispersus* was first found in Hainan in 2006. *E. africanus* was also first detected in Hainan, in 2014. *Bemisia tabaci* is curently distributed in most cassava fields in China. *T. cinnabarinus*, *H. armigera*, *D. granulosus* and grubs were found in many cassava fields in China, while *S. oryzae* was found only in Hunan and Guangxi Provinces.

2. Ecological Adaptability of the Green Mite *M. mcgregori*

2.1 Development and reproduction of the green mite at different temperatures

The most suitable temperature for the cassava green mite, *M. mcgregori,* to develop and reproduce were found to be at 24-27 ºC (**Figures 1** and **2**). After being exposed to 24-39 ºC temperature, the developmental duration was shorter and the fecundity was higher than when exposed to 21 ºC. However, the fecundity of mites exposed to 21 ºC and 30-39 ºC was lower than of those exposed to 24-27 ºC. 42 ºC was the extremely high temperature for the development and the reproduction of *M. mcgregori* and under this temperature the eggs could not hatch and not fulfill their subsequent development.

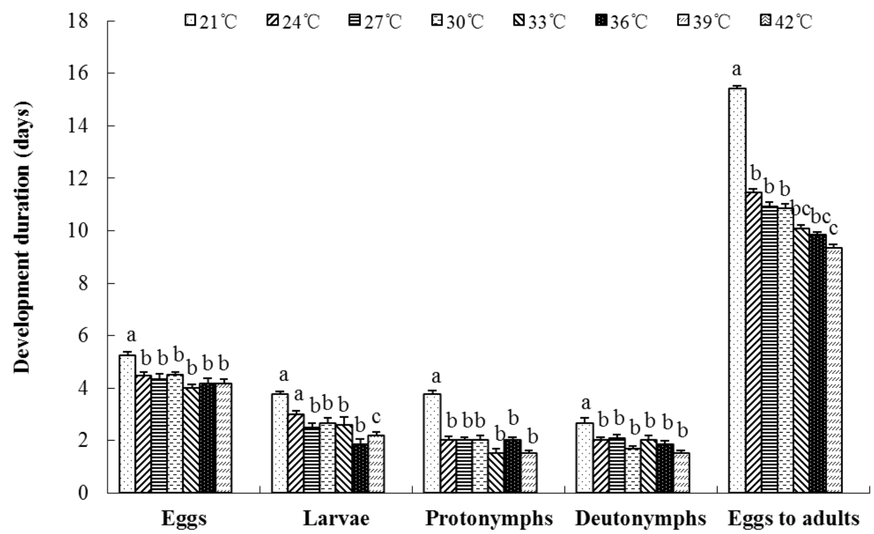

Figure 1. The effect of different temperatures on the developmental duration of M. mcgregori.

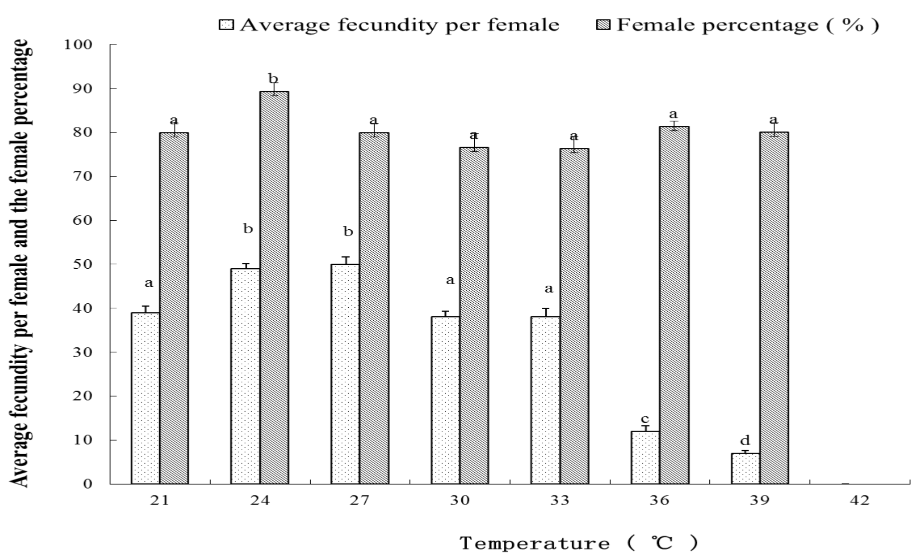

Figure 2. The effect of different temperatures on the fecundity and the sex ratio of M. mcgregori.

2.2 Alternative hosts of the green mite *M. mcgregori*

The most suitable host plants for the cassava green mite *M. mcgregori* to develop and reproduce were found to be cassava and rubber tree (**Figures 3, 4**). Feeding on the leaves of cassava or rubber tree, the development duration of the green mite was shorter and the fecundity was higher than feeding on any of the other three plant species tested, i.e. papaya, mango or codiaeum.

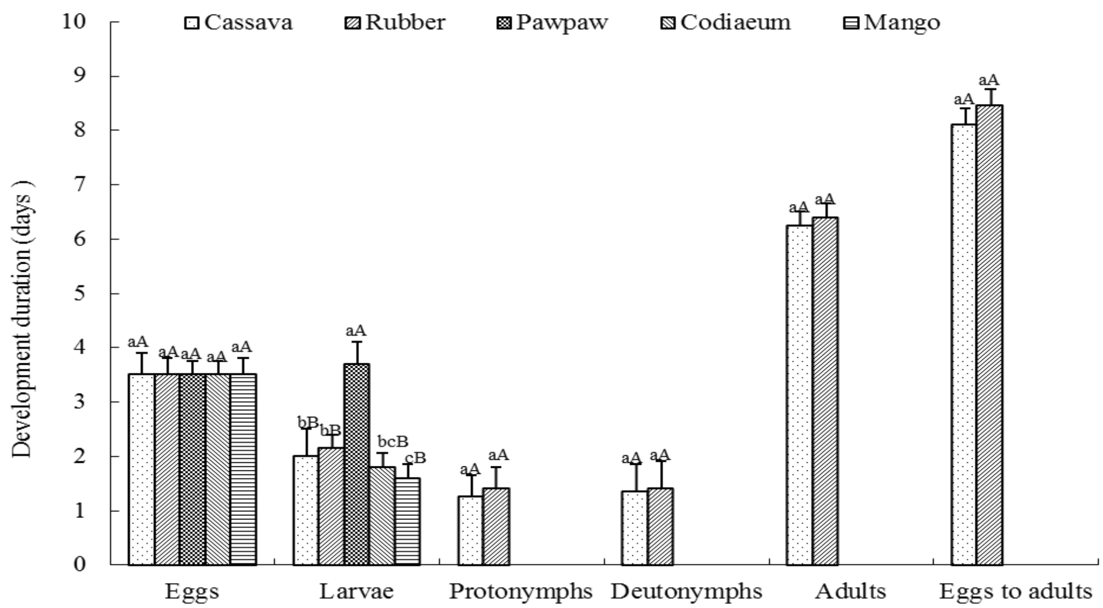

Figure 3. The effect of host plant on the developmental duration of M. mcgregori.

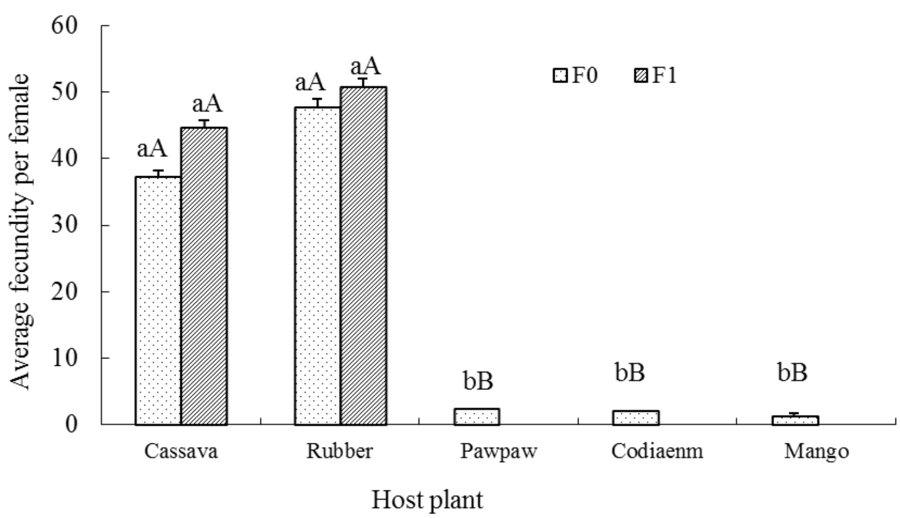

Figure 4. The effect of host plant on the fecundity of M. mcgregori.

2.3 Development of the green mite feeding on different varieties

Resistant cassava varieties had a significant effect on the development and reproduction of *M. mcgregori* (**Figure 5, 6**). The mites could not survive on the resistant cassava varieties C1115 and Myanmar. Compared with the mites feeding on susceptible cassava varieties (CM1210-10, ZM9066, BRA900 and SwissF21), those feeding on resistant varieties (PII167, Colombia-4D, Myanmar and C1115) had a significantly longer developmental duration, the production and hatchability of the eggs decreased significantly, and the female and male adult lifespans shortened significantly. It suggests that the resistant cassava varieties inhibited the development and reproduction of *M. mcgregori*.

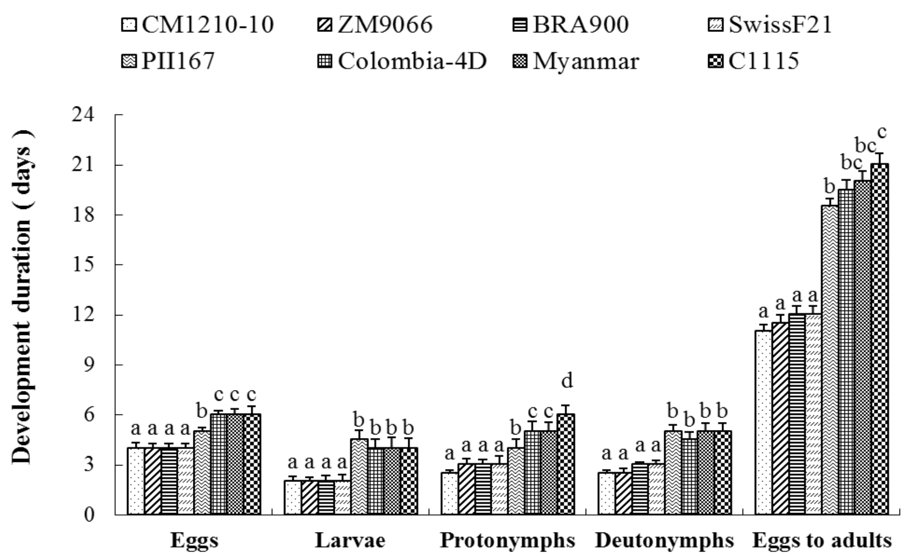

Figure 5. The effect of different cassava varieties on the development of M. mcgregori.

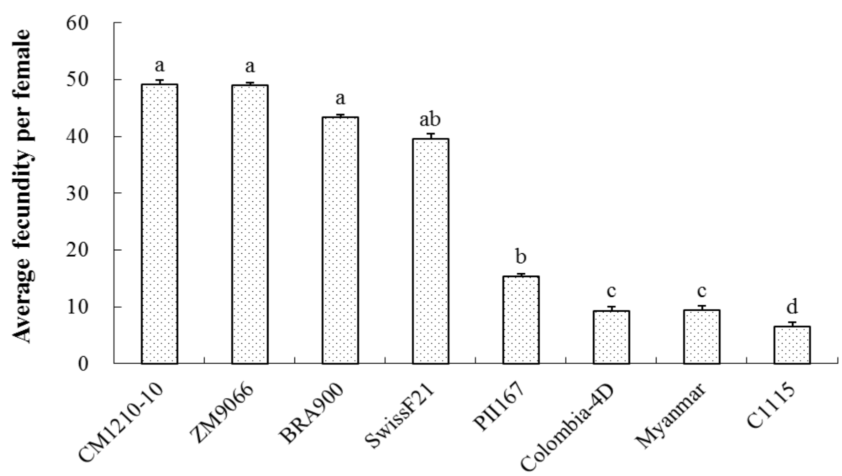

Figure 6. The effect of different cassava varieties on the fecundity of M. mcgregori.

2.4 Adaptation of the Green Mite to High Temperatures

Exposure to high temperatures for only 1 hour probably has an important impact on the mite's population growth (**Figures 7-11**). The activities of polyphenol oxidase (PPO), peroxidase (POD), ascorbic acid oxidase(APX), and catalase (CAT) were significantly increased in the larval mites and female adult mites of *M. mcgregori*; CAT activity was significantly decreased in protonymphs and deutonymphs; the stability of their PPO, POD and APX activities may be associated with the thermos-stability of *M. mcgregori*. The changes of the protective enzyme PPO, POD, APX and CAT activities *in vivo* of *M. mcgregori* in each development period after the extremely high-temperature stress at 42 ºC may be significantly associated with the tolerance of *M. mcgregori* to high temperature. It suggests that the long-time stress from high temperature may result in the increase of its thermally stable individuals, enhancement of the population's thermal stability and thereby lead to rapid expansion of the population.

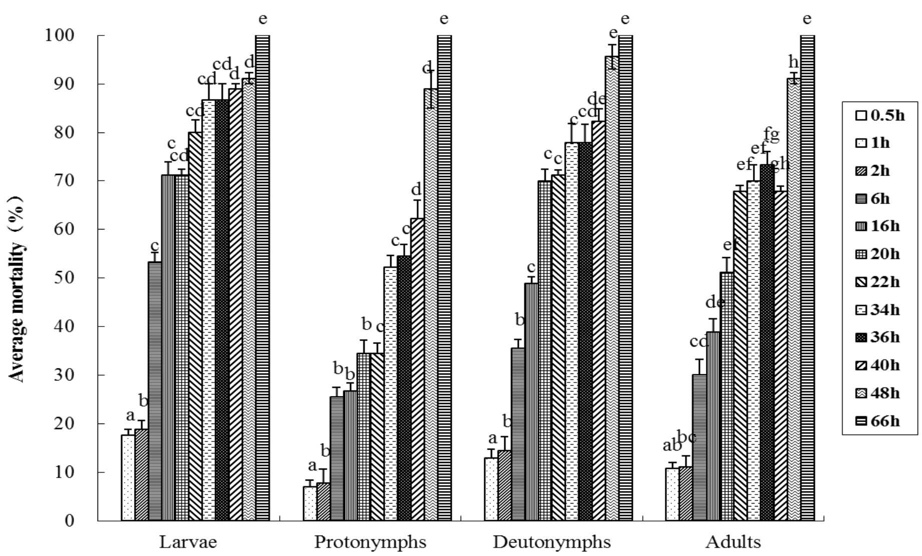

Figure 7. The effect of different exposure times to high temperature (42 ºC) on the development of M. mcgregori.

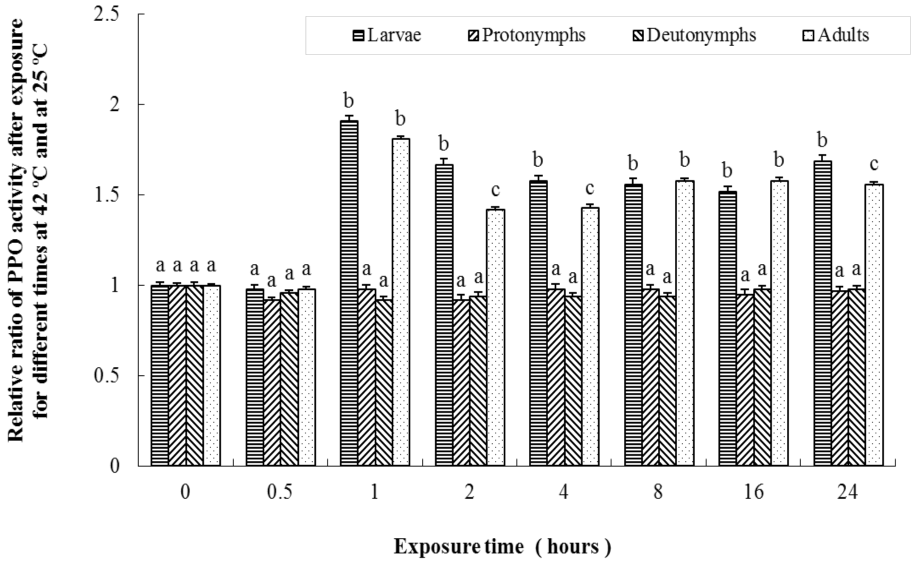

Figure 8. Activity changes of PPO in M. mcgregori after exposure to the extremely high temperature of 42 ºC for different times in each development period.

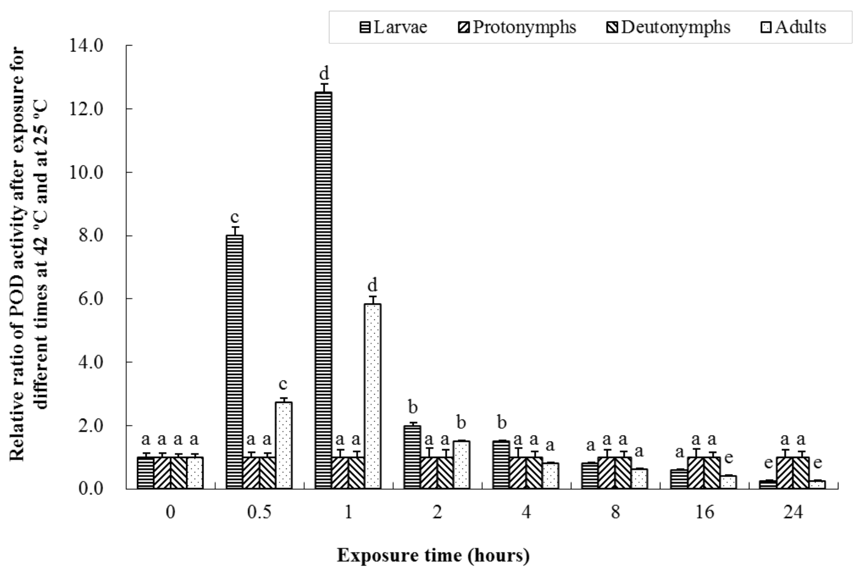

Figure 9. Activity changes of POD in M. mcgregori after exposure to the extremely high temperature of 42 ºC for different times in each development period.

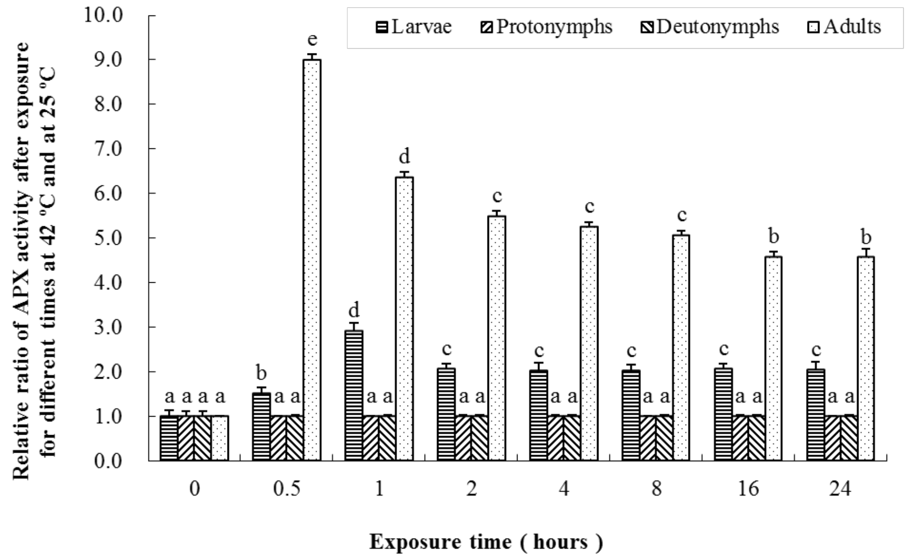

Figure 10. Activity changes of APX in M. mcgregori after exposure to the extremely high temperature of 42 ºC for different times in each development period.

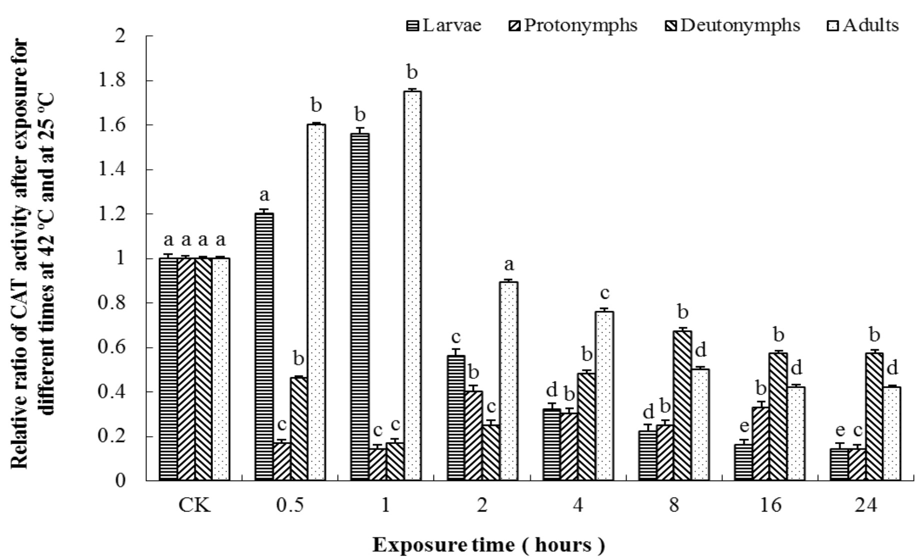

Figure 11. Activity changes of CAT in M. mcgregori after exposure to the extremely high temperature of 42 ºC for different times in each development period.

2.5 Mass rearing of green mites

The optimal conditions for mass rearing of green mites were found to be: temperature of 24-27 ºC; relative humility 75-85%; light period Light：Dark = 8-12 hours：12-16 hours; and cassava varieties with broad leaves.

3. Potential Geographic Distribution of the Green Mite *M.tanajoa* in Hainan and Yunnan Provinces

In order to effectively monitor and manage this serious pest, it is necessary to investigate its potential geographical distribution worldwide. We used the ecological niche models, maximum entropy (Maxent), based on the biological data and known distribution of *M. tanajoa*, as well as meteorological data from the years 1950 to 2000 in WorldClim, to predict the potential geographic distribution of *M. tanajoa*. The results suggest that the suitable areas for infestation of this species of cassava green mite were mainly restricted to west Hainan (Danzhou, western Changjiang, western Dongfang, and southeast Ledong), north Hainan (Lingao, eastern Chenmai and northern Haikou), east Hainan (northern Lingshui and southern Wanning) and south Hainan (southern Sanya). In addition, some counties of eastern Hainan were predicted to be unsuitable areas, e.g. Wenchang and Qionghai. A jackknife test in Maxent shows that the temperature annual range was the most important environmental variable affecting the distribution of *M. tanajoa*. Consequently, the study suggests several reasonable regulations and management strategies for avoiding the introduction or invasion of this high-risk cassava pest to these potentially suitable areas. The results show that there are four levels of suitability assessment of *M. tanajoa* in Yunnan Province，in which western and eastern areas are in the most suitable，including parts of Simao, Lincang, Baoshan, Nujiang, Diqing, Qujing and Wenshan areas.

4. Effect of the Red Spider Mite *Tetranychus cinnabarinus* on Photosynthesis of Cassava Leaves

The contents of leaf chlorophyll-a, chlorophyll-b and β-carotene were significantly different after the leaves were damaged by different numbers of individuals (25, 35 45 and 55 mites per leaf) of *T. cinnabarinus* (**Figures 12-14)**. There were also significant differences in the activities of various photosynthesis-related metabolic enzymes, including polyphenol oxidase (PPO), peroxidase (POD) and catalase (CAT) after the leaves were damaged by *Tetranychus cinnabarinus*. After being damaged by the mites for eight days, the activities of PPO, POD and CAT in leaves with 25 and 35 mites per leaf were higher than those in the undamaged leaves; however, the activities of PPO, POD and CAT in leaves with 45 and 55 mites per leaf were significantly lower than those in the undamaged leaves (**Figures 15-17)**. The results suggest that spider mite damage can result in serious loss of cassava yield.

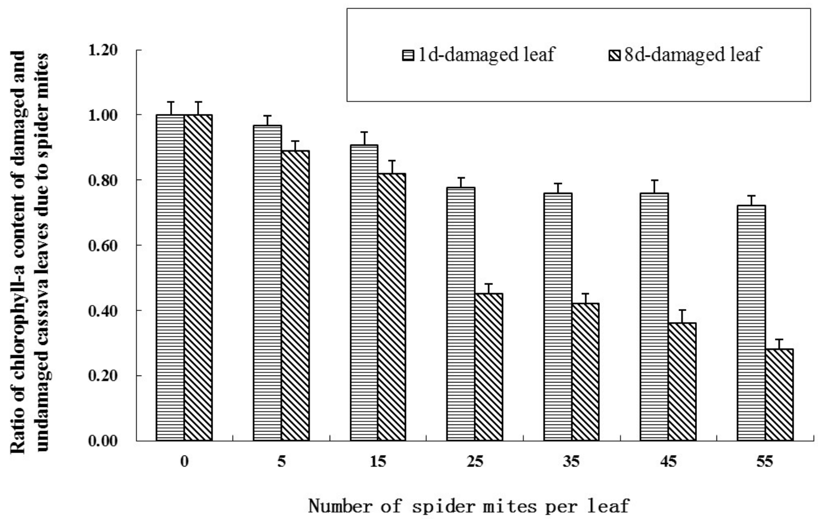

Figure 12. Ratio of chlorophyll-a content of damaged and undamaged cassava leaves after exposure to spider mites for one and for eight days.

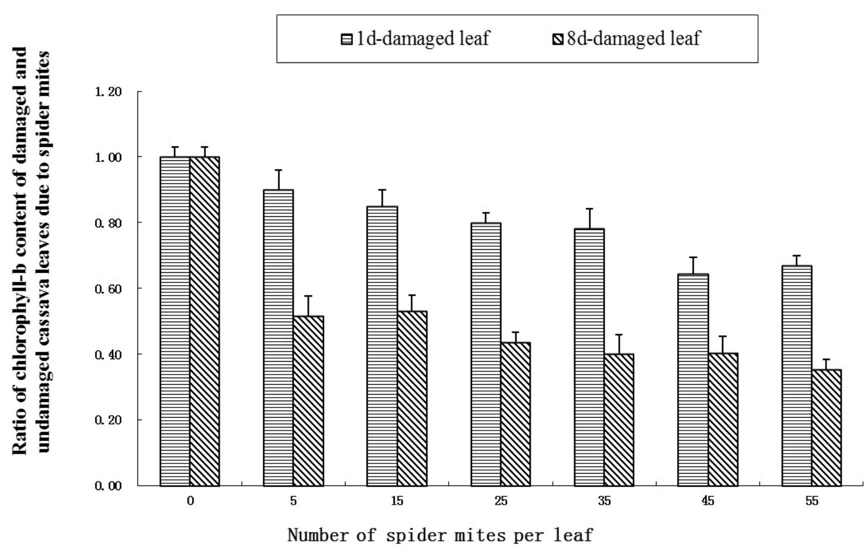

Figure 13. Ratio of chlorophyll-b content of damaged and undamaged cassava leaves after exposure to spider mites for one and for eight days.

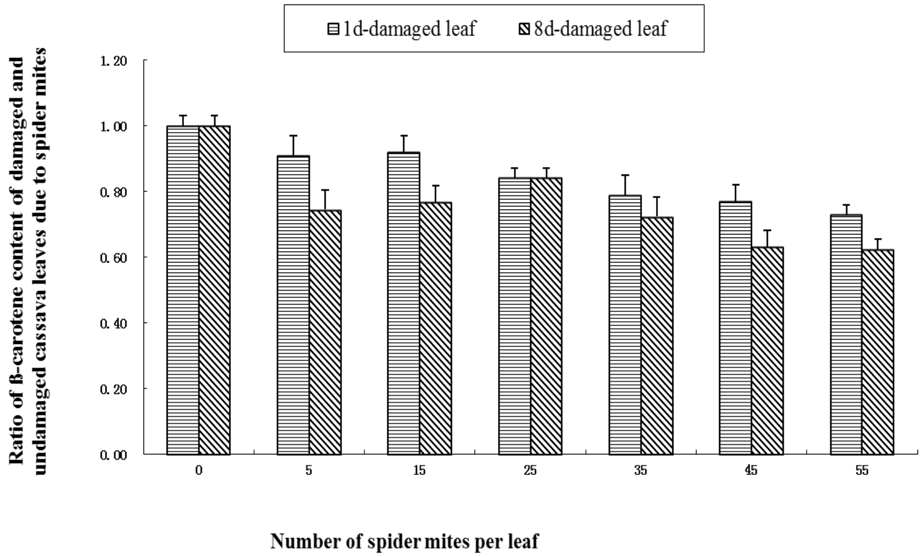

Figure 14. Ratio of ß-carotene content of damaged and undamaged cassava leaves after exposure to spider mites for one and for eight days.

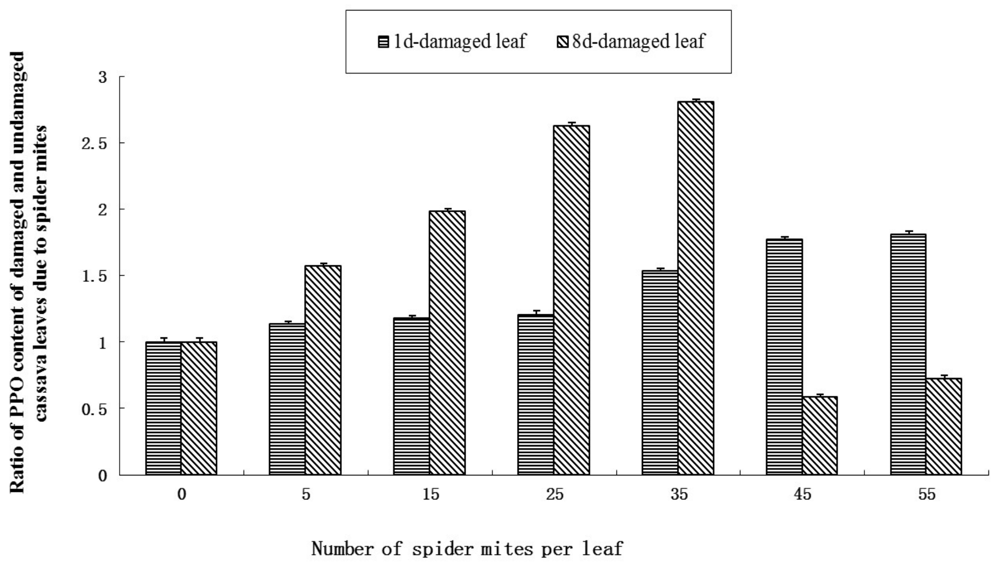

Figure 15. Ratio of PPO content of damaged and undamaged cassava leaves after exposure to spider mites for one and for eight days.

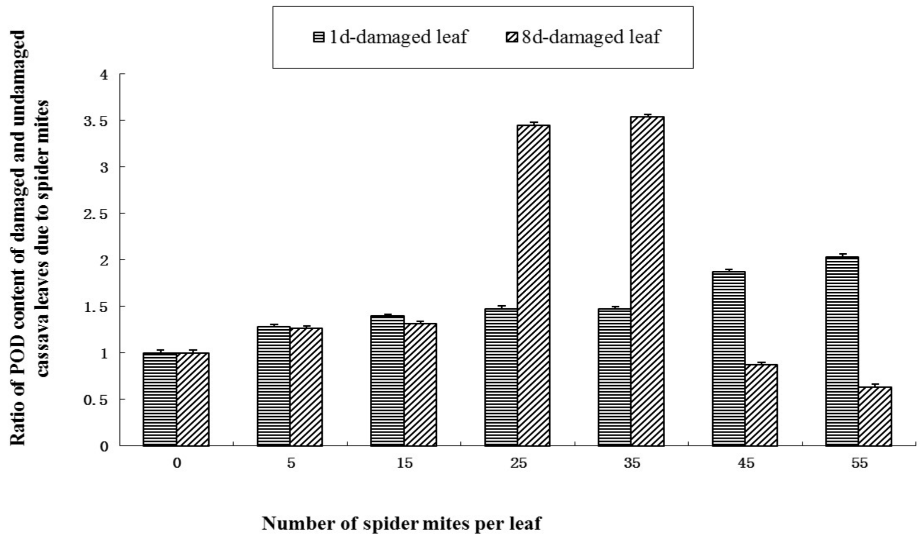

Figure 16. Ratio of POD content of damaged and undamaged cassava leaves after exposure to spider mites for one and for eight days.

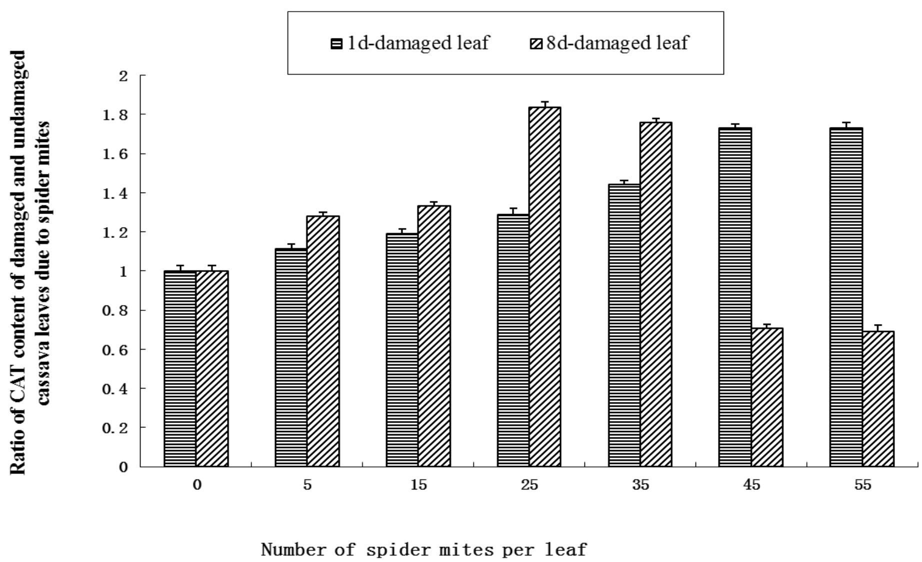

Figure 17. Ratio of CAT content of damaged and undamaged cassava leaves after exposure to spider mites for one and for eight days.

5. Cassava Resistance to the Red Spider Mite *T. cinnabarinus*

The Evaluation standard for the identification of cassava-germplasm resistance to *T. cinnabarinus* was established (**Table 1** and **Table 2**). Based on the standard, the resistances of 227 cassava germplasm accessions to *T. cinnabarinus* were identified and the effect on the development and reproduction of *T. cinnabarinus* on four resistant and four susceptible cassava varieties were determined. The results show that the resistant and susceptible varieties had significantly different effects on the development and reproduction of *T. cinnabarinus*. In the resistant varieties the developmental duration of the mites was significantly prolonged, egg production and their hatchability decreased significantly, and the lifespan of female and male adults was shortened significantly, as compared to those of mites feeding on susceptible varieties. Furthermore, *T. cinnabarinus* feeding on the highly resistant varieties C1115 and Myanmar could no longer reproduce (**Figures 18, 19**). This suggests that the resistant cassava varieties inhibited the development and reproduction of *T. cinnabarinus*.

Table1. The standard for the classification of cassava-germplasm resistance to the red spider mite *T. cinnabarinus* in the laboratory.

Resistance level	IM	HR	R	MR	S	HS
F_0 survival rate (%)	0	0.1 - 10.0	10.1 - 30.0	30.1 - 60.0	60.1- 80.0	>80.0

Table 2. The standard for the classification of cassava-germplasm resistance to the red spider mite *T. cinnabarinus* in the field.

Resistance level	IM	HR	R	MR	S	HS
I (%)[1)]	0	0.1 - 12.5	12.6 - 37.5	37.6 - 62.5	62.6 - 87.5	> 87.5

[1)] I (mite index) = ∑(damaged scale x the number of damaged plants) x100/(total no of plants x 4)

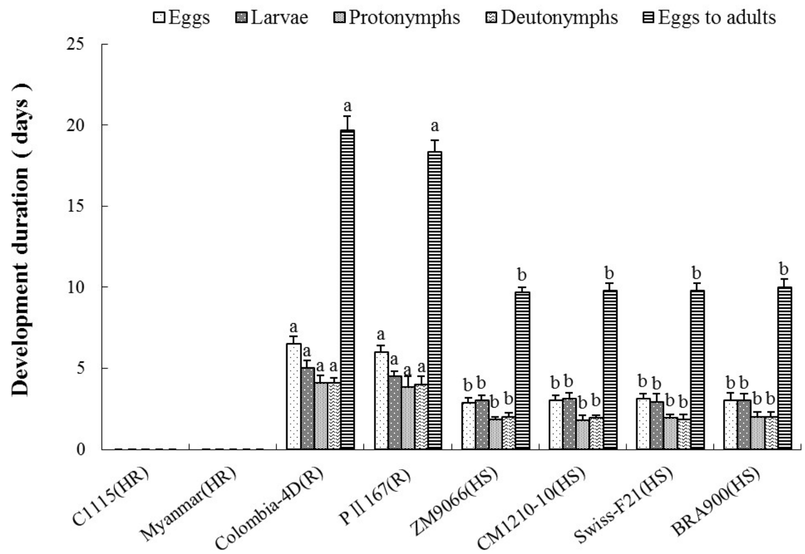

Figure 18. Development duration of T. cinnabarinus feeding on four resistant (on left) and four susceptible (on right) cassava varieties.

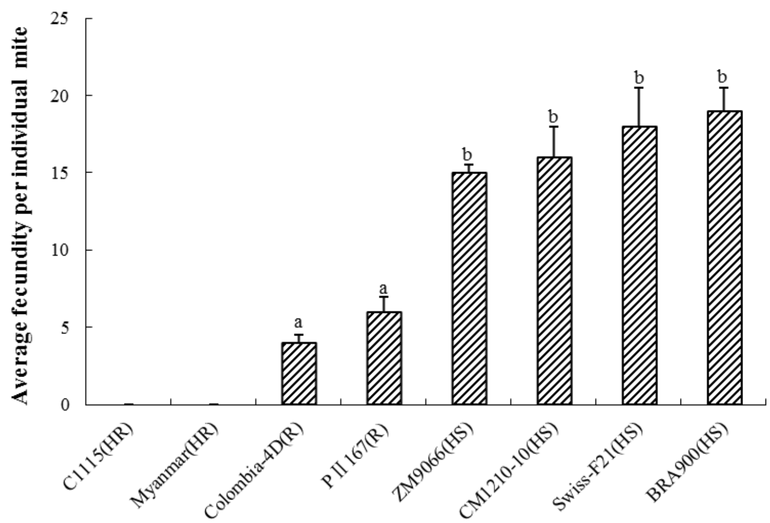

Figure 19. Fecundity of T. cinnabarinus feeding on four resistant (on left) and four susceptible (on right) cassava varieties.

6. Occurrence of *Dorysthenes granulosus* and Grubs

Some basic information about *D.granulosus* and the grub *A.corpulenta* is shown in **Table 3**.

Table 3. Occurrence of *D. granulosus* and the grub *A. corpulenta*.

Item	*D. granulosus*	Grub (*A. corpulenta*)
Development	2-3a per generation	About 1a per generation
Egg period	About 10-18 days	About 20-25 days
Eclosion	Often in April to June and after the rainy season	Often in June to August and after the rainy season.
Oviposition	Copulate often in night and eggs often distributed in 1-3 cm soil	After copulating for about 10 days; eggs are often oviposited in about 4 cm soil; 1 egg per egg room; 3-6 cm every egg room; 7-14 eggs per distributed area
Average eggs per female	250 eggs	14-47 eggs
Over-wintering	Mature larvae in soil	Larvae in compost or organic compounds in the soil
Tropism	Phototaxis	Phototaxis and tend to rot

7. Integrated Pest Management (IPM) of Cassava

The following IPM recommendations are based on the results of field experiments combined with experiences of actual field management:

- Before planting: select resistant varieties
- At the time of planting, soak the stem cuttings in a solution containing the insecticides Chlorpyrifos and Abamectin for 5-10 minutes
- During planting, mix the fertilizer and insecticide together and place with the stem cuttings in the soil
- After planting, carefully manage the use of fertilizers and water and protect from enemies
- During the crop cycle, the pest's tropism, the trapping with the use of black lights and soil pits are often effective
- The key control period is generally from the fourth to the sixth month after planting
- When there is a serious pest outbreak, chemical control is often the most effective
- After the cassava harvest, reasonable intercropping and rotation are often very effective to lower the pest population density.

CONCLUSIONS

Up to sixty cassava pests have been reported in China up to 2014, including 56 species of insects and four mites. Green mites, *E. africanus*, spiraling whiteflies and mealybugs were reported for the first time. Outbreaks of spider mites, two spot mites, longhorn beetles, grubs and noctuids have become more serious and have caused great damage during the past five years.

A system for mass rearing of mites was developed so that enough red and green mites could be provided for studies on their ecological adaptability, variety resistance to mites and integrated pest management. Research results indicate that rubber tree is another important host plant of the cassava green mite *M. mcgregori*. The results of high temperature adaptability indicate that the changes of the protective enzymes PPO, POD, APX and CAT activities may be significantly associated with the tolerance of *M. mcgregori* to high temperature. The longtime stress from high temperature may result in the increase of its thermally stable individuals, enhancement of the population thermal stability and thereby lead to rapid expansion of the population.

Based on the biological data, the known distribution of the green mite *M. tanajoa* and meteorological data for the years 1950 to 2000 in WorldClim, the potential geographical distribution of *M. tanajoa* in Hainan and Yunnan Provinces were predicted via the ecological niche models and maximum entropy (Maxent) studies.

A comparison of leaf chlorophyll-a, chlorophyll-b, and ß-carotene contents and the photosynthesis-related metabolic enzyme activities in cassava leaves when damaged by different numbers of individuals (25, 35, 45 or 55 per leaf) of the red spider mite *T. cinnabarinus* confirmed preliminarily the relation between spider mite damage and yield loss.

After establishing the standard for cassava varietal resistance to spider mites, the resistances of 227 cassava germplasm accessions to *T. cinnabarinus* were evaluated and the influence of four resistant and four susceptible varieties on the development and reproduction of the mites were studied. The results showed that the resistant cassava varieties can significantly inhibit the development and reproduction of *T. cinnabarinus*.

Some basic information about two important soil insect pests *D. granulosus* and the grub *A. corpulenta* which feed on cassava fresh roots were confirmed. Finally, an IPM protocol for cassava pests was developed and applied successfully in the field.

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INTRODUCTION OF *Anagyrus lopezi* FOR BIOLOGICAL CONTROL OF THE PINK CASSAVA MEALYBUG, *Phenacoccus manihoti* IN THAILAND

Amporn Winotai[1]

The first outbreak of pink cassava mealybug, *Phenacoccus manihoti* (Homoptera: Pseudococcidae) occurred in Thailand in 2008. Chemical control was applied to control the mealybugs but this measure could not keep the pest under control. A biological control program was started with the introduction of *Anagyrus lopezi* (Hymenoptera: Encyrtidae). *A. lopezi* had been reported as the most effective biological control agent for the control of pink cassava mealybug in West Africa. The Department of Agriculture (DoA) contacted the International Institute of Tropical Agriculture (IITA) in Benin, for help with introducing *A. lopezi* to Thailand. After obtaining an import permit, 500 adult *A. lopezi* were introduced into Thailand in September 2009. Host specificity testing of the parasitoid was conducted on six species of beneficial insects and eight species of insect pests in a quarantine laboratory. The results concluded that *A. lopezi* was highly host-specific: it attacked only *P. manihoti* and was therefore safe for use as a biological control agent of the pink cassava mealybug in Thailand. The developmental time of *A. lopezi* was investigated and the duration from egg-laying to adult emergence ranged from 11-25 days. The third and the fourth instar nymphs or the 21-25-day-old mealybugs were suitable stages for rearing *A. lopezi*, and the resulting sex ratio ranged from 1:1 to 2:1. The parasitoids could develop on the second instar mealybugs but more male parasitoids were developed. The mass-rearing procedure for *A. lopezi* was developed by using the pink cassava mealybugs reared on cassava plants. Rearing of pink cassava mealybugs on pumpkin was developed and used for rearing *A. lopezi* in order to reduce the cost of parasitoid mass production. Field release of the parasitoid was studied. Three hundred pairs of *A. lopezi* wasps per hectare were recommended for release once the pink cassava mealybugs were found. In the case of heavy infestations, the release of 1,250 pairs per hectare was recommended. A release permit was obtained and area-wide release started in July 2010. Several training courses were organized for transferring technologies of mass rearing and release of *A. lopezi* to extension officers from eight Pest Management Centers under the Department of Agricultural Extension, researchers from six DoA Regional Research and Development Offices and the private sector. The Ministry of Agriculture and Cooperatives arranged a budget to support a parasitoid-rearing project. More than 30 parasitoid rearing units were established and run under the Department of Agriculture and the Department of Agricultural Extension facilities. The Thailand Tapioca Development Institute (TTDI) and the other four private sector associations: the Thai Tapioca Trade Association (TTTA), the Thai Tapioca Starch Association (TTSA), The North Eastern Tapioca Trade Association (NETTA) and the Thai Tapioca Products Factory Association arranged their budgets and facilities for parasitoid rearing and release. Through this cooperation, more than 6,000,000 pairs of *A. lopezi* were produced and released around the areas where the cassava mealybug outbreak was observed during July 2010 to August 2011. Subsequently the number of areas of infestation observed and reported was reduced. It is too soon to evaluate the impact of the control. More information is required for conclusion of the project.

Key words: Pink cassava mealybug, *Phenacoccus manihoti*, *Anagyrus lopezi*; parasitoid introduction, biological control, mass rearing, Thailand.

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MODELING OF MEALYBUG DYNAMICS

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Papaya mealybug (*Paracoccus marginatus*) has become a serious menace for the cassava crop in most of the cultivated areas of Tamil Nadu, where the crop is grown mainly for industrial purposes. It has already affected the cultivation of other crops like papaya, cotton and mango, resulting in heavy losses to farmers. A sudden outbreak of this pest occurred during 2009/10 and it spread rapidly during the season because proper control measures could not be taken. Studies were conducted by the Central Tuber Crops Research Institute (CTCRI) for developing an early warning system to provide advanced information about the pest outbreak and thus help farmers take protective measures.

The districts of Salem, Dharmapuri, Erode and Coimbatore were worst hit by the mealybug attack. Rainfall was scant during this period and the temperature was very high. Thus favorable environmental conditions prevailed for the outbreak of the pest. From its center of origin, the pest is most likely to have reached India from Sri Lanka. The areas in Tamil Nadu where cassava is cultivated on a commercial scale are agriculturally vibrant with crops like mango, papaya, rice etc. also grown on a large scale. Large quantities of chemical pesticides like endosulfan, monocrotophos, dimecron etc. have been used for all crops, including cassava, for many years. Farmers also use chemical pesticides against mealybug. The natural control system for controlling the pest was seriously upset by the indiscriminate application of chemical pesticides

A model for simulating mealybug dynamics was developed at CTCRI. Simulation of the life cycle of the pest using the temperature requirements for each stage of its life was the main component. In the natural environment, mortality for each stage is induced by predators, parasites and by environmental conditions. The mortality values were fixed for each stage and these values were obtained mainly from experts. The populations of the parasites and predators were affected by the application of chemical pesticides. This influenced the growth of mealybugs indirectly. Another important component of the model was the database on alternate hosts present in the region. Data on the duration and date of planting of these alternate hosts are still required. Data on chemical fertilizers applied in the region (quantity, concentration etc.) are also used by the model.

Weather data was the driving variable of the model and temperature and rainfall intensity had key roles in deciding the dynamics of the pest. Initial inoculum load played the most vital role in the occurrence of the pest as long as proper control measures were not standardized.

A fuzzy logic model is also being developed to predict the dynamics of this pest because pest occurrence conditions are highly imprecise and vague. These vague data are being classified into different fuzzy sets and a fuzzy inference system is being developed using the already available scientific information. This model is expected to give very conclusive predictions from the available vague input data.

Key words: Mealybug dynamics, modelling, fuzzy logic, India.

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CASSAVA DISEASE RESEARCH IN CHINA AND THE CONTROL OF CASSAVA BACTERIAL BLIGHT (CBB)

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ABSTRACT

From 2007 to 2011, a cassava disease survey was conducted in Guangxi, Guangdong, Hainan, Yunnan, Jiangxi and Fujian Provinces, which are the main cassava planting areas in China. The results indicate that there were at least eight types of cassava diseases in China, of which seven were fungal diseases and one bacterial disease. Cassava Brown Leaf Spot (BLS), caused by *Passalora henningsii,* was the most frequently observed and most widespread disease, found in most cassava planting areas, while Cassava Bacterial Blight (CBB), caused by *Xanthomonas axonopodis* pv *manihotis,* was the most serious disease and the area affected was only slightly less than that of BLS. Bipolaris leaf spot caused by *Bipolaris setariae*; *Corynespora* leaf spot caused by *Corynespora cassiicola*; and *Phytophthora* root rot caused by *Phytophthora palmivora* were detected for the first time in China.

The pathogen causing CBB was isolated from diseased leaves collected in Guangxi province. The toxicity of twelve pesticides was determined by the toxic medium method. The results showed that 2% Triadimefon·30% Ethylicin emulsifiable concentrate (EC), 80% Ethylicin EC, 70% Mancozeb wettable powder (WP) and 72% Strepolin soluble powder (SP) had the lowest effective concentration and the best inhibitory effect, while 12.5% Myclobutanil SP, 20% Thiodiazole-copper SC and 20% Bismerthlazol WP had the highest effective concentration, but the worst inhibitory effect. Field tests of six pesticides were conducted in Zhanjiang City of Guangdong province in 2011, and the results indicate that 3% Zhongshengmycin WP, 2% Triadimefon·30% Ethylicin EC and 80% Ethylicin EC were effective in controlling the disease and were thus recommended to be used for field control.

Keywords: cassava, disease research, cassava bacterial blight (CBB), pesticide screening, China.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), belonging to the family *Euphorbiaceae*， is a shrubby perennial crop, which is widely planted in Africa, Latin America and Southeast Asia. It is the main source of calories in the daily diet for many people living in tropical regions. Cassava has the characteristics of high yield, tolerance of poor soil, wide adaptability and easy to plant. The crop was first introduced to China around 1820. Currently, cassava is widely planted in the southern part of China, and the cultivated area is about 400,000 ha. The roots of cassava are rich in starch, and are therefore used in the food, feed and bio-energy industries, as well as in other related industries in tropical areas of China where cassava plays an important part of the agricultural economy.

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Previously, cassava was not considered an important crop in China. For that reason there was only little research conducted on cassava diseases, and the results did not satisfy the current needs of the cassava industry. According to Lozano *et al.* (1981), there are more than 30 cassava diseases in the world, but only Cassava Bacterial Blight (CBB) and Cassava Anthracnose had been reported in China (Tang Xuecheng, 1984; Jiang Dongrong, 1993). In order to learn more about the types, the distribution and frequency of occurrence of cassava diseases, from 2007 to 2011 a disease survey was conducted in Guangxi, Hainan, Yunnan, Jiangxi and Fujian Provinces, which are the main planting areas of cassava in China.

CBB, caused by *Xanthomonas axonopodis* pv. *manihotis,* is one of the most important cassava diseases in the world（Boher and Verdier, 1995; Lozano, 1986). This is also one of the most devastating diseases in Latin America and Africa, and the yield losses have reached 12-90%. The root quality is also seriously affected, and under severe conditions the whole field may not be harvested. CBB is common in the rainy season, especially in typhoon weather, usually at the middle and late growth stages. When CBB infected cuttings are used for planting, this can also seriously affect plants in the early stages of growth. The pathogen usually infects the leaves and stems. The initial lesions are usually found on the mature leaves which are close to the soil, and then spread to the above leaves and nearby plants. CBB can be recognized by the presence of water-soaked angular spots and blight on the leaves as well as by shoot wilt, dieback, cankers and necrosis of some vascular strands on the stems. White or yellow gum exudations may be present on the lesions of the leaves and stems under high humidity conditions. Symptoms may differ depending on the resistance of the variety, the growth stage, the nutritional status and the weather.

After pathogen isolation and identification of CBB, a pesticide screening test was carried out in the laboratory, followed by a field efficacy evaluation.

EXPERIMENTAL PROCEDURES

Cassava disease survey

A survey of cassava disease incidence and severity were conducted from August to November of 2007, from May to November of 2008, from June to October of 2009, from May to August of 2010, and from August to October of 2011. These covered the cassava planting areas of Hainan, Guangxi, Guangdong, Yunnan, Jiangxi and Fujian provinces, and was referred to as “Invasive alien species investigation and security technology study program” (see Workshop on Chinese invasive alien species and their safety study, 2007）.

Strains, Media, and Pesticides

The strain XamGX11 was isolated from CBB samples from Beihai City of Guangxi Province. The isolation, purification, identification and pathogenicity test of this strain had been done by the Environment and Plant Protection Institute, Chinese Academy of Tropical Agricultural Sciences according to Koch's rule. The pathogen was cultured on YGP medium, which was the method described in “Plant Pathology Research Methods” by Fang Zhongda (1998). Twelve pesticides were used in this research, including five wettable powders (WP), three soluble powders (SP), two suspension concentrates (SC) and two emulsifiable concentrates (EC). The types and concentrations of pesticides are shown in **Table 1**.

Table 1. The pesticides used in this study.

Pesticides	Manufacturer/packaging manufacturer
32% Zhongshengmycin WP	Shenzhen Noposion Agrochemical Co., Ltd.
72% Strepolin SP	Shijiazhuang Shuguang Pharmaceutical Factory
20% Thiodiazole-copper SC	Zhejiang longwan Chemical Co., Ltd.
6% Kasugamycin SP	Shaanxi Welch Crop Protection Co., Ltd.
70% Mancozeb WP	Hebei Shuangji Chemical Industry Co., Ltd.
64% Oxadixyl•mancozeb WP	Suzhou Syngenta Crop Protection Co., Ltd.
20% Bismerthlazol WP	Wenzhou Pesticide Factory
22.7% Dithianon SC	Zhejiang Heyi Pesticide & Chemicals Co., Ltd
12.5% Myclobutanil SP	Hainan Zhengyezhongnong Gaoke Co., Ltd.
77% Copper hydroxide WP	Zhejiang Heben Pesticide Chemical Co., Ltd.
80% Ethylicin EC	Hainan Zhengyezhongnong Gaoke Co., Ltd.
2% Triadimefon•30% ethylicin EC	Zhengzhou Modern Chemical Co., Ltd.

Pesticides Screening in the Laboratory

The CBB pathogen was cultured at 28℃, 180 r/min for 48 hours in liquid YGP medium, and the suspension with the concentration of 10^6 CFU/mL was prepared with sterile water.

The minimum inhibitory concentration of toxic medium method was adopted in this study（Zhao Youfu and Zhang Le, 1992）. Each pesticide was diluted into five concentrations, and measured several times. The right amounts of sterile water (preparation for WP, SP and SC) and acetone (preparation for EC) were used to prepare the mother liquor of various pesticides. 0.5 ml mother liquor of each pesticide that was 100 times its treatment concentration was prepared by the series dilution method; this was added to 49.5 ml YGP medium that had been sterilized and cooled to about 50℃, then mixed evenly and poured into three petri dishes of 9 cm diameter to prepare the toxic medium. The same medium added with 0.5 ml sterile water or acetone was used as a control. 0.1 ml bacterial suspension was dropped on each plate, and coated evenly, then cultured at 28℃ for 48 hours to check the growth status of the pathogens. The results were checked and calculated according to the method of Mu Liyi (1999).

Efficiency Evaluation of Pesticides in the Field

Six pesticides were selected for efficiency evaluation in the field; their names and concentrations are listed in **Table 2**. This research was conducted in Suixi county of Zhanjiang City, Guangzhou Province, in 2011.

Table 2. The types and concentrations of pesticide used for field evaluation.

Pesticides	Concentration	Pesticides	Concentration
2% Triadimefon•30% Ethylicin EC	1500 times	6% Kasugamycin SP	1000 times
80% Ethylicin EC	1000 times	64% Oxadixyl•Mancozeb WP	800 times
70% Mancozeb WP	600 times	32% Zhongshengmycin WP	1000 times

A cassava field where CBB was quite serious last year was selected for this study. The field has a light-textured soil, is of moderate soil fertility, and is located on flat terrain. A total of nine treatments were set out (eight pesticide treatments and one control of water) with three replications. There were a total of 21 plots, each being 30x10 m, and three protection cassava lines were set in each plot. The cassava variety used in this study was SC8, and the variety for the protection lines was Nanzhi 199. The row spacing was 1 m, and plant spacing within the row was 60 cm. The cassava cuttings were planted on March 1 and the field was uniformly managed. The first spraying of the pesticide was done on July 10 and this was repeated two more times at 10 day intervals. The effectiveness of the spraying was evaluated after the first spraying, and again on the 40th day after the first spraying.

The effectiveness of each treatment was evaluated in every plot using a five-point scale. Five sites were evaluated in each plot, three plants for each site; five leaves each were taken from the upper, middle and lower parts of the cassava plant, giving a total of fifteen leaves from each plant. The leaves were classified according to the following standard: **grade 0**: the leaves were healthy without any lesions; **grade 1**: total lesion area accounted for less than 1/16 of total leaf area; **grade 3**: total lesion area accounted for 1/16-1/8 of total leaf area; **grade 5**: total lesion area accounted for 1/8-1/4 of total leaf area; **grade 7**: total lesion area accounted for 1/4-1/2 of total leaf area; **grade 9**: total lesion area accounted for more than 1/2 of total leaf area, or the leaves were yellowed and withered.

The disease index of each plot, decreased rate of disease, and corrected control efficiency of each pesticide were calculated according to the following formulas:

Disease index = (∑ leaf number of each grade × the number of the corresponding grade) / (total number of investigated leaves × the highest number of the grade) ×100

Decreased rate of disease = (disease index before treatment – disease index after treatment) / disease index before treatment ×100

Corrected control efficiency = (decreased rate of disease in each treatment – decreased rate in control) / (100- decreased rate of disease in control) × 100.

RESULTS

Survey on cassava disease incidence and severity

Eight diseases were identified to affect cassava in China, including seven fungal diseases and one bacterial disease. The *Bipolaris* Leaf Spot, *Corynespora* Leaf Spot and *Phytophthora* Root Rot diseases were the first to be found in China. It was found that Brown Leaf Spot (BLS) disease was the most widespread, while CBB was the most serious disease in China. For each disease, the infected tissues, the incidence at each site where the disease was detected, and the severity of infection of each cassava variety are shown in **Table 3**.

Table 3. Evaluation of disease incidence and severity of cassava fields in China.

Disease	Causal agent	Infected tissues	Sites and degree of disease incidence	Cassava varieties and their degree of disease severity
Cassava Bacterial Blight	*Xanthomonas axonopodis* pv *manihotis*	Leaves and stems	**Hainan**: Danzhou+, Wenchang++, Qionghai+, Qiongzhong+++, Baisha++ **Guangxi**: Nanning+, Wuzhou+, Beihai+++, Chongzuo++, Wuming+++ **Guangdong**: Zhanjiang+++, Yunfu+ **Yunnan**: Baoshan+++ **Jiangxi**: Wuzhou++	SC5+++, SC6+++, SC7+++, SC8+++, SC124++, SC205++, SC874+++, NZ188++, XX048+
Brown Leaf Spot	*Passalora henningsii*	Leaves	**Hainan**: Danzhou +++, Wenchang +, Qionghai\+, Baisha +++, Changjiang++, Tunchang++ **Guangxi**: Wuzhou+, Guigang+, Nanning+, Beihai+++, Chongzuo++, Yulin+, Hepu++ **Guangdong**: Zhanjiang ++, Maoming++,Yunfu++, Zhaoqing+ **Yunnan**: Wenshan++, Honghe+	SC5+++, SC6+++, SC7++, SC8+++, SC9++, SC10+++, SC124++, SC205+++, SC874+++, NZ188++, XX048+++, GR4+++
Anthrac-nose	*Colletotrichum gloeosporioides*	Leaves and stems	**Hainan**: Danzhou+, Baisha++ **Guangxi**: Beihai+, Nanning+, Wuming+++ **Guangdong**: Zhanjiang+, Maoming+ **Yunnan**: Wenshan+	SC5+++, SC6++, SC7+++, SC8+++, SC9+++, SC10++, SC124+++, SC205+++, NZ188+++, NZ199++, SC874++
Bipolaris Leaf Spot	*Bipolaris setariae*	Leaves	**Hainan**: Danzhou+ **Guangxi**: Beihai+ **Yunnan**: Honghe+	SC8++, SC205+++, NZ188+, SC874+
Coryne-spora Leaf Spot	*Corynespora cassiicola*	Leaves	**Hainan**: Danzhou+, Baisha++ **Guangxi**: Wuming+, Beihai++ **Guangdong**: Maoming+, Zhanjiang+	SC8+++, SC205++, SC874+++
White Leaf Spot	*Phaeoramularia manihotis*	Leaves	**Hainan**: Danzhou+, Baisha+ **Guangxi**: Hepu+, Wuming+++ **Guangdong**: Zhangjiang+, Zhaoqing++, Maoming++	SC5+, SC8, SC5++, GR4++
Blight Leaf Spot	*Cercospora vicosae*	Leaves	**Hainan**: Changjiang+, Baisha++ **Guangxi**: Wuming++ **Yunnan**: Honghe++, Wenshan +	SC5+, SC8+++, SC205++, NZ199++, XX048++
Phytoph-thora Root Rot	*Phytophthora palmivora*	Leaves	**Hainan**: Danzhou ++ **Guangdong**: Zhangjiang + **Yunnan**: Dehong+++	SC205+++, NZ199++, SC5++，SC8++, SC11+

Note: “+” means slight disease, “++” means moderate disease, “+++” means serious disease.

Toxicity of Pesticides

The inhibitory effects of twelve pesticides against the CBB causal agent XamGX11 are shown in **Table 4**. The results indicate that 2% Triadimefon•30% Ethylicin EC had the lowest effective concentration against the pathogen, while its effectiveness was the highest. The minimum inhibitory concentrations of 80% Ethylicin EC, 70% Mancozeb WP and 72% Strepolin SP were lower than 15 mg/L, and they were highly effective. The minimum inhibitory concentrations of 6%

Kasugamycin SP, 64% Oxadixyl•Mancozeb WP, 32% Zhongshengmycin WP, 22.7% Dithianon SC and 77% Copper hydroxide WP were 20.0, 45.0, 60.0, 73.3 and 75.0 mg/L, respectively, and these were quite effective as well. The minimum inhibitory concentrations of 12.5% Myclobutanil SP, 20% Thiodiazole-Copper SC and 20% Bismerthlazol WP were 312.5, 500.0 and 800.0 mg/L, respectively, and their effectiveness was poor.

Table 4. Inhibitory effect of different pesticides against the pathogen of CBB.

Pesticides	Concentrations (mg/L)					Repeat times	Minimum effective concentration
2% Triadimefon•30% Ethylicin EC	50	25	12.5	6.25	3.125	3	9.4
80% Ethylicin EC	50	25	12.5	6.25	3.125	3	12.5
70% Mancozeb WP	50	25	12.5	6.25	3.125	4	12.5
72% Strepolin SP	60	30	15	7.5	5	3	15
6% Kasugamycin SP	80	60	40	20	10	5	20
64% Oxadixyl•Mancozeb WP	100	75	50	25	12.5	3	45
32% Zhongshengmycin WP	120	60	40	30	20	4	60
22.7% Dithianon SC	200	100	80	50	25	3	73.3
77% Copper hydroxide WP	200	150	100	50	25	5	75
12.5% Myclobutanil SP	500	250	125	62.5	31.25	3	312.5
20% Thiodiazole-Copper SC	800	400	300	200	100	3	500
20% Bismerthlazol WP	1600	800	400	300	200	3	800

Evaluation of field effectiveness of six pesticides

The field effectiveness of six pesticides were determined in 2011, and the results, shown in **Table 5,** indicate that the control effectiveness of 80% Ethylicin EC, 3% Zhongshengmycin WP and 2% Triadimefon•30% Ethylicin EC were the best at 77.33%, 63.36% and 52.95%, respectively. These were followed by 70% Mancozeb WP, with the control effectiveness of 45.64%. The effectiveness of 6% Kasugamycin SP and 64% Oxadixyl•Mancozeb WP were poor, as they were lower than 30.65%.

Table 5. Field effectiveness of six pesticides against Cassava Bacterial Blight (CBB).

Pesticides	Average disease index before treatment	Disease index after treatment				Corrected control effectiveness (%)
		Plot 1	Plot 2	Plot 3	Average	
2% Triadimefon•30% ethylicin EC	3.1	22.3	19.7	27.8	23.2	52.95
80% Ethylicin EC	3.3	11.4	12.2	12.1	11.9	77.33
70% Mancozeb WP	3.4	30.3	28.6	29.3	29.4	45.64
6% Kasugamycin SP	2.9	40.2	38.3	37.8	38.8	15.89
64% Oxadixyl•mancozeb WP	3.3	37.6	39.3	32.4	36.4	30.65
32% Zhongshengmycin WP	3.5	18.4	20.2	22.6	20.4	63.36
Water control	3.2	46.8	54.7	51.3	50.9	—

DISCUSSION

Cassava has become an economically important and major energy crop in China, and it plays an outstanding role in related industries in tropical or subtropical areas. From 2007 to 2011 a disease survey was conducted in the main cassava growing areas of the country. The preliminary results show that only two main categories and eight types of diseases were found, although some other minor unknown diseases may affect small areas. There are three types of quarantine cassava diseases in China, i.e. Cassava Bacterial Leaf Spot and mosaic virus but they were not found, while Cassava Bacterial Blight (CBB) was found to be the most serious disease and was also the most widespread after Cassava Brown Leaf Spot (BLS). The area affected by BLS was the largest and this disease was also quite serious in China. Anthracnose, White Leaf Spot and Blight Leaf Spot were also found but were less serious and less abundant. In addition, three diseases, namely *Bipolaris* Leaf Spot, *Corynespora* Leaf Spot and *Phytophthora* Root Rot were found for the first time in China (Liu *et al.,* 2010; T. Shi *et al.,* 2010; H. Guo *et al.,* 2012). All these cassava diseases could become serious limiting factors for the cassava processing industries.

The toxicity of twelve pesticides to control the pathogen of CBB was determined in this study. The results show that 2% Triadimefon•30% Ethylicin EC, 80% Ethylicin EC, 70% Mancozeb WP and 72% Strepolin SP had the greatest inhibitory effects. The inhibitory effects of pesticides used in this test are ranked as follows: 2% Triadimefon•30% Ethylicin EC, 80% Ethylicin EC, 70% Mancozeb WP, 72% Strepolin SP, 6% Kasugamycin SP, 64% Oxadixyl•Mancozeb WP, 32% Zhongshengmycin WP, 22.7% Dithianon SC, 77% Copper hydroxide WP, 12.5% Myclobutanil SP, 20% Thiodiazole-Copper SC, and 20% Bismerthlazol WP.

A field test indicated that application of 32% Zhongshengmycin WP, 2% Triadimefon•30% Ethylicin EC and 80% Ethylicin EC were the most effective in the control of CBB, so these pesticides were recommended for the control of CBB in cassava fields.

The preliminary research results show that CBB often occurs together with various fungal diseases, such as Brown Leaf Spot, Anthracnose, *Bipolaris* Leaf Spot, *Corynespora* Leaf Spot etc. Since there were demands for simultaneous control against several types of diseases in cassava fields, three typical fungicides, namely Mancozeb, Oxadixyl•Mancozeb and Myclobutanil, have been selected to evaluate their inhibitory effects against CBB. Yuan Gaoqing *et al*.（2004）also screened various control agents against CBB, and found that Streptomycin, Oxadixyl•Mancozeb, Mancozeb, Amobam and Thiram had good inhibitory effects. Our current study also found that Mancozeb and Oxadixyl•Mancozeb had good inhibitory effects, while Myclobutanil was relatively less effective. Mancozeb can inhibit the synthesis of pyruvate to hinder the growth of the pathogen; it also contains Zn to increase the ability of cassava plants to resist CBB. Myclobutanil is a steroid demethylation inhibitor, specifically inhibiting ergosterol biosynthesis, which is only found in cell membranes of fungi and protozoa, not in bacterial cells. So in our research the control effects of Mancozeb and Oxadixyl•Mancozeb were found to be better than that of Myclobutanil.

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EMERGING DISEASES AND PESTS OF CASSAVA IN VIETNAM

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INTRODUCTION

Cassava plays an important socio-economic role in Vietnam. Particularly in some of the poorer rural communities, cassava is critical for food and livestock feed. With increasing domestic and export demand, cassava is now grown on over half a million hectares by more than two million households and contributes to both poverty reduction and export income for the country. However, significant threats to cassava production are some of the recently emerging disease and insect pest problems that have occurred since about 2008.

Major Diseases

. The most important disease is Cassava Witches' Broom (CWB), the typical symptom of which are the stunting of infected plants and the excessive proliferation of branches, small shoots with small leaves and shortened internodes, as well as vascular browning. This disease has affected cassava production in many regions of the country, especially in varieties KM-94 (=KU50) and in KM-140. In 2010, the area affected was estimated at 45,000 ha, causing local reductions of 10-15% in yield and 25-30% in starch content. Using molecular tools, we have detected and identified a phytoplasma associated with CWB. Under the Transmission Electron Microscope (TEM), this phytoplasma was detected only in CWB-symptomatic plants and had a round or oval shape. An amplicon with approximately 1.2 kb was amplified using nested-PCR with two universal primer pairs. The RFLP profile suggested that all the tested samples were infected by the same phytoplasma.

Another rather wide-spread disease is Cassava Bacterial Blight (CBB), caused by *Xanthomonas axonopodis* pv. *manihotis*. This disease has also a significant economic effect on cassava production. The typical symptoms occur initially as angular, water-soaked leaf spots, which rapidly expand before turning brown. Leaves wilt, desiccate, roll and fall off. Petioles are also attacked, leading to vascular infection of young shoots, as well as stem rot and dieback. Yellowish exudate often collects in droplets on leaf spots or is exuded from cracks that develop on young infected stems and petioles. There is no good estimate of the effect of CBB on cassava starch content and yield.

Cassava Anthracnose Disease (CAD), caused by the fungus *Colletotrichum manihotis or Gloeosporium manihotis,* is widely detected in most cassava-growing provinces of Vietnam. It usually affects first the leaves and the upper stem. CAD is

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characterized by cankers on the stems, branches with leaf spots and die-back. It is considered of major importance due to its potential to cause major stem damage. Infected plants usually wilt and die partly, starting from the top to the base.

Major Pests

The pink mealybug (*Phenacoccus manihoti*), which has caused serious problems in Thailand and Cambodia, along with a number of other pests, pose additional threats to cassava production in Vietnam. Until now, the population of this mealybug has been low and has been mainly found in the southern provinces of Vietnam. However, we suspect that it will become a major problem, not only for the south but for the whole country in the near future if we do not control its population from now on.

The following steps are recommended for the integrated management of these cassava pests and diseases:

- Destroy completely all the infected plants and weeds after the cassava harvest to eliminate any inoculum remaining in the field
- Do not use infected planting material or transfer stem cuttings from infected areas to other regions to prevent the spread of diseases and insect pests
- Rotate with other crops, such as peanut, soybean or maize
- Establish nurseries of disease- and pests-free planting material and provide these stems to cassava farmers
- Use resistant or highly tolerant varieties for management of CWB, CBB and other diseases or pests
- Identify the insect vector(s) (if any) responsible for the transmission of CWB.
- Control the population of the pink mealybug in the southern provinces by the use of chemical methods.

WEED MANAGEMENT IN CASSAVA

M. Nedunchezhiyan[1], R.S. Misra[1] and S.K. Naskar[1]

Cassava weed infestation at the early stage of growth causes severe yield losses. It is one of the major concerns in cassava-growing areas in India. Weeding consumes about 30 percent of total labor input and about 150-200 person-days/hectare. In Tamil Nadu, farmers do up to five manual weedings costing US$233/hectare. Availability of laborers during the peak season for weeding is a major problem in commercial cassava-growing areas. Chemical weed control can reduce the dependency on hand weeding. However, its effect on cassava yield and starch content has received scant attention in the literature. An experiment was therefore conducted to study the effect of hand and chemical weeding on cassava.

A field experiment was conducted during 2010/11 in a randomized block design with three replications at the Regional Centre of CTCRI, Bhubaneswar, Orissa. The ten treatments consisted of a weedy check; two hand weedings (one and two months after planting [MAP]); four hand weedings (1, 2, 3 and 4 MAP); Oxyfluorfen application at 0.06 kg a.i./ha (pre- emergence); Oxyfluorfen application at 0.06 kg a.i./ha (pre-emergence) + one hand weeding (3 MAP); Oxyfluorfen application at 0.06 kg a.i./ha (pre-emergence) + two hand weedings (2 and 3 MAP); Glyphosate application at 2.0 kg a.i./ha (post-emergence at 1 MAP); one hand weeding (1 MAP) + Glyphosate application at 2.0 kg a.i./ha (post-emergence at 2 MAP); two hand weedings (1 and 2 MAP) + Glyphosate application at 2.0 kg a.i./ha (post-emergence at 3 MAP); and black polythene mulch. The variety H-226 was planted at 75x75 cm spacing and managed with the recommended package of practices. Post-emergence herbicides were applied directly on the weeds.

The major weed species observed were *Cyperus rotundus, Cyanodon dactylon, Amaranthus viridis, Cleome viscose* and *Portulaca oleraceae*. The highest root yield (38 t/ha) was recorded with four hand weedings (1, 2, 3 and 4 MAP). This was statistically comparable with the application of Oxyfluorfen at 0.06 kg a.i./ha (pre-emergence) + two hand weedings (2 and 3 MAP), black polythene mulch and two hand weedings (1 and 2 MAP) + Glyphosphate at 2.0 kg a.i./ha (post-emergence at 3 MAP). Lower weed infestation in the above treatments led to higher cassava root yields. Higher weed density and the application of post-emergence herbicide reduced the starch content of the roots. The lowest starch contents in the roots were observed in the weedy check and in the post-emergence application of Glyphosate at 2 and 3 MAP along with hand weeding. This might be due to higher weed density in the former case, and the residual effect of Glyphosate in the latter case. Though post-emergence application of Glyphosate did not affect the cassava root yield, it drastically reduced the starch content of the roots. The highest net return was observed in the four hand weeding treatment (1, 2, 3 and 4 MAP). It was followed by pre-emergence application of Oxyfluorfen + two hand weedings (2 and 3 MAP). Though post-emergence application of Glyphosate in the 2 and 3 MAP treatments recorded higher root yield, the net returns were lower due to the lower starch content. Black polythene mulch resulted in lower net return and benefit-cost-ratio due to its higher cost of cultivation in spite of higher root yield.

It can be concluded that four hand weedings were required for higher root yield, starch content and net returns. When labor is scarce, weeds can also be managed by pre-emergence application of Oxyfluorfen (0.06 kg a.i./ha) + two hand weedings (2 and 3 MAP) or two hand weedings (1 and 2 MAP) + post-emergence application of Glyphosate (2.0 kg a.i./ha) at 3 MAP.
Key words: cassava, weed management, chemical application, labor shortage, India

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EVALUATION OF THE INDUSTRIAL POTENTIAL OF NOVEL CASSAVA STARCHES WITH LOW AND HIGH AMYLOSE CONTENTS IN COMPARISON WITH OTHER COMMERCIAL STARCH SOURCES

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The industrial starch market is undergoing major expansion, but certain specific industrial uses cannot be satisfied by native starches; therefore, chemical or physical modification is necessary. These modifications are often harmful to the environment and generate additional costs. Mutations in cassava starch biosynthesis pathways were recently discovered at CIAT, Cali, Colombia. CIRAD, in partnership with CIAT, carried out a study on the physicochemical and functional properties of these starches, which could result in interesting industrial applications and create new markets for cassava starch.

Among the new cassava starch types, two new mutant cassava starches with extreme amylose contents (0 and 31 percent) have been recently reported. These mutants are drastically different from normal cassava starch whose amylose content typically ranges between 15-25 percent. The new mutants were compared with normal cassava starches and commercial versions of amylose-free cassava, or with normal potato, rice and maize starch. The structure of cassava amylopectin was not modified by the waxy (amylose-free) mutation and waxy cassava starch exhibited properties similar to those of waxy maize starch.

On the contrary, the higher-amylose mutations, induced by gamma rays, in cassava deeply modified the branching pattern of amylopectin as well as other starch characteristics and properties. These modifications resulted in changes in starch granule ultrastructure (e.g. decreased starch crystallinity), a weak organized structure and increased susceptibility to mild acid and enzymatic raw starch hydrolysis (fastest and most efficient hydrolysis of all studied native starches). This mutation could offer interesting advantages for the production of bioethanol. Gels from normal root and tuber starches (potato, cassava) after refrigeration and freeze/thaw had lower syneresis than cereal starches (maize, rice). Gels from waxy starches (except for potato) did not present any syneresis after five weeks of storage at 4°C. Waxy cassava starch was the only one not showing any syneresis after five weeks of storage at -20°C.

The distinctive properties of the new cassava starches suggest new opportunities and commercial applications for tropical sources of starch.

Key words: Novel cassava starches, industrial potential, commercial starch.

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SIMPLE TECHNOLOGY FOR SAFE FEEDING OF BYPRODUCTS OF THE CASSAVA INDUSTRY TO RUMINANT ANIMALS AS PRACTICED BY FARMERS IN EAST JAVA, INDONESIA

Marjuki[1]

ABSTRACT

A field survey was conducted to study the production of byproducts by the small-scale cassava processing industry, and its utilization by farmers as feed for ruminants. The survey was conducted in four areas with small-scale cassava processors in East Java, i.e. the cassava starch industry in Blitar and Kediri Districts, and the cassava *krupuk* (crackers) industry in Batu and Malang Districts.

Byproducts produced by the cassava starch industry potentially useful as animal feed are in the form of cassava peel and cassava pulp (wet fibrous residue), either mixed or separate, while those produced by the cassava *krupuk* industry are only in the form of cassava peel. All the produced pulp is used as ruminant feed. Cassava peel is entirely used as ruminant feed during the dry season, but only a part of the peel produced during the rainy season is used as feed. Cassava pulp is directly fed to ruminants in fresh (wet) form mixed with concentrate feed, rice bran or wheat pollard at a ratio of 2 to 5 parts of wet pulp to one part of concentrate, rice bran or wheat pollard, on a volume basis. Farmers feed cassava peel to ruminants after it is sun-dried, or just simply by storing fresh cassava peel in woven bags or in bamboo baskets covered with a woven bag to let it ferment for four or five days. Cassava peel is used to substitute about 50 to 70% of forage given to ruminants on a wet basis. Using these methods, farmers can safely feed these byproducts to ruminants. No case of cyanide toxicity in ruminants has been experienced by farmers. The ruminants seem to prefer consuming fermented cassava peels rather than the unfermented peels. Almost all households operating these small-scale cassava starch industries also raise ruminant livestock (goats, sheep or cattle) as part of their enterprises, or they sell the excess to other farmers who raise ruminants.

Key words: cassava, feed, peel, pulp, ruminants, Indonesia.

INTRODUCTION

In some areas of Indonesia the production of ruminants has faced serious problems from time to time. As the human population has grown, this has resulted in some consequences, including an increase in the demand for livestock products. In contrast, the availability of resources which support livestock production has decreased, mainly the availability of land used as forage resources for ruminants. This condition has become most serious in highly populated areas, such as East Java, which is part of the most densely populated island of Indonesia. In addition, average land ownership by farmers in Indonesia is very small, usually not more than 0.5 ha per farm family. The first priority of use of the land is for food crops rather than for forage production. Almost no land is specifically used for growing fodder. Consequently, the demand for non-conventional feedstuffs, including crop residues and industrial byproducts, for use in animal diets, has increased.

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Cassava is one of the most important food crops in Indonesia, after rice and maize. Indonesia is also the third largest cassava producer in the world, after Nigeria and Thailand, and the second largest cassava producer in Asia, after Thailand (FAOSTAT, 2014). Cassava is cultivated in Indonesia mainly for industrial processing, and also, to a lesser extent, for direct human food. The cassava industry produces byproducts mainly in the form of cassava pulp (wet fibrous residue after starch extraction) and root peels. These byproducts have potential use as animal feed, as reported by many authors and reviewed by Iyayi and Losel (2001), ITTA (2005), Moran (2005) and Ubalua (2007). Grace (1977) reported that cassava pulp contains about 56.0% starch, 35.9% crude fiber, 5.3% protein, 0.1% fat and 2.7% ash, on a dry matter basis. The nutrient content of cassava peel, as reported by Oboh (2006), is carbohydrate 64.6%, crude fiber 12.5%, protein 8.2%, fat 3.1% and ash 6.4%, on a dry matter basis. With these nutrient contents, cassava pulp as well as peel must have potential use as an energy feed source, especially for ruminant animals. Unfortunately, the byproducts, mainly cassava peels, are known to contain high levels of hydrogen cyanide, which is toxic to the animals. There are some methods, however, to decrease the potential toxicity to the livestock of hydrogen cyanide in cassava byproducts. This paper reports the methods practiced by farmers in safely feeding cassava byproducts to ruminant animals in East Java, Indonesia.

MATERIALS AND METHODS

The research was conducted with households involved in home-scale cassava processing in Blitar, Kediri, Malang and Batu Districts of East Java Province, Indonesia, in June-July 2010. A Rapid Rural Appraisal (RRA) was conducted, followed by a survey. The RRA was aimed to get general information about home-scale cassava processing. During the RRA, interviews and discussions were held with key persons, including owners of home-scale cassava processing facilities and workers, as well as ruminant livestock farmers who utilize cassava industry byproducts as feed. Based on the RRA data, five home-scale cassava starch processors each in Kediri and Blitar Districts, and three and five cassava cracker industries in Malang and Batu Districts, respectively, were selected as respondents and were further studied. A semi-structured questionnaire was prepared and used for interviewing the respondents during the survey. The main points listed in the questionnaire were about how cassava was processed to produce the main products and/or by-products, how the byproducts were produced, managed and utilized, and the reason for utilizing the byproducts.

RESULTS AND DISCUSSION

The cassava industry in East Java, Indonesia, is mostly for production of starch, and to a lesser extent for production of *krupuk* (crackers), *thiwul* (small starch kernels similar to sago), and sorbitol. Based on the quantity of cassava roots processed and machinery used, cassava starch production can be grouped into three sectors, i.e. large (industrial), medium, and small or home-scale industries (Marjuki, 2010). The descriptions of the three scales of the cassava starch industry are summarized and presented in **Table 1**, while cassava crackers and *thiwul* production is done only at the home-scale level.

Table 1. Description of three scales of the cassava starch industry in East Java, Indonesia.

Industrial (large) scale	- Whole roots are mechanically washed, grated, and pressed to extract the starch and the resulting waste/pulp. Finally the starch is dried with hot air - Fully mechanized - Capacity : 100-500 tonnes of roots/day
Medium-home scale	- Roots are sorted, peeled, and washed by hand, grated and screened to extract the starch and the resulting waste/pulp. Finally, the starch is sun-dried - Partly mechanized (grating and screening) - Capacity 5-10 tonnes of roots/day
Small-home scale	- Roots are sorted, peeled, washed, grated and washed and squeezed with water to extract the starch and the resulting waste/pulp. Finally, the starch is sun-dried - Fully done by hand except for grating - Capacity 200-300 kg of roots/day

Source*: Marjuki, 2010.*

With respect to their by-products, the industries produce different types of byproducts. At the large (industrial)-scale of the cassava starch industry, processing of the roots into starch is completely mechanized, starting from washing and rasping/grating whole cassava roots (without peeling), as well as extracting and drying the starch; only the sorting and cutting off the stem part of some roots is done by hand. This sector of the cassava industry produces byproducts in the form of mixed cassava pulp and peel skin residues. These byproducts are entirely sold and distributed to farmers and are intensively used as animal feed, especially for dairy cattle (Marjuki, 2010).

Unlike the large-scale sector, at the medium- and small-scale level of the cassava starch industry, cassava roots are peeled by hand prior to washing and grating, followed by sieving, settling, removing the water, collecting the settled starch and sun-drying. Thus, the medium- and small-scale sectors of the cassava industry produce separate byproducts of cassava pulp and peel. Cassava pulp produced at these two smaller scales must have lower levels of hydrogen cyanide than those produced by the large-scale sector, as the cyanic acid content is mostly concentrated in the peel. The medium-scale sector partly uses machinery, including for grating of peeled cassava roots and sieving the starch, while the other processes are done by hand, and the drying of starch is done by sun-drying. At the medium-scale, about 3-5 tonnes of cassava roots are processed per day per industrial unit. The small-scale cassava starch industry uses mostly manpower in the processing of cassava roots to produce starch. The only equipment used in this process is a machine for grating cassava roots.

In the small-scale sector of the cassava starch industry, most processing is done by household relatives in groups, with 5 to10 members per group. Each group is coordinated by one household. Most often, the members work for the coordinator. The coordinator provides the cassava roots as raw material and a communal machine for grating the roots, while the members have the responsibility to do all the remaining processes to produce cassava starch. The members have to return dried cassava starch back to the coordinator and they receive 5 kg of dry starch as payment for every 20 kg of dry starch that they have submitted to the coordinator. In addition, the members could also take home the peels, culled small-size cassava roots, and the pulp to feed their own livestock. Almost all households operating at this level of the cassava starch industry also rear ruminant livestock (goats, sheep or cattle) as a part of their enterprise. These households utilize byproducts of the cassava starch industry as additional or supplemental feed for their ruminants, and they sell the excess to other farmers. Some households store the excess cassava peel in dry form and use it as feed when there is a lack of other feed available. Households working in the cassava industry but not rearing ruminant livestock, sell the byproducts of their cassava industry to other farmers, especially the cassava pulp. The cassava peel is usually given free to other farmers. Workers hired to work in the cassava industry are allowed to take home for their ruminant livestock the cassava peel and pulp produced from the amount of roots they had processed.

Cassava peel is entirely used as ruminant feed during the dry season, but only a part of the peel produced during the rainy season is used as feed. Cassava pulp is fed to ruminants in fresh (wet) form, mixed with concentrate feed, rice bran or wheat pollard at a ratio of 2 to 5:1 on a volume basis, as reported by Marjuki (2010). However, for feeding cassava peel, to reduce the risk of cyanide toxicity, farmers feed the peel to ruminants only after it is sun-dried, or just simply by storing fresh cassava peel in woven bags or in bamboo baskets covered with a woven bag to let it ferment for four or five days. Cassava peel is used to substitute 50-70% of the forage given to ruminants on a wet basis. The farmers found that by these feeding methods, especially for cassava peel, they can avoid the risk of cyanide toxicity for their ruminant livestock. There has been no case of cyanide toxicity in livestock experienced by farmers. There were two possible reasons for this condition. First, the ruminant had been accustomed to consuming cassava peels, because most farmers provide some period of adaptation in feeding cassava peels when livestock is fed these byproducts for the first time. Secondly, drying or fermenting the peel decreased its hydrogen cyanide content due to the effect of heat during drying or microbial activity during the fermentation processes (Tewe, 1992; Tweyongyere and Katongole, 2002; Salami and Odunsi, 2003; Oboh, 2006). It is also observed in the field that fermented cassava peels are more palatable to the cattle as compared to the unfermented peels. This might be related to a better flavor and lower hydrogen cyanide content of the fermented cassava peels.

CONCLUSSIONS

Cassava pulp and peel, the principle byproducts of the cassava industry, have good potential as feed and have been widely used in ruminant feeding, especially for small-holder farmers. However, attention needs to be paid for safely feeding these products by avoiding cyanide toxicity of the products to the animals, especially when feeding cassava peel. Drying and fermentation are effective pretreatments to reduce the hydrogen cyanide content of the products. When feeding these byproducts for the first time, it is suggested to give some time for the animals to adapt, as this helps to reduce the risk of toxicity.

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A SIMPLE TECHNOLOGY FOR THE PHYTOREMEDIATION OF WASTE WATER DISCHARGED FROM CASSAVA STARCH FACTORIES

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ABSTRACT

Indonesia is known as one of the largest cassava (*Manihot esculenta* Crantz) producers in the world. Cassava plays an important role in Indonesian society and economy. In the past, cassava was an important food crop, mainly for the poor rural and urban sectors of the population. However, the use of cassava as a food is now declining, and its use for industry is becoming more and more important. The cassava starch industry in Indonesia, especially in Java, is mostly small- to medium-scale. These factories play an important role in the rural community; however, these small and often simple industries also create very serious environmental problems. The cassava factories generate a large volume of solid and liquid waste. Because of their high cost, most of these small- to medium-scale starch factories do not have efficient waste water treatment facilities and mostly discharge their liquid waste directly into rivers. Therefore, a simple and low cost waste water treatment technology would be very useful.

Experiments were carried out to explore the potential use of vetiver grass (*Vetiveria zizanoides* L.) to remediate waste water discharged from cassava starch factories. The first experiment studied the ability of vetiver grass to improve the quality of this waste water, while the second experiment tested the remediated waste water for various uses in agriculture.

The experimental results show that vetiver grass not only tolerated and grew well in a medium that contained waste water discharged from a starch factory, but the grass was also very effective in improving the quality of the waste water. The remediation efficacy was influenced by the two systems being used – both the wetland and hydroponics systems – as well as the age of the vetiver plants at the start of the remediation process. Vetiver remediation was more efficient in a wetland system than in a hydroponic system. To achieve the water standard quality mandated by the East Java Province of Indonesia, with the initial waste water having a biological oxygen demand (BOD) of 3,600 mg/l, a chemical oxygen demand (COD) of 3,840 mg/l and a hydrogen cyanide (HCN) content of 4.2 mg/l, the required plant density for 30 days remediation was $\geq$ 65 g dry biomass/1,256 cm^2. The resulting remediated waste water was safe for use in agriculture, both for growing maize and for fish culture.

Keywords: organic waste, vetiver grass, phytoremediation, cyanide, aquaculture, Indonesia.

INTRODUCTION

In the past, cassava in Indonesia was mainly grown for human food. However, since 2007 the use of cassava as a food has been declining and this now accounts for only 53% of total production (*versus* 64% in 2002). Its use for the production of starch, modified starch, sorbitol, and fuel-ethanol is becoming more and more important (CBS, 2007). The most common cassava processing industry in Indonesia are starch factories (locally known as tapioca factories), and these are mainly small- to medium-scale industries. Wargiono and Suyamto (2006) reported that from 423 tapioca factories in Indonesia, 340 factories can be categorized as small- to medium-scale industries, and 299 of these factories are operated in Java. This is good, because it increases the use of cassava and farmers' income, both through the creation of employment and of value-

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added products. However, these small and often simple tapioca factories create environmental problems because most of them lack the infrastructure for efficient waste water treatment, and directly discharge their liquid waste into rivers.

Hien *et al.* (1999) calculated that in order to produce 1 tonne of starch, a tapioca processing factory discharges about 12 m^3 of waste water with a pH of 4.5-5.0, and having a chemical oxygen demand (COD) of 11,000-13,500 mg/l, and total suspended solids (TSS) of 4,200-7,600 mg/l. Mai *et al.* (2004) reported that the concentration of cyanide in the waste water of a large-scale tapioca factory in Vietnam could be as high as 19-28 mg/l.

The acidic nature of the tapioca waste water can harm aquatic organisms and interfere with normal ecosystem functions in the receiving stream. Suspended solids present in the waste water are primarily organic in nature; they decompose easily and thus reduce the oxygen concentration of the water. Similarly, the high biological oxygen demand (BOD) of the waste water can also cause rapid depletion of the oxygen content in the receiving water body and promote the growth of nuisance organisms (eutrophication). In addition, cassava is a plant containing cyanide compounds, which are well-known as metabolic inhibitors.

Toxicity problems in the Brantas River, one of the most important rivers in East Java, due to waste water from tapioca factories have been reported since 1996, and continuously occur every year, especially during the dry season (Ecoton, 2003; Rohimah, 2009). Serious environmental problems associated with the discharge of tapioca waste water have also been reported in many other countries, such as India (Padmaja *et al.*, 1990) and Thailand (Rajbhandari and Annachhatre, 2004).

The simplest system to treat waste water from a tapioca factory is the open pond system in which solid materials settle and the organic compounds degrade naturally by means through chemical or microbial pathways (Rajbhandari and Annachhatre, 2004). However, this system needs a large area of land (Hasanuddin, 2008), and often results in poor degradation. The application of chemical substances to treat waste water is not recommended because of the high price and environmental risk associated with such treatments. It seems that the more appropriate technology for waste water management of small- to medium-scale tapioca companies is the use of phytoremediation. This technique is relatively simple, cheap, possesses a relatively low risk, and has been proven to work very well for both metal and organic compounds (Alkorta and Garbisu, 2001; Cunningham and Ow, 1996; Salt *et al*., 1998; and Trap and Karlson, 2001).

The application of phytoremediation for cleaning up waste water has been discussed extensively by Schröder *et al.* (2007). Bindu *et al.* (2008) used taro (*Colocasia esculenta)* to remove pollutants from domestic waste water. The potential of water hyacinths (*Eichhornia crassipes*) for tapioca factory waste water management has been studied by Jauhari *et al.* (2003). Truong *et al.* (2008) extensively studied the use of vetiver grass (*Vetiveria zizanioides* L.) for waste water management, and reported good potential for the use of this species owing to the ability of vetiver grass to tolerate toxic conditions, and to grow very fast with a high yield of biomass. Indrayatie *et al.* (2013) has shown the effectiveness of vetiver grass for remediation of tapioca factory waste water.

The study reported here was conducted to develop a simple technology in employing vetiver grass for remediation of waste water generated by the tapioca industry. The objective of this work was to clean waste water to meet the standard mandated by the government. In addition, to ensure the effectiveness of the remediation, the cleaned waste water was also tested for its potential use in agriculture and fish culture.

MATERIALS AND METHODS

Experimental Procedure

Two experiments were conducted in a glasshouse at Brawijaya University, Malang, Indonesia. The first study aimed to explore the potential of vetiver grass for phytoremediation of tapioca factory waste water, and the second experiment tested the resulting cleaned waste water for growing maize and for fish culture.

The technology developed in this study was directed to determining the most suitable growth medium and the best time (age) of the vetiver grass for the remediation to be most effective. Two growth media were used, i.e. (1) a wetland system, consisting of a soil flooded with waste water, and (2) a hydroponic system, consisting of only the waste water. The best time of starting the remediation was determined by starting the waste water treatment at 15, 30, 45, 60, and 75 days after planting the vetiver grass in the two media. These 10 treatment combinations were arranged in a Completely Randomized Design, with four replications. As the control, vetiver grass was grown in wetland and hydroponic systems using de-ionized water.

Vetiver plantlets with a height of 30 cm and root length of 5 cm were planted on 15 kg of wetland soil as well as in a 15 liter hydroponic system in a plastic pot of 35 liter capacity. The waste water was applied to each system for 60 days, and the waste water quality was measured periodically at 4, 8, 15, 30, 45, and 60 days after the start of remediation. The height of flood water was maintained by adding waste water or de-ionized water every 7 days. The waste water used for this purpose was diluted so that it had the same characteristics as the experimental treatments at the time of each waste water addition.

At the time of harvest, the plants were measured for biomass, cyanide concentration in plant tissue, and a Tolerance Index (TI) was determined. The quality of the treated waste water was determined by measuring pH, biological oxygen demand (BOD), chemical oxygen demand (COD), and the concentrations of cyanide and dissolved oxygen (DO)

In the second study, two experiments were conducted to determine the suitability of the remediated waste water for growing maize and for fish culture. The result of the first experiment indicated that the best remediation was found to be using 75-day old vetiver plants and after 30 days of remediation time; this remediated waste water was used for fish culture and maize growing. In addition, as the control, the experiment also used the factory-treated waste water, as well as the untreated factory waste water for fish culture and maize growing. The characteristics of these various types of waste water are given in **Table 1**.

Table 1. Characteristics of the various types of waste water and the soil used in the experiment.

Experimental materials	pH	BOD (mg/l)	COD (mg/l)	Cyanide (mg/l)	DO (mg/l)
Soil	6.7	-	-	-	-
Untreated waste water	3.6	7,760	10,240	6.24	Undetected
Factory-treated waste water (first study)	4.6	3,600	3,840	4.20	Undetected
Factory-treated waste water (second study)	4.9	3,400	3,840	4.28	Undetected
Vetiver- remediated waste water	7.3	185	266	0.62	5.2

Maize was grown on 10 kg soil in a plastic pot of 5 liter capacity, The treatments were: (1) untreated tapioca factory waste water (FW), (2) factory-treated waste water: watered with factory-treated wastewater (TTW), (3) factory remediated wastewater: watered with vetiver-remediated wastewater (TRW), and (4) vetiver-remediated waste water, watered with vetiver-remediated wastewater (RW), and (5) de-ionized water as the control (C). The maize plants were fertilized with 90 kg N/ha, 50 kg P/ha, and 50 kg K/ha and grown for 45 days. At harvest, the total dry biomass and cyanide content of the tissue were determined.

The fish culture experiment was conducted in a glass aquarium of 5 liters. The treatments were (1) untreated tapioca factory waste water (FW), (2) factory-treated waste water (TW), (3) vetiver remediated wastewater (RW), (4) Vetiver-remediated wastewater + spring water (1:1) (RWS), and (5) spring water (SW). Ten freshwater fish of the *Barbonymus gonionofus* species with 5-7 cm length were put into these aquariums, and grown for 30 days. The measured parameters were the number of dead fish and the weight of the remaining fish.

Laboratory Analysis

Waste water analysis was done following the American standard methods (APHA, 1992). COD was determined by oxidization with $K_2Cr_2O_7$, and cyanide was determined using silver nitrate ($AgNO_3$) standard titrations. The pH was measured with a pH-meter (Jenway 3305). Nitrogen was extracted with Nestler reagent, and phosphorus with ammonium molybdate and both were determined with a spectrophotometer (Vitatron). Total potassium was extracted by wet acid digestion, and the concentration was read with an atomic absorption spectrophotometer (Shimatzu).

RESULTS AND DISCUSSION

Effectiveness of Remediation

The results presented in **Table 2** show that the effectiveness of the vetiver remediation was dependent on the system used, and it was also influenced by the age of the vetiver plants at the start of remediation. The wetland system (W) was more effective than the hydrophonic system. This is a reasonable phenomenon because in a soil system there are many organisms, which act as decomposers of the organic compounds in the waste water, so the decomposition of these compounds will be faster than in the hydroponic system.

Table 2. The effect of the remediation system used, and the age and biomass of vetiver plants at the start of remediation on the quality of tapioca factory waste water after 60 days of remediation.

Vetiver at the start of remediation		Solution concentration (mg/l)							
Age (days)[1)]	Dry biomass (g/pot)	BOD		COD		DO		CN	
		W[2)]	H	W	H	W	H	W	H
Control	0[3)]	445 g	618 h	470 e	688 f	1.10 a	0.96 a	1.46 cd	2.60 e
7	5.1	165 c	413 f	199 b	450 e	2.42 b	1.06 a	0.99 bc	2.08 de
15	9.4	85 b	375 f	100 b	390 c	3.04 b	0.98 a	0.63 ab	1.61 cd
30	11.5	30 a	325 e	34 a	350 c	3.48 c	1.24 a	0.62 ab	1.45 cd
45	22.6	36 a	270 d	30 a	298 c	5.98 cd	2.36 b	0.28 ab	1.51 cd
75	37.4	6 a	265 d	24 a	320 c	6.40 d	2.46 b	0.26 a	1.40 cd

1) The time variable was the age, and thus biomass, of plants at day 0 of the remediation period

2) W = wetland system; H = hydroponic system. Means followed by the same letters for each characteristic measurement are not significantly different (P= 0.05).

3) No plants

Using the "purification index, η" term which was defined as the percentage of the removed pollutant by the plants, as used by Lin *et al.* (2002), it can be seen that with the wetland system, the use of 45-day old vetiver plants at the start of remediation had resulted in the reduction of BOD, COD and HCN of more than 90% (**Table 3**). This indicates that the quality of remediated waste water was nearly the same as that of fresh water.

Table 3. The effect of the remediation system and the plant age and biomass of vetiver plants at the start of remediation on the purification index (η) of tapioca factory waste water after 60 days of remediation.

Vetiver at the start of remediation		η (%)					
Age (days)[1)]	Dry biomass (g/pot)	BOD		COD		CN	
		W[2)]	H	W	H	W	H
Control	0[3)]	86.87 ab	81.77 a	87.76 a	82.60 a	65.23 bc	38.09 a
7	5.1	95.13 b	87.82 ab	94.81 b	88.28 a	76.42 bcd	50.47 ab
15	9.4	97.49 cd	88.94 ab	97.39 b	89.84 a	85.00 cd	61.66 ab
30	11.5	99.11 cd	90.41 bc	99.11 b	90.88 a	85.23 cd	65.47 bc
45	22.6	99.00 d	92.50 bcd	99.21 b	92.23 b	93.33 d	64.04 bc
75	37.4	99.82 d	92.18 bcd	99.37 b	91.67 ab	93.80 d	66.67 bc

1) The time variable was the age, and thus biomass, of plants at day 0 of the remediation period

2) W = wetland system; H = hydroponic system. Means followed by the same letters for each characteristic measurement are not significantly different (P= 0.05).

3) No plants

The purity of the remediated waste water increased with increasing age and biomass of the vetiver plants used at the start of the remediation. This is likely due to the fact that as the plants grow older, their root and top biomass will develop, and hence their nutrient absorption and photosynthesis rates will increase; older plants at the start of the remediation period had a greater starting biomass (**Tables 2** and **3**) and thus a greater degradation potential. Furthermore, in older plants, with increasing root biomass, there will be an increase in surface area for biological processes that occur at the root-soil interface. These processes assist in the decomposition of organic compounds in the waste water.

The data in **Table 2** show that at the end of the 60 day remediation period, the cyanide concentration was still higher that the required standard (more than 0.06 mg/l; Pemprov Jatim, 2000). To determine the remediation period required to attain the quality standard for cyanide concentration, a further experiment was conducted to determine the cyanide concentration in solution as a function of biomass at different remediation periods, using the wetland system. The waste water for this experiment had an initial BOD concentration of 3,600 mg/l; COD concentration of 3,840 mg/l and cyanide concentration of 4.2 mg/l. The remediation process started using vetiver plants with biomass values of 0 (control); 5.1 g/pot; 9.4 g/pot; 17.7 g/pot; 35.1 g/pot; and 51.4 g/pot and continued for up to 60 days. The concentration of cyanide in the remediated waste water was determined in two replicates. The results, shown in **Table 4**, indicate that within the 60 day remediation period, the lowest cyanide concentration of about 0.25 mg/l could only be obtained using vetiver biomass values of 35.1 and 51.4 g/pot. This concentration is still considerably above the prescribed cyanide quality standard of 0.06 mg/l.

Table 4. The cyanide concentration in tapioca factory waste water as a function of varying initial vetiver biomass and the length of the remediation period (up to 60 days) in a wetland system (Experiment 3).

Remediation period (days)	Cyanide concentration in waste water (mg/l)					
	Vetiver biomass at the start of the remediation period (g/pot)					
	0	5.1	9.4	17.7	35.1	51.4
0	4.22	4.22	4.22	4.22	4.22	4.22
7	3.64	3.54	3.21	3.23	2.98	2.04
15	3.06	2.96	2.34	1.76	1.45	0.76
30	2.22	1.95	1.62	1.25	0.86	0.36
45	1.94	1.21	0.97	0.84	0.33	0.26
60	1.46	1.15	0.83	0.36	0.24	0.26

Values are the mean of two replicates.

Utilization of Remediated Waste Water

The maize planted in pots with soil and watered with untreated tapioca factory waste water did not germinate (**Table 5**). However, maize grown in the treatment of factory-treated waste water, and the other two treatments (in the vetiver remediated waste water, RW, and in de-ionized water, C) grew quite well. The highest total biomass of maize (24.67g/plant) was obtained by the maize planted in factory treated waste water, and this was significantly different from the other treatments. This is not surprising, because this waste water still contains a lot of plant nutrients, while many nutrients in the vetiver remediated waste water had been taken up by the vetiver plants. The total dry biomass of maize planted in factory-remediated waste water and watered with vetiver-remediated waste water (TRW) treatment was not significantly different from that planted in the vetiver-remediated waste water treatment, and the de-ionized water treatment (C).

Table 5.The effect of using various remediated tapioca factory waste waters for watering maize plants grown in potted soil on the total maize biomass and their cyanide contents at 45 days after planting.

Remediated waste water treatments	Total maize biomass (g/plant)	Plant CN concentration (mg/kg)	Soil CN concentration (mg/kg)
Untreated waste water (FW)	0	0	3.40 c
Factory-treated waste water (TW)	24.67 c	1.80 b	2.25 b
TW, then watered with RW (TRW)	20.76 ab	0.80 a	0.22 a
Vetiver-remediated waste water (RW)	17.24 a	0.76 a	0.12 a
De-ionized water (C)	19.45 ab	0.60 a	0.04 a

Means followed by the same letters, in each column are not significantly different (P=0.05)

The results in **Table 5** also show that the maize planted in the soil watered with factory-treated waste water not only had the highest dry biomass, but also the highest cyanide concentration in the tissue. Therefore, if the maize biomass is used for animal feeding this phenomenon should be taken into consideration. The cyanide concentrations of soils watered with untreated waste water or with factory-treated waste water were both quite high, i.e. 3.4 mg/kg and 2.2 mg/kg, respectively.

The results of the experiment on using remediated waste water for fish culture are presented in **Table 6**. Soon after the fish were put into the untreated waste water (FW), all fish died. This was due to either the high cyanide content, or because of lack of dissolved oxygen due to the high BOD and COD of the water. Even after 30 days, the cyanide content in this medium was still high (3.4 mg/l). This was also the case for factory-treated waste water. The results also show that in the vetiver-remediated waste water the number of dead fish and the fish weight grown in this medium were not different from those grown in spring water. This indicates that the vetiver-remediated tapioca factory waste water was safe for the culture of *Barbonymus gonionofus* freshwater fish.

Table 6. The utilization of various remediated tapioca factory waste water for freshwater fish culture.

Treatments	Number of dead fish at					Fish weight at 30 days (g/fish)
	0 days	2 days	5 days	15 days	30 days	
Untreated waste water (FW)	10	-	-	-	-	-
Factory-treated waste water (TW)	5	2	3	-	-	-
Vetiver-remediated waste water (RW)	0	0	0	0	2	24.6
RW + spring water (1:1) (RWS)	0	0	0	1	2	24.5
Spring water (C)	0	0	0	0	3	25.4

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WASTE RECOVERY OF CASSAVA STARCH PROCESSING

Liang Guo Tao [1]

ABSTRACT

The research project "Waste Recovery of Starch Processing Based on Polymer Technology", proposed by ACRO Bio-Tech Co., Ltd., (ACRO), received financial support from the Innovation Fund for Technology Based Firms (INNOFUND) in May, 2009.

The purpose of this research is to recover the wastes generated by starch processing, including:

1. *Liquid waste treatment*: according to the physical and chemical properties of the liquid wastes from a starch plant, separate the solid phase, which contains a large amount of protein from the waste liquid, by using polymer flocculation and sedimentation. The protein powder, after dehydration and drying, could be used for animal feed production, while most of the waste water could be reused after clarification. This method will not only save water, but also reduce the investment and operating costs of the waste water treatment system.
2. *Solid wastes treatment*: the wet residue from the wet method of starch production still contains a lot of starch, fiber, protein and other organic substances. Dehydrating this material is difficult because it is rich in hydrophilic groups. Because of their high cost, conventional dehydration and drying methods cannot be used. But, by using polymers, the effectiveness of the dehydration can be increased and energy consumption for drying can be greatly reduced. The cassava residue recovered in this way can partially replace corn as a raw material for animal feed production, as it is competitive due to its low cost. Besides, the recovery of starch from the filtered water, effectively increases the yield of starch production.

The intermediate stage test of the project has been successfully accomplished, and the project was accepted in May, 2011.

INTRODUCTION

1. Project background

The treatment of waste liquid and residue generated from cassava starch processing is widely recognized to be difficult. Most of the cassava processing factories have not invested in a complete waste recovering system. This has caused not only a waste of resources but also serious pollution of the environment around the factory.

The wastes from cassava starch processing consist mainly of wet cassava residue and solid organic substances; most of the latter is protein and this can be recovered from the waste water. Cassava ethanol factories also produce plenty of recoverable wet fiber.

In 2008, ACRO started investigating and researching the cassava starch processing industries in Asian countries and obtained the following primary data:
The amount and composition of recoverable dry cassava residues and protein powder from a starch factory, per 1000 kg of fresh cassava roots processed, is shown in **Tables 1** and **2**.

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Table 1. Average weight and composition of recoverable products from the waste of 16 cassava starch factories in China, Thailand, Vietnam and Indonesia.

Recoverable substances	Weight (kg/t of fresh roots processed)	Composition (%)				
		Starch	Fiber	Protein	Others	Water
Dry cassava residue	50-60	25-35	21-38	16-19	8-12	12
Protein powder	20-25	31-39	4-6	32-43	8-15	10

Table 2. Estimated amounts of recoverable by-products from cassava starch factories in four countries in Asia.

Country	Recoverable dry cassava residue (t/year)	Recoverable protein powder (t/year)
China	150,000	60,000
Vietnam	230,000	90,000
Indonesia	300,000	120,000
Thailand	900,000	350,000
Total	**1,580,000**	**620,000**

Some factories recovered part of the cassava residue by natural solar drying, and recovered part of the wet gluten by natural sedimentation. These products could be used as animal feed in the market. However, more than 70% of the factories could not recover these products because the efficiency of the conventional method is too low, and they could not ensure the quality of the products. A few factories tried to use thermal energy from the boiler to dry the cassava residue in recent years, but the cost is too high, and this could not be put into operation.

Due to the serious lack of protein and starch-based resources, China spent more than 180 billion RMB annually for importing protein-based agricultural products. So, all of the recoverable resources are very valuable.

ACRO established a "SoilNet Polymer Asia Solution Center" jointly with a polymer laboratory of Wisconsin University in the USA. It screened many polymers and selected the polymer which would be suitable for cassava residue dehydration and separation of protein in waste liquid. This makes it possible to achieve the high efficiency and industrial-scale required for recovering waste from starch processing factories.

RESEARCH AND TECHNICAL DEVELOPMENT

1. Questions raised

The moisture content of cassava processing residues is normally more than 80%. Using a mechanical squeezing process one can get the moisture content of wet cassava residue down to 65%, but to be dry, the moisture content must be below 12%. The cost of drying using thermal energy is even higher than the market price of the dried cassava residue. If the factory wants to benefit from the recovered cassava residues, they must try to reduce the moisture content of the wet residue to below 60%.

In general, the processing of one tonne of fresh cassava roots produces about 5 tonnes of waste water. Using the conventional process, the content of solid substances (including dissolvable substances) is about 0.95%. The recoverable solid substances in the waste water should be more than 70%, while the recoverable wastes is less than 40% by conventional natural sedimentation. The solid substances, with 32-43% dry protein content, will greatly increase the difficulties in waste water treatment.

2. Objective and content of the research

Research Objective

The purpose of this project is to test the polymer flocculation and sedimentation method based on the physical and chemical characteristics of solid substances in starch liquid waste. In waste water from agro-products processing, the composition of suspended solid substances is very complicated. It mainly contains organic substances, such as carbohydrates, protein, starch, fiber etc. According to the properties of organic molecules, they will combine tightly with water molecules. Polymers are used to make unstable colloidal particles by polymerization, and separate the particles from the aqueous medium. The polymer makes the solid polymerized substance suspend so as to make the water clearer, and these solid particles can be easily and rapidly separated from the water. By applying the function of polymerization to the wet residue with many hydrophilic radicals, the water molecules could be effectively released.

The waste water from starch production contains many solid organic substances such as protein, starch and fibers. The water could be recycled in starch processing after flocculation, sedimentation and separation of these solid substances by using bio-polymers, and those separated solid substances, after drying, produce high quality raw material for production of animal feed. Dehydration of the wet residue, resulting from the wet method starch production line, is difficult because it is rich in hydrophilic groups, but by using polymers, the effectiveness of the dehydration can be increased and energy consumption for drying can be greatly reduced.

Based on the above theory, the objective of the research was defined as follows:

- Apply the polymer to efficiently separate and extract the solid substance in the starch liquid waste, and reduce the time of flocculation and sedimentation to within 20 seconds. The protein powder recovering ratio should be more than 65%, and more than 60% of the clarified waste water recirculated for cassava processing. This helps to save water consumption and greatly reduces the cost of waste water treatment
- With the function of filtering the water by the use of polymers, the moisture content of the cassava residue after mechanical squeezing will be less than 60%, thus reducing the consumption of thermal energy for drying. The cassava residue after drying can be used as the raw material for feedstuff production.

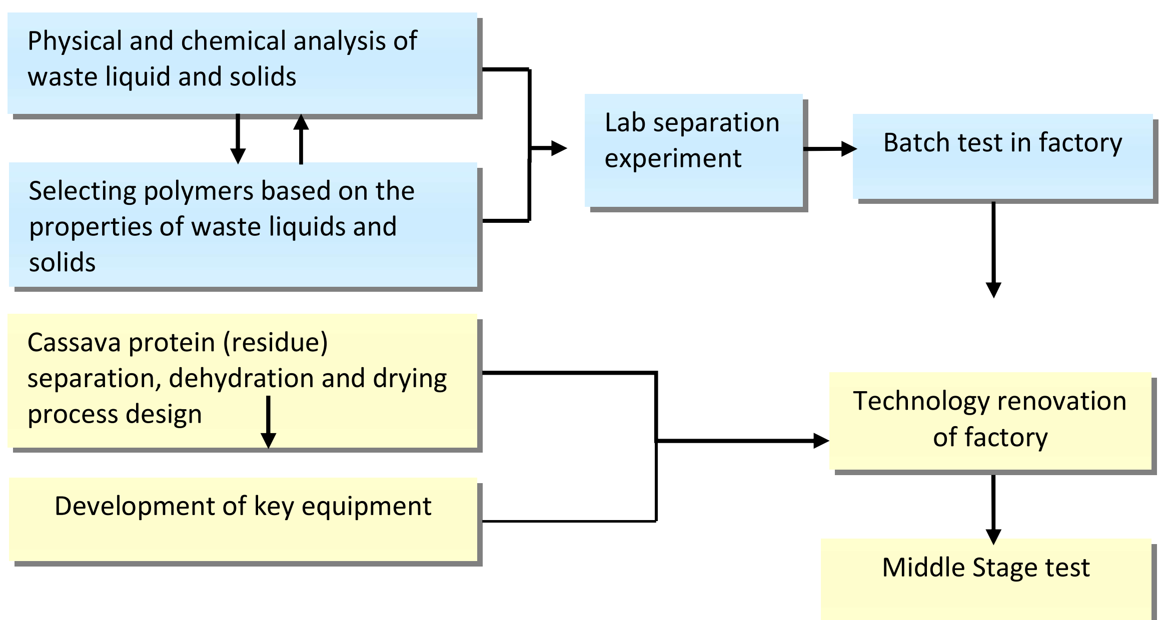
Research content

The research mainly includes:

- The selection of those polymers that are most suitable for the treatment of cassava waste water and residues produced by starch factories
- The technology for protein recovery and process water recirculation
- The technology of cassava residue dewatering and drying.

The key point of the technology is to select polymers which are suitable under acid conditions, and are used for protein separation and cassava residue dehydration, respectively.

3. Technology development route



4. Project execution

After the project received the innovation fund support, the project development team of ACRO, together with professor Aicardo Roa, biochemist from Wisconsin University in the USA, started the planned work as follows:

Laboratory separation experiment and polymer selection

The project team sampled and analyzed the cassava residue and waste liquid from six cassava starch factories. SoilNet Polymer Center simultaneously analyzed and made a preliminary selection of about 50 different types of polymers. They then conducted thousands of tests in the Polymer Center and in the laboratories of four cassava starch factories. The experiment expanded to separate the protein in the waste from three corn starch factories, and finally selected 12 types of polymers in the S-200VAL, S-300VAL, S-400VAL, S-500VAL and S-1000VAL series.

Process technology and equipment development

Based on the experimental data, and depending on the general production requirement of the factory, the project team finished by making two technical proposals:

- Protein powder extracting system of 2,000 t/day starch waste liquid
- 120 t/day wet cassava residue dehydration and drying system

A special polymer adding system is required for the above process; so, the ACRO project team designed, manufactured and tested a 1000 L fully automated polymer delivering and adding system, and made sure that the tested data meet the technology requirements.

Technology renovation of factory and running of tests

The running test is supported by a 400 t/day cassava starch factory

The technology renovation was finished in May, 2010, and the factory was running continuously for testing from January 3 to 15, 2011. The test report showed the following:

During the Middle Stage test of the protein powder extraction system of 2,000 t/day starch waste liquid, after the application of the S-500VAL series polymer (10 ppm) into the starch waste liquid, the main technical indices tested were as follows:

- The time of protein solid flocculation and sedimentation period was 18-20 seconds, the protein solid substance had good dehydration and drying performance
- After dehydration and drying, the average protein powder recovery was 0.61%.
- The recycling ratio of clarified waste liquid could reach 62.3%.

In the Middle Stage test of the 120 t/day wet cassava residue dehydration and drying system, after the application of the S-1000VAL series polymer (100 g polymer solution with an average concentration of 0.01% applied to 1 m^3 wet residue) the main technical indices tested were as follows:

- The moisture content of the wet residue was less than 60%; after belt press dewatering, the moisture content was reduced to 20.95%-26.50%.
- The recovered starch from the filtrate increased to about 0.35%.

CONCLUSIONS

An independent expert team evaluated the project results in May, 2011, and reached the following conclusions:

- The Protein Powder Extracting System of 2,000 t/day Starch Waste Liquid under the ACRO INNOFUND project: It is a creative way to apply polymer technology for the recovery of protein from the waste water during starch processing, substantially reducing protein flocculation and sedimentation time, and increasing the protein recovery rate. The most difficult and innovative point of the project is to separate the solids from the liquid without changing the pH of the process water. The results of the Middle Stage test shows that the project has successfully solved the problem of the acidity effect of the process water in protein separation. The clarified liquid, after separating, could be reused as process water, which not only can effectively save water, but also decreases the investment pressure for environmental protection. The system could be applied and popularized in starch production.

- The Dehydration and Drying System of 120 t/day Wet Cassava Residue under the ACRO INNOFUND project: Because of the application of polymer technology, the moisture content of wet cassava residue was effectively reduced, which in turn reduced the thermal energy consumption for cassava residue drying. Moreover, it increased the starch recovery rate. The system could easily be applied and popularized in the cassava starch production process.

PARTICIPATORY LEARNING AND ACTION IN CASSAVA TECHNOLOGY TRANSFER: IMPACTS ON ADOPTION OF CASSAVA TECHNOLOGIES IN INDIA

M. Anantharaman[1] and S. Ramanathan[1]

ABSTRACT

Cassava in India is a secondary crop extending primary functions of food security and livelihood to a large majority of weaker sections of the population, including many tribal sects operating in complex and diverse risk-prone areas. In India, the Central Tuber Crops Research Institute (CTCRI) provides leadership in research and development of cassava and its five decades of intensive research has yielded technologies in terms of improved cassava varieties, cassava production management and value addition.

Participatory Learning and Action (PLA) is an approach for learning about and engaging with communities. CTCRI has undertaken a sequence of technology transfer events on cassava suiting changing needs of farmers, namely the Lab-to-Land Programme, Farmer Participatory Research, Village Linkage Programmes etc. These programmes had different levels of participation in learning and action on cassava technologies. CTCRI has also conducted adoption studies associated with the technology transfer programmes as well as overall adoption studies. The Lab-to-Land programme, which had a nominal participatory learning level, implemented in different states, was not only useful in spreading the then cassava varieties and production technologies, but it also helped in improving significantly the adoption behavior. An experimental study on the adoption behavior of cassava farmers showed that participatory learning has significantly helped in improving the adoption level. A model was developed for the farmers' participatory learning on the evaluation of cassava varieties. The programme on farmers' participation in varietal evaluation helped in identifying suitable varieties for different production systems, its adoption by the farmers and the resultant spread. The Village Linkage programme was effective in transforming the cassava farmers into experimenters in terms of problem diagnosis, action plans, conducting field experiments and the evaluation of both varieties and production practices.

INTRODUCTION

Cassava in India is a secondary crop extending primary functions of food security and livelihood to a large majority of weaker sections of the population, including many tribal sects operating in complex and diverse risk-prone areas. In India, the Central Tuber Crops Research Institute (CTCRI) provides leadership in research and development of cassava, and its five decades of intensive research has yielded technologies in terms of improved cassava varieties, cassava production management and value addition. The average yield of cassava in India has progressed from a mere 10 t/ha to the present 35 t/ha. The improvement in the productivity was due to adoption of high-yielding varieties of cassava (HYVC) and effective production practices, complemented with appropriate technology transfer programmes. The initial low cassava yield was due to non- or partial-adoption of improved technologies. The yield gap was mainly due to a lack of extension efforts coupled with complex socio-economic factors of the farmers. Sivaramakrishnan (1981) found that the extent of adoption of recommended practices in Kerala were least for cassava as compared to rubber, coconut and rice. Anantharaman *et al.* (1993) observed that only a minority of cassava farmers belonged to the high adoption category. This situation demanded

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appropriate extension strategies with better learning experiences for farmers brought in, which will help in facilitating improvements in the adoption level of technologies. Participatory Learning and Action (PLA), which is an umbrella term for a wide range of approaches and methodologies, including Participatory Rural Appraisal (PRA), Rapid Rural Appraisal (RRA), and Participatory Learning Methods (PALM), is effective in providing better learning experiences for the farmers. Participatory Learning and Action is an approach for learning about and engaging with communities (Thomas, 2005). CTCRI has implemented over the years various Transfer of Technology (TOT) programmes where the social scientists involved the farmers in various degrees of participation, from nominal to decision making modes. They include the Lab-to-Land Programme (LLP), Farmer Participatory Technology Development (PTD), and the latest Technology Assessment and Refinement through Institution Village Linkage Programme (TAR-IVLP). The impacts of these TOT programmes were assessed in terms of the adoption behavior of cassava farmers. This paper provides a description of the TOT programmes backed by participatory learning and action, and the results of adoption studies related to TOT programmes, as well as other adoption studies carried out by CTCRI.

Participatory Learning and Action

Like farmer participatory appraisal, or farmer participatory research (FPR), participatory learning and action involves a set of methods designed to enable the farmers to make an active contribution as decision makers to planning and executing agricultural technology generation and transfer. Farmers' participation can be classified according to the level of control and management exercised by farmers and researchers. This classification includes four categories. According to Ashby *et al.* (1987), FPR could be categorized as Nominal, Consultative and Decision Making, while Selener (1997) categorized these as researcher-managed on-farm trials, consultative farmer-managed on-farm trials, collaborative farmer-researcher participatory research and farmer-managed participatory research. CTCRI's PLA follows the categories as stipulated by Ashby *et al.* (1987) (**Table 1**).

Table 1. CTCRI outreach programmes involving PLA.

Sl. No.	Technology Assessment Project	Year	Type of farmers' participation
1.	National Demonstration	1970-1974	Nominal
2.	Lab-to-Land Programme	1979-1996	Nominal
3.	Participatory Technology Development (varieties)	1994-2002	Consultative
4.	Institution Village Linkage Programme	1996-2005	Decision Making

1. National Demonstrations (ND)

The main concept under ND was that unless scientists demonstrate the technologies in the farmers' fields their advice may not be accepted by the farmers. In total, 27 NDs were conducted on three high-yielding varieties of cassava, i.e. H-97, H-165 and H-226, by scientists in cooperation with local extension agents and farmers in four states: Kerala (23 NDs), Tamil Nadu (2), Andhra Pradesh (1) and Karnataka (1). The dissemination of high-yielding cassava varieties was started through these NDs, in which researchers managed the demonstrations in the farmer's field, and farmers were involved as nominal partners (Anantharaman and Ramanathan, 2001).

2. Lab-to-Land Programme (LLP)

The LLP is a massive TOT programme aimed to transfer viable technologies by a multidisciplinary team of scientists to farmers' fields. The cassava technologies, transferred mainly through demonstrations in farmers' fields, were: 1) HYVC, namely H-226, H-2304 and H-1687; 2) improved methods of cultivation; and 3) intercropping cassava with groundnut and cowpea (Anantharaman and Ramanathan, 2001). Under this programme 16 villages were adopted over a period of seventeen years (1979-1996) covering three states and involving nearly 1,600 farm families. However, the participation of farmers in this programme was still nominal, but they were more actively involved than in the national demonstrations.

3. Participatory Technology Development (PTD)

PTD is the practical process of bringing together the knowledge and research capacity of local farming communities with that of the commercial and scientific institutions in an interactive way (ILEIA, 1991). CTCRI, in its attempt to use PTD on cassava varieties followed this methodology, which is presented in **Table 2**.The participation of farmers was consultative in the on-farm cassava trials.

Table 2.Farmer Participatory Technology Development methodology.

Cassava varietal evaluation and transfer			
OFT * -mode	Consultative participation of farmers		
Production systems	**Kerala** 1. Lowland rainfed 2. Upland rainfed 3. Hill agric. rainfed	**Tamil Nadu** 1. Plains irrigated 2. Hill agric. rainfed	**Andhra Pradesh** 1.Plains rainfed 2. Hill agric. rainfed
Steps followed in conducting the OFT		PRA techniques used	
Agro-ecosystem analysis of village		Key informant, direct observation, diagramming, transects, matrix ranking	
Selection of farmers and evaluation groups		Key informant, sociometry, direct observation	
Initial OFT and evaluation by user groups		Observation, semi-structured interview, ranking, diagramming	
Confirmation OFT and evaluation by user groups		Semi-structured interview, paired ranking, matrix ranking, triad techniques	
Validation OFT and evaluation by user groups		Semi-structured interview, direct observation	
Popularization of most preferred cassava varieties		Field days, demonstration by the user groups, seed production	

*OFT = On-farm trials

4. Technology Assessment and Refinement through Institution-Village Linkage Program (TAR-IVLP)

The program believes that the major cause for non- or low-adoption of agricultural technologies lies not with farmers, but with the technology itself. Most of the technologies developed under ideal conditions are unsuitable to complex and diverse risk-prone systems, which constitute the major share of the farm holdings. Farmers are never monocrop farmers but multiple-linked enterprises. There is a need for assessment and refinement of technologies under any particular agro-ecosystem. The program is a holistic one with emphasis on research through active farmer participation and linkages with scientists. It employs agro-ecosystem analysis for problem diagnosis by using various PRA tools and techniques for assessment and refinement of technologies by farmers, and a multidisciplinary team of scientists. TAR-

IVLP puts the main emphasis on technology assessment by the farmers and has the following steps: 1) selection of the operation area; 2) formation of a multidisciplinary team; 3) characterization of the agro-ecosystems of the selected village; 4) problem diagnosis; 5) identification of alternative technologies for solving problem(s); 6) drawing up an action plan; 7) technology assessment; and 8) extrapolation (Anantharaman *et al*., 2004). The TAR-IVLP was implemented in Chenkal village of Trivandrum district of Kerala. Based on the information obtained from the agro-ecosystem analysis and legitimized through focus group discussions, problems of various cassava enterprises were identified by the farmers, followed by the technology assessment through on-farm trials. The participatory mode was Decision Making as farmers made decisions on various aspects of the on-farm trials, including selection of practices and the execution of the trials.

ADOPTION STUDIES

Adoption studies were carried out to know the acceptance of the cassava varieties and the production practices with regard to LLP, PTD and TAR-IVLP. The nature of adoption studies on these programmes varied in view of the different objectives of each programme. This paper also covers other adoption studies conducted to assess the acceptance of various cassava technologies.

Adoption of a technology refers to a decision to make full use of an innovation as the best course of action available (Rogers, 1995). Adoption is defined as a collective term of the process in which a firm makes a decision to adopt or to not adopt a specific technology (Hultmana, 2004).

The adoption of the variety or practice was measured in terms of the percentage of farmers practicing the technology. The overall adoption level of the farmers was measured using the following adoption quotient (AQ) formula as suggested by Anantharaman *et al.* (1993):

$$AQ = \frac{\sum_{i=1}^{n}(e_i\, w_i/p_i)}{\sum_{i=1}^{n} w_i} \times 100$$

where e_i = extent of correct adoption of practice i

p_i = potential area for adoption of practice i

w_i = weight given to practice i

n = number of improved practices under consideration

1. Lab-to-Land Programme (LLP)

Adoption studies carried out on LLP farmers are presented in **Table 3**, which shows the overall adoption score of farmers of LLP before and after the programme (Anantharaman *et al.,* 1993). It is clear that prior to the introduction of the LLP only 2% of the farmers were in the high adoption category and the mean adoption score was only 29.6. The adoption score as well as the proportion of farmers in medium and high adoption categories increased after exposure to LLP. There was an increase in the adoption score after the LLP with the score being 51.2 after one year, 56.9 after two years and 59.7 after three years. The analysis of variance resulted in an F-value of 48.97**, indicating that there was a highly significant improvement in the adoption level of cassava farmers under LLP. This shows that cassava farmers were receptive and the LLP had helped farmers to have a good participatory learning experience.

Table 3. Overall adoption level of LLP farmers.

		% of Farmers			
Adoption level	AQ*	Period A	Period B	Period C	Period D
Low	0-33	47	12	10	3
Medium	34-66	51	65	59	65
High	67-100	2	23	31	32
Mean AQ*		29.6	51.2	56.9	59.7
Analysis of variance:					
Source of variation	df	Mean sum of squares		F-value	
Treatments	3	12 846.10		48.97**	
Error	296	262.32			
CD = 5.40 SE = 1.95					

Period A: pre-programme period
Period B: 1 year after exposure to the programme
Period C: 1 year after withdrawal of the programme
Period D: 2nd year after withdrawal of the programme
*AQ= Adoption quotient

An attempt was also made to know how the individual practices were adopted before and after LLP (**Table 4**).

Table 4. Adoption of recommended practices - Participating beneficiary.

	% of Farmers adopting the technology			
Recommended practice	Period A	Period B	Period C	Period D
High-yielding varieties	0	81 (25)	96 (25)	85 (17)
No. of setts per hill	77 (77)	100 (97)	100 (93)	100 (100)
Sett length	73 (73)	100 (100)	100 (96)	100 (99)
Method of planting	66 (65)	100 (97)	100 (96)	100 (100)
Plant spacing	19 (15)	80 (68)	91 (87)	86 (80)
Fertilizer application	58 (5)	74 (12)	75 (6)	82 (11)
Mosaic disease control	8 (8)	35 (23)	49 (32)	41 (34)
Shoots retained	13 (13)	58 (49)	66 (60)	65 (61)

Figures in parentheses indicate percentage of farmers adopting the recommended practices in their entire cassava area.

The data indicate that a considerable proportion of farmers (66-77%) had adopted correctly certain non-monetary practices such as number of setts, sett length etc. even prior to LLP. However, with the implementation of the programme all the farmers adopted these practices and continued to do so even after withdrawal of LLP. With regard to HYVC the variety introduced was not cultivated by any farmers before LLP, and there was a tremendous increase (from 0 to 85%) in the number of farmers adopting HYVC after LLP. Even in the case of fertilizer, a monetary-based practice, significant improvement could be seen between before and after LLP in the percentage of farmers adopting fertilizers.

2. Participatory Technology Development (PTD)

The outcomes of PTD, as implemented by CTCRI on cassava varieties in various production systems, indicate the farmers' selection of varieties for different production systems, and the preferred attributes. These are shown in **Figure 1**. PTD helped in its objective of selection of varieties by the farmers under various production systems.

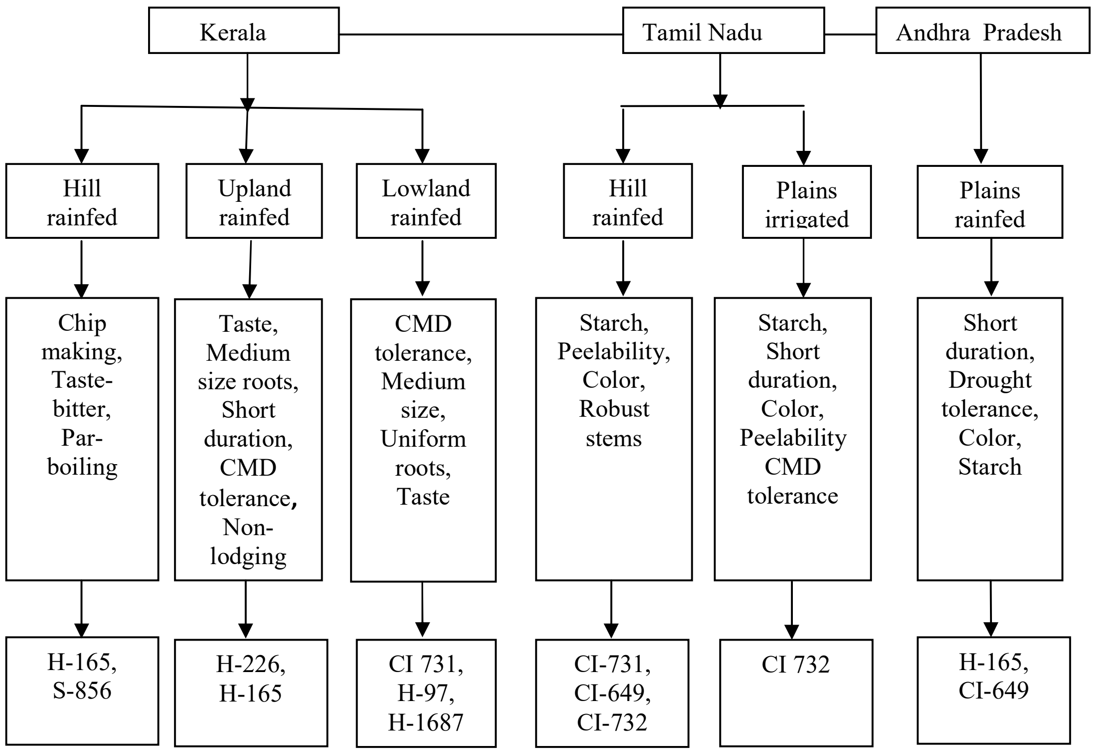

Figure 1. Farmer participatory evaluation: Cassava varietal attributes and varieties preferred by farmers for various production systems.

The adoption of the new cassava varieties, evaluated and selected by the farmers of the villages included for PTD, is shown in **Table 5**. It is evident that more than two thirds of the farmers had started adopting the identified cassava varieties in their farms. The cassava varieties evaluated and identified through a series of on-farm trials have become part and parcel of the cassava production system of the target population included in the project. It was also attempted to find out the diffusion effect of varieties preferred by the farmers. Since the farmer group participatory approach was followed, members belonging to the group are known to the other farmers, which helped the diffusion of varieties to neighboring villages and districts. The relatively low proportion of farmers adopting the new varieties in villages of Tamil Nadu and Andhra Pradesh may be due to the time lag factor as the project was implemented later when compared to the first three villages. However, an increasing trend was still observed in the adoption of the tested varieties in these villages.

Table 5. Adoption of new cassava varieties preferred by farmers under PTD.

Village	State	Production system	% Adoption
Anacode	Kerala	Lowland rainfed	94
Kodankara	Kerala	Upland rainfed	89
Chinnaparakudi	Kerala	Hill rainfed	85
Puthiragoundanpalayam	Tamil Nadu	Plains irrigated	79
Thengottupatty	Tamil Nadu	Plains irrigated	67
Uppalapadu	Andhra Pradesh	Plains rainfed	90
Yelamalakotta	Andhra Pradesh	Hill rainfed	50

The spread of the varieties to other villages of the same district where the project was implemented, and to other districts, was observed on field trips, indicating that CI 731 had diffused quite well, to more than 25% in Trivandrum district; and CI 649 to more than 20% in Kottayam and Patnamthitta districts, all in Kerala state. Stems of CI 731 were in high demand in nearby villages of Puthiragoundanpalayam of Salem district of Tamil Nadu. After seeing the performance of CI 649 in Uppalapadu village in Andhra Pradesh, there was also a great demand for the variety to the extent that requests for stems started coming to CTCRI. Progressive farmers in Uppalapadu village have since taken up multiplication of planting material in their farms to meet the demand.

5. Technology Assessment and Refinement through Institution-Village Linkage Program (TAR-IVLP)

Cassava Varietal Assessment

Under upland conditions of cassava cultivation, five varieties were evaluated in TAR-IVLP village Chenkal in Trivandrum district of Kerala, namely Sree Jaya, Sree Prabha, Sree Rekha and two local varieties, Manja Noorumootan and Narayana Kappa. Sree Rekha and Sree Prabha have recorded high root yields of 45 and 46 t/ha, respectively. Farmers also assessed these varieties possessing good cooking quality. It was expressed by the farmers that if these varieties could prove themselves in the market, there will be large areas coming under these varieties. Sree Rekha was adopted by 10% of farmers in upland conditions.

Three cassava varieties were also evaluated under lowland conditions in the TAR-IVLP village in Chenkal; this is a fast emerging potential production system for cassava. To our surprise, the local variety Ullichuvala outyielded the other two released varieties, Sree Viyaya and Vellayani Hriswa, registering a yield of 42 t/ha. Ullichuvala also enjoys currently a better niche in the local market. However, it was observed that Vellayani Hriswa, a newly tested variety, could also produce a comparable yield of 40 t/ha, close to that of Ullichuvala, which has an adoption rate as high as 80%. Farmers were of the opinion that this variety may pose a challenge to the popular Ullichuvala because of its short duration, six months only as compared to 8-9 months for Ullichuvala (**Table 6**).

Table 6. Technology assessment on varieties by the farmers of TAR-IVLP villages under upland and lowland conditions in Kerala.

SI No	Varieties	Yield (t/ha)	B/C ratio	Farmers reaction		Other remarks	Adoption
				Positive	Negative		
Cassava upland							
1.	Sree Jaya	25.9	4.37	High yield, good cooking quality, suitable for upland	Mosaic incidence	SreeRekha is better. It has to prove in market demand	
2.	Sree Prabha	45.9	7.87				
3.	Sree Rekha	46.7	7.76				10%
4.	Manja Noorumo-otan (Local 1)	25.6	4.34	Very good cooking quality	Low yield, heavy mosaic incidence		
5.	Narayanakapa (Local 2)	21.4	3.60	Very good cooking quality	Low yield, heavy mosaic incidence		
Cassava lowland							
1.	Sree Vijaya	35.4	5.90	Well suited for lowland conditions	Mosaic incidence	Ullichuvala is popular for its demand. Hriswa may become a challenge to it	
2.	Vellyani Hriswa	40.0	6.74				
3.	Ullichuvala (Local)	42.4	7.10				>80%

Note: Shaded boxes indicate farmers' preferences

4. Other Adoption Studies

Motivation level and adoption

CTCRI conducted a study on the level of motivation and adoption of farmers. (Anantharaman and Ramanathan, 2001) It had three groups of farmers: Group I: Full motivation in terms of all inputs, training and field visits (which may be categorized as strong PLA); Group II was provided with planting materials of HYVC and training (medium PLA), and Group III was the control (less PLA). Data on adoption of cassava technologies was collected for four years, namely one year before and three years after. Adoption was measured using the formula for calculating the adoption quotient of Anantharaman *et al.* (1993).

The measured overall adoption level by farmers was categorized into three levels for the four years studied and is presented in **Table 7**. The analysis of variance showed that mean adoption of the three farmer motivation groups during the before treatment period were at par, revealing that all the three groups were adopting the cassava cultivation practices more or less the same way, and groups were similar in this respect. Group I had shown significant difference over Group II and Group III, right from the first year after treatment (FAT) and maintained the same thereafter. The farmers of Group I had been provided with full motivation. This has helped the farmers not only in gaining knowledge but also in convincing them of the merits of the cassava technologies transferred. This conviction might have been mainly brought through the crop demonstrations laid out in these farmers' fields and the availability of planting material of HYVC from the demonstration plots. Hence, a faster change was noticed in this group as compared to the other two. In the case of Group II, a significant difference in the adoption level was observed only during the second (SAT) and third year after treatment (TAT) and not in the FAT as in the case of Group I. This indicates that farmers provided with partial motivation through the supply of only planting material and training were likely to exhibit improvement in the adoption behavior, but the response was delayed, unlike in Group I. It may be mentioned here that the quantity of planting material supplied to Group I worked out to be 300 setts/farmer as compared to 100 setts/farmer in Group II; this obviously would have provided more planting material in the subsequent seasons for Group I farmers. At the same time, Group II required more time for sufficient multiplication in order to bring more area under HYVC and adopting the improved package of practices for these high yielding varieties. These reasons could be attributed for the delayed response shown by Group II. However, the study revealed that the mere supply of planting material, coupled with technical guidance, could motivate the farmers. Comparing the adoption scores of the three groups of farmers during the four years, it was observed that the adoption scores of Group I during FAT, SAT and TAT were higher than during the before-treatment period . In the case of Group II the difference was during SAT and TAT. However, Group I did not display any difference over the years under study.

Table 7. Adoption level of three groups of cassava farmers with different levels of motivation.

Category	Before treatment (%)			After treatment (%)								
				FAT			SAT			TAT		
	I	II	III	I	II	III	I	II	III	I	II	III
High	2	-	5	13	-	2	32	18	3	28	10	3
Medium	25	35	30	68	53	32	65	54	47	67	63	47
Low	73	70	65	19	47	65	3	28	50	5	27	50
Mean adoption score	28.15	29.98	32.45	44.8	32.77	31.07	59.62	44.27	35.27	57.35	43.37	34.52
F-value	1.97 NS			10.43**			19.02**			23.79**		
CD value				6.43			7.73			6.63		

Note: FAT, SAT and TAT refer to the first, second and third year after treatment, respectively.

Relationship between Adoption and Socio-economic Characteristics of Farmers

CTCRI also undertook studies on the relationship of socio-economic characteristics of farmers with their adoption level of technologies in Tamil Nadu and Kerala (Anantharaman *et al.,* 1989). A correlation and path analysis were done on the level of adoption with famers' socio-economic characteristics (**Table 8**). These characteristics, namely knowledge, age, farm size, mass media exposure and scientific orientation, exhibited a positive correlation with the level of adoption of cassava technologies by farmers. The characteristics of area under cassava and contact with the extension agency were not statistically significant but indicated a trend of positive correlation. Formal education and risk preference did not show any relationship with adoption. The path analysis also gives a clear picture of the direct and indirect effects of the characteristics on adoption. Variables with direct effect and magnitude exceeding 0.2 were subjectively considered to be substantial. The knowledge on cassava technology had the greatest direct effect (0.892), indicating that it had the strongest influence on adoption. Moreover, it had the largest indirect effect channeled substantially through variables such as age, farm size, area under cassava, mass media exposure, and scientific orientation. Next in importance are scientific orientation and extension agency contact, which had a substantial direct effect with a correlation with adoption of 0.233 and 0.277, respectively.

Table 8. Relationship between adoption and socio-economic characteristics of farmers.

Variable	Correlation coefficient (r)[1)]	Direct effect	Total indirect effect	Variable having substantial indirect effects	
				I	II
1. Age	0.294*	-0.242	0.536	0.271(9)	0.235(5)
2. Formal education	-0.008	-0.023	0.015	-0.112(5)	0.100(1)
3. Farm size	2.281*	-0.059	0.331	0.292(9)	0.971(4)
4. Area under cassava	0.225	0.081	0.147	0.228(9)	-0.069(1)
5. Mass media exposure	0.274	-0.319	0.584	0.289(9)	0.184(1)
6. Extension agency contact	0.225	0.227	-0.002	0.037(9)	0.032(7)
7. Scientific orientation	0.267*	0.233	0.034	0.253(9)	-0.181(5)
8. Risk preference	0.001	-0.126	0.127	0.091(7)	-0.066(5)
9. Knowledge on cassava technologies	0.771	0.892	-0.121	0.100(5)	-0.074(1)

[1)] *, ** significant at 5 and 1% level, respectively

Figures in parenthesis indicate the variables having substantial indirect effect.

Adoption of cassava varieties

CTCRI has conducted studies on adoption of cassava varieties during 1985 covering Tamil Nadu and Kerala (Ramanathan *et al.,* 1989; Ramanathan *et al*., 1990) and during 2005 covering all the three major cassava growing states of Tamil Nadu, Kerala and Andhra Pradesh (Srinivas and Anantharaman, 2006).The information was also updated from the contributions made by farmers during many of the farmers' forums and surveys. The findings are pooled in **Table 9**.

Table 9. Percent adoption of cassava varieties in 1985 and in 2005.

	Kerala		Tamil Nadu		Andhra Pradesh		India	
Varieties	1985	2005	1985	2005	1985	2005	1985[1)]	2005[2)]
Local varieties	68.18	90.96	23.10	19.29	-	-	43.03	35.48
Improved varieties[3)]	25.01	7.32	4.41	0.30	-	-	12.77	3.81
HYVC	6.81	1.72	72.49	80.42	-	100	44.20	60.71
H165	1.95	-	22.33	25.50		58.13		
H226	3.27	-	49.73	27.47		29.78		
Mulluvadi[4)]				24.30				
H1687	0.86		0.43	0.51				
H2304	0.73			-				
Sree Vijaya	-	1.43		1.83				
Sree Jaya		0.29		0.20		11.66		
Sree Prakash	-	-	-	0.61		0.43		

[1)] Based on Kerala and Tamil Nadu

[2)] Based on Kerala ,Tamil Nadu and Andhra Pradesh

[3)] Improved varieties are those selections, especially M4, released during the sixties by the erstwhile Tapioca Research Station, Trivandrum, Kerala

[4)] Mulluvadi variety was released by the erstwhile Tapioca Research Station , under the Department of Agriculture, Tamil Nadu, in Athur, Salem (probably from the accessions received from CTCRI during the early seventies).

It can be seen that there was a clear-cut difference in adoption of cassava varieties by the farmers of Tamil Nadu and Andhra Pradesh as compared to those of Kerala. While farmers of Tamil Nadu and Andhra Pradesh adopted more HYVC, Kerala farmers continued to adopt mainly local varieties. It is also clear that there was a tremendous increase in the adoption of HYVC from 44 to 60% in India during the period between 1985 and 2005. There was an increasing trend in the adoption of HYVC in Tamil Nadu, from 72% in 1985 to 80% in 2005. As far as Andhra Pradesh is concerned, HYVC occupied the entire cassava growing area, the major ones being H165 and H226. Sree Jaya, introduced by CTCRI's SBI Project Uptech, is also slowly emerging by its increasing trend in area (12%). It could be observed from **Table 9** that there is a shift in the adoption of HYVC in Tamil Nadu where H226 was dominating the cassava scene in 1985,but has given way to Mulluvadi, which occupied 24% of the cassava area in Tamil Nadu in 2005.

CONCLUSIONS

CTCRI was able to implement various outreach TOT programmes in which PLA formed a part. The degree of PLA also ranged from nominal to decision making. All these PLA-based TOT programmes were implemented over a period of time from 1970 to 2005, one after another, in which it could be observed that the intensity of PLA improved with each successive programme. The TOT influenced the adoption of the introduced technologies or helped in the development of appropriate technologies. Farmers' adoption could be influenced with minimum motivational efforts, mainly by supplying planting materials coupled with simple training programmes. Farmers could be made good researchers by proper facilitation, as found in the case of TAR-IVLP. Higher adoption of HYVC was found in Tamil Nadu and Andhra Pradesh where cassava roots are marketed to the starch and sago industries, while local varieties still dominate in Kerala where the roots mainly go for domestic use. Knowledge of the technologies had the strongest influence on the adoption of technologies. In general, PLA guarantees the effective learning process for the users as well as the researchers. PLA could humanize the research and transfer process. Farmers are the better judges of technology options and technology attributes. PLA is an effective and useful tool for cassava researchers and farmers, especially of those in the weaker sections of the population.

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ASSESSING THE IMPACT OF CLIMATE CHANGE SCENARIO A2 SRES ON CASSAVA PRODUCTION IN THAILAND

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ABSTRACT

Cassava, a crop for food, feed and fuel, is an important economic crop of Thailand. However, variation in yields often occurs throughout the country because of the variation of soil properties and climate, i.e. rainfall, temperature and the amount of CO_2. The objective of this study is to define where (spatial) and when (temporal) this will happen, and the magnitude of the impact of global warming on cassava production. GIS and a DSSAT version 3.5 model, coupled under the CropDSS 1.0 shell, are employed in this research to simulate cassava yields throughout the country during the period 1980-2099. Map data of cassava growing areas was obtained from the land use map. A weather data set from ECHAM4 A2 GCM and downscaled by PRECIS regional climate model was managed and input into the model including genetic coefficients, soil data, the atmospheric CO_2 concentration, which increased from 330 ppmv in 1980 to 833 ppmv in 2099, and management of crop production. Preliminary results show that the simulated cassava yields in 2090-99 will have decreased by 43% as compared to those in the period 1980-89 (base years). The yields fluctuated much in both temporal (34%) and spatial (33%) dimensions due to the changes in climate and soil. Thus, the reduction in cassava yield may be because of the interaction between climate and soil properties at the studied areas throughout the country. The hotspots on the production map during three periods have been defined, and this revealed that there were 14,684 ha (0.70%) in the base years of 1980-89, While this was estimated to increase to 708,743 ha (35%) in the period of 2030-39 and to 1,610,388 ha (79%) in 2090-99. These phenomena suggest that cassava yields in Thailand will be greatly affected by climate change.

Key words: ECHAM4, GCM climate model, PRECIS regional climate model, GUMCAS cassava model, CropDSS, Thailand.

INTRODUCTION

Cassava, a crop for food, feed and fuel, is one of the most important economic crops of Thailand. It was introduced to Thailand during 1786 and the cultivation area in the country currently covers more than 1.02 million hectares, spread over various rainfed ecosystems. During the early 2000s, government policies to promote ethanol production in the country increased the demand for cassava roots and made an increase in cassava yield a priority at both farmer and researcher levels. However, large variations in yield often occur throughout the country because of the variation in soil properties and climate, i.e., rainfall pattern and amount, temperature, and the concentration of CO_2, a dominant greenhouse gas. Climate variability, known as ENSO (El Niño-Southern Oscillation), and climate change are adding to this variability.

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Thus, it is important to assess the impacts of climate change on current and future rainfed cassava production systems, which in turn may provide valuable information on how to deal with household income and other related issues. However, there are few studies available on the assessment of the impact of climate change under various climate scenarios on cassava yield and production at the farm and regional level in Thailand.

The objective of this paper is to define where (spatial) and when (temporal) this will happen, as well as the magnitude of the impact of global warming on cassava production in Thailand.

MATERIALS AND METHODS

The study covers some 1.02 million ha of rainfed cassava production area in Thailand, covering an area between 12^o - 22^o latitude north and 98^o - 105^o longitude east. Based on 2002-2003 satellite image analysis, the total cassava land in Thailand is unevenly distributed among five cassava production regions, namely: the north, northeast, central, western and eastern regions, having approximately 8.81, 53.90, 7.01, 5.20 and 24.32% of the total cassava production area, respectively (OAE, 2004).

The GUMCAS-Cassava model, a cassava simulation model in DSSAT v3.5 package, was used in our study (Matthews and Hunt, 1994). It was tested in various production systems in Thailand (Sarawat *et al*., 1998). It is still undergoing testing and refinement by scientists of the International Consortium of Application of System Approaches (ICASA) and International Center for Tropical Agriculture (CIAT). The model simulates carbon dynamic, soil water uptake and plant demand during its life cycle. The model requires cultivar-specific coefficients that account for the way genotypes differ in their response to environmental variation; these coefficients are called genetic coefficients. In addition to allowing the user to vary the variety, the model accommodates the user's choice of sowing date, sowing depth, plant spacing, date and amount of irrigation. The model requires daily weather data including solar radiation, maximum and minimum air temperature, and rainfall. Initial soil conditions required by the model include drainage and runoff coefficients, evaporation and radiation reflection coefficients, rooting preference factors, and initial soil water for each soil horizon. Storage root yield is determined by the rate and duration of storage root growth as influenced by genotype and environmental conditions. The model, as yet, does not incorporate genetic coefficients for resistance to insects and pathogens.

A detailed description of the ECHAM4 climate model can be found in Roeckner *et al.* (1996). The ECHAM4 model is based on the weather forecast model of the European Centre for Medium Range Weather Forecasts (ECMWF). We obtained daily weather data generated from ECHAM4 Global Circulation Model for SRES A2 climate scenario (IPCC, 2000). The daily data set was used to assess the impact of global warming on cassava production areas in Thailand, covering the period from 1980 to 2099. The period 1980-1989 is known as the "baseline" period. We obtained soil maps and corresponding attributes, by soil layer, data from the Land Development Department of Thailand.

We linked the model with climate scenario, soil attributes, cassava management and cassava genetic coefficients under CropDSS shell (Jintrawet, 2009). The shell requires two kinds of minimum data sets (MDS) for cassava yield and production estimation at the various administrative levels, which include spatial and attributes data sets. These data sets have a simple text file format so new data can be entered directly into the system (Hoogenboom *et al*., 2003).

We developed the "Climate Impact Index" method to calculate 'hot spot' areas for cassava production under climate change A2 scenario. ***Climate Impact Index*** is expressed as follows:

$$Climate\ Impact\ Index = M \bullet A \bullet D \bullet T \qquad (1)$$

where:

M is the magnitude of yield reduction compared to the base years (1980-1989). The critical value for *M* is > 30%.

A is the proportion of the affected area, where yield is under M, normalized by the total planted area in 1980-89.

D is duration that *A* is found under M in 2030-39 and 2090-99,

T is inversely D to represent the degree of urgency and certainty of the problem.

Areas with high impact were used to identify the causes of yield reduction and determine means for adaptation.

RESULTS AND DISCUSSION

Impact of A2 scenario of cassava yield in Thailand

Model simulation showed that average yields of cassava decreased linearly from 27 t/ha during 1980-89 to only 14 t/ha during 2090-99 (**Figure 1**), a reduction of 43 percent. Furthermore, yield variability between years and also between locations was substantially high as indicated by the coefficient of variation of 0.34 and 0.33 respectively (**Figure 1**).

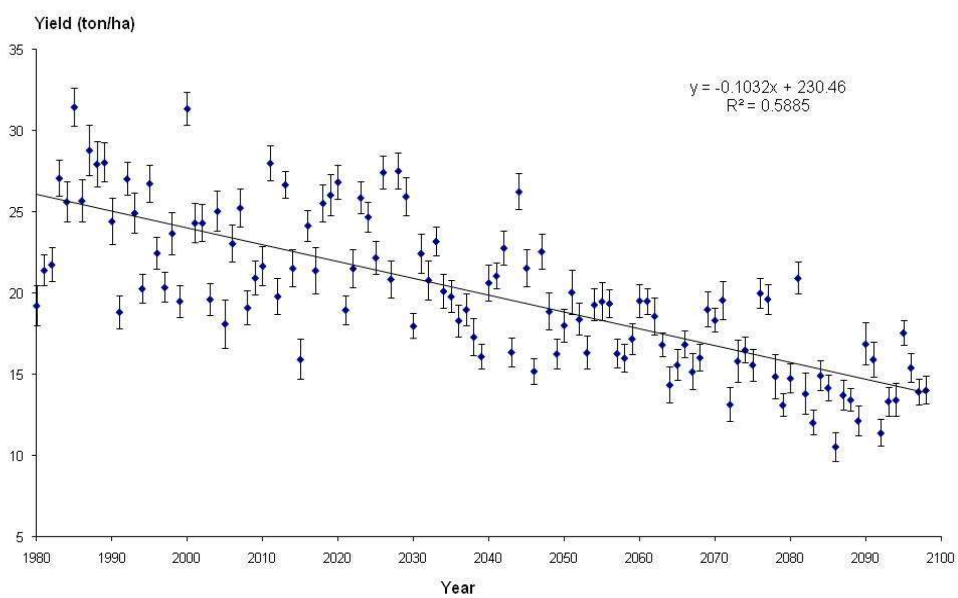

Figure 1. Yield variability between years and locations of cassava varieties KU50 simulated under SRES A2 in Thailand during 1980-2099.

These results indicate that variability of weather, especially rainfall, as a consequence of climate change was the primary determinant of cassava yield, both temporally and spatially. The impact would be exacerbated further by low water holding capacity of the soil that is common in the cassava planting areas. The interaction of these physical environments was especially evident in the northeastern region of Thailand (**Figure 2**).

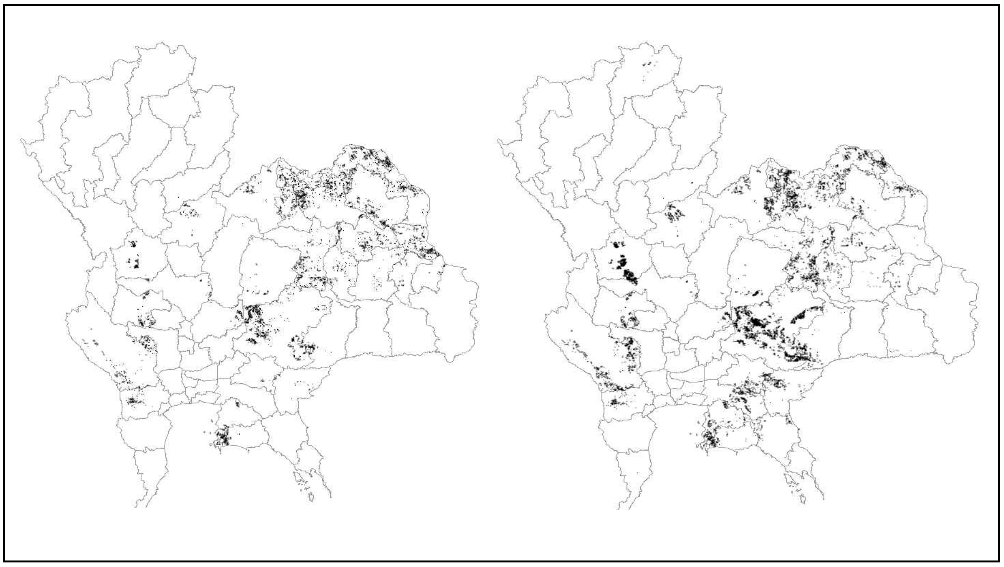

Figure 2. Maps showing the cassava growing areas where the yield reductions were more than 30 percent during the period from 2030-39 (on the left) to 2090-99 (on the right).

The impact of climate change on yield of cassava that relates to the magnitude of yield reduction, the extent of affected area and duration, and the urgency to cope with these events (measured as timing of occurrence) was combined into a single index, called the "Climate Impact Index". The areas with high Climate Impact Index, as shown in **Figure 3**, are concentrated in the northeastern region.

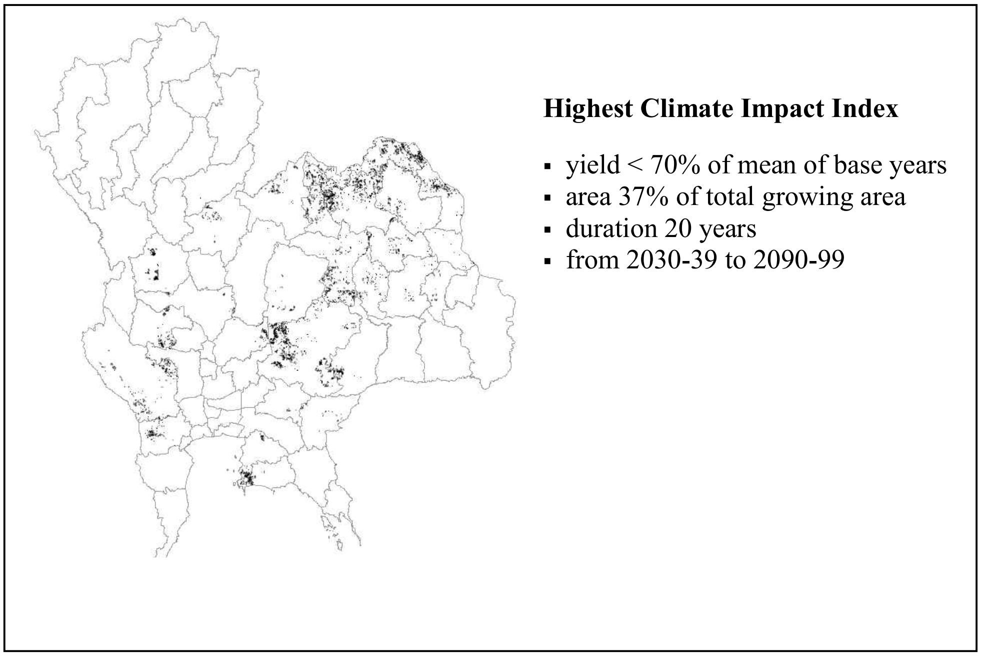

Figure 3. Map showing the cassava growing areas with the highest Climate Impact Index.

Detailed analysis of the impact of climate change on yield of cassava was then focused on those areas with a high *Climate Impact Index* in order to find means and options for adaptation. Sensitivity analysis of soil physical properties and weather revealed that, although the interaction of weather-crop-soil is highly complex, the variability of soil alone may lead to differences in cassava yield up to 40 percent on average, while weather, especially rainfall, can contribute to yield differences of only 20 percent.

Adaption to climate change

To adapt to climate change would require long-term improvements in crop management that would increase water retention of the soil, and allow roots to grow deeper into the soil. A change in planting date, from the beginning of the wet season (May) to the end of the season (October) also allows the crop to avoid serious water stress. Changing the cassava cultivar, from Kasetsart 50 to Rayong 9 or Rayong 11 will also result in less yield reduction due to climate change. Change of land use is also an important option for adaptation. It was found that the yield of sugarcane was not substantially affected by climate change when grown in some of the areas where cassava was seriously affected.

CONCLUSION

We found that cassava yields in Thailand will decrease by 43% in 2099, compared to the yield levels in the 1980s, as a result of climate change A2 SRES emission scenario. The cassava production areas affected will increase over time in all cassava production regions in Thailand. We also found that rainfall distribution and the physical properties of the soil are the key factors contributing to cassava yield reductions.

In addition, our findings suggest that it is possible to develop solutions for small-scale cassava growers in Thailand. For example, changing the cassava cultivar and planting dates, or switching from cassava to sugarcane as an alternative crop in waterlogged or high rainfall zones.

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THE CHALLENGE OF LARGE-SCALE CASSAVA PRODUCTION

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ABSTRACT

In most parts of the world cassava is a smallholder crop, produced mainly for home consumption or for sale in nearby markets. In some parts of Indonesia and the Philippines, the crop has also been grown in large plantations, owned and managed by starch factories. These plantations are mostly located in Lampung Province of Indonesia and on Mindanao Island of the Philippines. These plantations provide the basic feedstock necessary to operate the starch factory year-round, while nearby cassava farmers supply the bulk of the roots during the main harvesting season. Additional labor to operate both the plantation and factory is often imported from other areas, requiring the building of living quarters, schools, clinics and churches or mosques.

With the recent increasing demand for cassava roots, dry chips, starch and ethanol, there is a new trend towards large-scale cassava plantations, mostly in Indonesia, Cambodia, Philippines and Myanmar, and to a lesser extent in Thailand and Lao PDR. Even in Australia and the USA there are attempts to grow cassava in large plantations of several thousand hectares. These large plantations have their own challenges. To find large areas of unoccupied land, these plantations are often located in remote areas with poor infrastructure, poor soils and/or unfavorable climates. They are also located in areas with low population density, requiring either the importation of outside labor to work in the plantation and factory, or to full mechanization for production and processing. In Australia and the USA labor is so expensive that fully mechanized production and processing is imperative, while super-high yields are required to make the process economically feasible. These plantations also need to prepare large areas of land quickly and either import or produce their own planting material, since acquiring these large amounts of suitable varieties from the local population is generally not possible. Also, due to the need to supply feedstock to the factory year-round, cassava needs to be planted and harvested almost throughout the year, often when weather conditions are not optimal for the operations required. Moreover, the continuous presence in the field of cassava in every stage of development tends to result in a build-up of disease and pest problems. This requires intensive monitoring of diseases and pests throughout the plantation, and quick action to eliminate or reduce the problem as soon as possible and before it spreads to other parts. Several examples of these problems will be presented for plantations in Indonesia, Australia and the USA.

In many cases, some additional on-site research is needed to find solutions to these problems. The results of this research may also be applicable to similar situations faced by more traditional cassava farmers, so an open exchange of information and a strong link between the public and private sector is most desirable for the benefit of all concerned.

Key words: Large-scale cassava production, plantations, labor costs.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is traditionally grown by small-holder farmers, each cultivating about 0.2-4 ha. It is estimated that in Asia cassava is produced by at least seven million households. The crop is produced both for home consumption (mostly for food and animal feed) and for sale, either to middlemen or directly to local markets or to processing plants which produce dry chips, starch, animal feed or ethanol, both for

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domestic use and for export. In remote areas, far from markets, cassava is still grown as a subsistence crop, but in most countries in Asia it has become mainly a commercial crop and a very important source of income.

Until recently there were no large-scale cassava plantations, managed by large companies, except in southern Philippines and on Sumatra island of Indonesia. In these cases the crop was usually grown for production of starch or drinking alcohol (the latter only in the Philippines). The size of these cassava plantations was usually less than 5000 ha.

Because of recent concerns about the excessive use of mineral oil – a finite natural resource – for production of benzene (gasoline) for transport, as well as its effect on global warming as a result of large amounts of CO_2 being released during its combustion, there is an increasing interest in the use of sugar or starch crops as feedstock for production of fuel-ethanol that can either partially or totally replace the use of benzene to run cars. Many countries have set mandates to replace a certain percentage of benzene with a renewable and less polluting energy source like crop-based ethanol. Among several potential crops to be used as feedstock for ethanol production, cassava is favored in many countries in Asia because it is a relatively cheap raw material that can be produced under suboptimal soil and climatic conditions where other crops, such as sugarcane or maize, would not grow well. As such, several countries in Asia have been building fuel-ethanol factories, which will need very large quantities of either fresh roots or dry cassava chips. Furthermore, with the rapidly increasing standard of living in many countries in Asia, people will want to eat more meat, which requires more animal feed, and they will also increase their use of starch, mainly in processed food, in paper or textiles. Since cassava can be used as a raw material for all these products, the demand for cassava has markedly increased during the past few years resulting in inadequate supplies and increasing prices. Because large factories need a large and year-round supply of cassava roots or dry chips, they will generally want to set up their own large cassava plantations, to supply all or at least part of their raw material needs. These plantations may range in size from about 5000 to >30,000 ha. Several of these have now been established in Indonesia, the Philippines, Myanmar and Cambodia, as well as in northern Australia. Several others are in the planning stage.

Other countries with similar mandates for the use of renewable energy sources, but where cassava can not grow, such as Japan and Korea, – or where not enough land is available to expand the cassava area, such as China – are setting up cassava plantations in other countries where suitable land is still available, such as Cambodia, Lao PDR, Indonesia, Philippines and Myanmar. However, in those countries where large pieces of land are still available, these areas are usually far away from population centers and may have serious limitations in terms of soil or climatic conditions. As such, there may be many challenges to overcome to set up a large cassava plantation, but the nature of these challenges will vary from country to country, and from place to place. This paper describes a number of these challenges and gives a few examples of ways to deal with them.

Under small-holder conditions most agronomic practices are done by hand using simple tools. Thus, land preparation is usually done by hoe, or by plowing with an animal-drawn plow, or by 2-wheel or 4-wheel tractors, the latter oftentimes on contract. All other crop management practices, such as planting, weeding and harvesting are also done by hand, although there is some use of herbicides, mainly in Thailand, Malaysia and China. In Thailand farmers also sometimes use a tractor-mounted implement to aid in the harvest.

Total labor use varies but ranges from about 65 to 210 mandays per ha in different countries in Asia (Howeler, 2010).

In large plantations labor may not be available or it may be too expensive. In that case every step in the production process will need to be mechanized as much as possible. Under the most extreme conditions labor use will need to be reduced to 3-4 mandays/ha, or one person managing about 100 ha.

CHALLENGES TO OVERCOME

1. Lack of Infrastructure

Large pieces of unoccupied land are generally available only in areas far from populated urban centers, so they tend to lack good roads, a reliable electricity supply, agricultural input suppliers etc. They also tend to be rather far from air- and sea-ports, adding to the cost of transport. In many cases the companies wanting to establish large cassava plantations will need to build or improve the roads and establish their own electricity supply.

2. Lack of people and their required facilities

In the rather remote places where many companies want to set up large cassava plantations, there may not be a sufficiently large labor force to work in the fields or factory. In some cases, labor will need to be imported from elsewhere, in which case the company has to build houses, schools, clinics and churches, temples or mosques.

3. Poor soils or climatic conditions

"Empty" land usually means that there are some serious constraints to agricultural development. Thus, currently unused land may have very poor soils, either being too acid, of low fertility, poorly drained or too sandy. There may also be climatic reasons why the land has been under-utilized, such as being too cold (at high elevation), too wet, too dry, too cloudy, or the area is frequently affected by typhoons. While some soil constraints can be ameliorated with fertilizers, lime, or gypsum, this will add to the cost of production. Climatic constraints, on the other hand, are nearly impossible to overcome, except in the case of drought when irrigation may solve the problem.

4. Lack of sufficient planting material

Unless the land for the new plantation is close to an existing cassava growing area, it will be very difficult to obtain enough planting material nearby. This means that the company may have to source their initial planting material elsewhere and bring in about ten million cassava stems for every 10,000 ha to be planted. This is quite expensive and has the danger of bringing in mixtures of unidentified varieties, as well as diseases, pests and even weeds that were not present previously. A better solution is to start slowly building up planting material during a 2-3 year initial phase before the whole available area is planted. One can start, for instance, bringing in planting material (about 10,000 stems) for about ten hectares, hopefully using one or more well identified high-yielding varieties that are well-adapted to the new location. At about 8-10 months, the woody parts of the stems can be cut into 2-3 node cuttings. This will provide about 30 cuttings per plant, or enough planting material to plant 300 ha. The next year, the woody stems can be cut into short stakes of 10 cm length to obtain about 20 stakes per plant, enough to plant 6,000 ha. The following year one can cut normal-size stakes of about 20 cm length and plant about 60,000 ha. Thus, starting with a small area of only ten hectares, one can have enough planting material to plant very large areas within 3-4 years.

It would be advisable to start with a number of high-yielding varieties, test these in replicated yield trials, and then multiply mainly one or a few of the highest yielding varieties. Alternatively, if after 1-2 years of testing one variety is clearly superior, that variety can also be rapidly propagated by tissue culture (Ospina *et al*., 2007a), or by other rapid multiplication methods using rooted shoots or rooted petioles (Cock *et al*., 1976).

5. Lack of personnel with experience in cassava and in the management of large plantations

Many companies interested in setting up large cassava plantations have no previous experience with cassava or with the day-to-day management of large plantations. For that reason it is advisable to start planting only small areas in order to learn about the crop and the various problems that may be encountered. In many cases, the company would like to hire cassava researchers from public institutions, but few of these people want to give up a secure government position to work in the private sector, especially if this involves relocating to fairly isolated areas without good schools, hospitals etc. More likely, they are willing to work as part-time consultants. It is important, however, that some people with experience in cassava research are involved to train the local staff in conducting simple replicated experiments in order to identify the most suitable varieties, the most economic fertilization practices, plant spacing, use of herbicides, best times of planting and harvesting etc. The proper identification of the most suitable production practices can prevent many serious problems and can save the company thousands of dollars by maximizing yields and reducing costs. Also, it is important to have experienced plantation managers that know cassava and know how to keep proper records of what is planted where, when, how and at what cost.

6. Lack of suitable machinery for completely mechanized cassava production

Managing large-scale cassava plantations is very different from small-holder farming where most operations are done by hand. The lack of manpower and the difficulty of providing facilities for thousands of imported laborers make the use of labor-intensive operations impractical. Thus, as much as possible, all operations need to be mechanized. This can be done at different scales, depending on the size of the plantation, and the availability and cost of labor. In plantations up to about 5000 ha, much can be achieved with standard equipment for plowing, harrowing and bed formation. Stems to be used as planting material can be cut by hand or with a hand-held rotary cutter. These stems can be bundled in groups of 25 or 50 stems, using several rubber bands cut from inner tubes and spaced at about 20 cm from each other. These bundles of stems are cut with a circle saw between rubber bands to obtain bundles of 25 or 50 stakes held together with one rubber band. If stakes are to be planted vertically or inclined, it is useful to mark the upper ends of the stakes with a red dye by dropping the upper ends of the bundles of 25 or 50 stakes onto a large sponge soaked in red dye. These bundles of stakes can be easily carried in the field for vertical planting, with the red dye indicating which side of the stakes should face up.

In larger plantations where planting by hand is not practical, it is useful to plant with a Brazilian type planter, which drops the stakes horizontally in a 5-10 cm deep trench, made by the planter, and then covers the stakes with soil and firms the soil over the stakes. These planters can also apply fertilizers at time of planting in a continuous band at about 5-10 cm from the planting line and 5-10 cm deep; the fertilizers are then covered with soil.

These planters are available for planting two to six rows at the time, which requires one person for each row plus a tractor driver. A 2-row planter can plant about 6-7 ha/day, while a 3-row planter can plant about 8-10 ha/day (Ospina *et al.,* 2007b).

For plantations larger than 10,000 ha it may be more practical, depending on the availability and cost of labor, to use a modified sugarcane planter, which is being developed in Australia (see under CassTech below).

In large plantations weeds are generally controlled by pre-emergence herbicides applied right after planting, followed by a tractor-mounted cultivator at 2-3 months after planting (MAP) and, if necessary, followed by a non-selective systemic herbicide like Glyphosate or a contact herbicide like Paraquat. When using the latter two herbicides it is very important to attach a shield over each nozzle to prevent the herbicide from hitting the lower leaves and stems of cassava.

To harvest cassava, a blade attached behind the tractor is often used to lift the root clumps partially out of the ground. People are still necessary to collect these clumps and pile them into heaps, while others have to cut off the roots from the stumps. Roots are then carried in baskets to trucks or trailers for transport to the processing factory. Different models of these harvesting implements have been developed in Thailand, China, Malaysia and Brazil. A more sophisticated harvester is currently being developed in Australia; this machine will dump the root clumps into a trailer traveling alongside the harvester (see under CassTech below).

7. Requirement of year-round planting and harvesting

Small-holder farmers can wait and plant whenever there is enough rainfall to moisten the soil, and harvest during the dry season when the soil is dry and the root starch content is highest. But in large plantations, in order to keep the processing factory continuously supplied with raw material, it is necessary to plant and harvest almost year-round. This means that the land needs to be prepared, stakes planted and plants harvested during parts of the year when the climatic conditions may not be the most suitable. The soil may be too wet for plowing or harvesting, or too dry for planting. In the latter case, there may be a need for supplemental irrigation, which complicates the planting procedures, adds considerable costs and tends to increase weed growth.

Continuous planting also tends to stimulate a build up of insect and disease problems, as there will always be some young plants with fresh leaves in the field. To prevent insect and disease problems from spreading rapidly over large areas it will be necessary to monitor the whole plantation regularly, and to control the problem quickly in the hot spots before they spread to other parts of the plantation. To do this effectively, it is necessary to have trained personnel that can identify the various pests and diseases and take quick action to control the problem.

EXAMPLES OF LARGE PLANTATIONS AND THEIR SPECIFIC CHALLENGES

Several large cassava plantations have recently been established in different parts of the world for the production of dry chips, starch or ethanol. Each company at each location may face different challenges that may or may not have been foreseen. A few examples are shown below.

P.T. ASA – Indonesia

Objective: to plant 30,000 ha of cassava for production of starch and dry chips (for export to China)
Starting date: Dec 2010
Plantation site: Napu, Central Sulawesi, Indonesia
Major challenges:
1. *Very acid and low fertility soils:* While the need for lime has not yet been established, it is clear that the soils are very deficient in N, P and K, as well as Zn in certain locations. High inputs of fertilizers will be required to obtain high yields.
2. *Poor roads.* The plantation can be reached only by driving 3-4 hours on a narrow and winding road through the mountains from the nearest air- and seaports.
3. *High elevation.* The plantation is located at about 1,300 meters above sea level and has a year-round cool climate with overcast skies and almost daily rainfall. The relatively low temperature and cloudy skies will reduce the photosynthetic rate and thus the rate of growth of cassava. The rather even distribution of rainfall will facilitate year-round planting, but will also make land preparation, harvesting and the production of dry chips more difficult.
4. *Lack of labor.* The area around Napu is sparsely populated, so local labor is not readily available. The Indonesian government is using an area near the plantation as a transmigration area and is building houses, schools and roads to accommodate people coming from other parts of Indonesia, mainly from Java and Madura islands. The cassava plantation and associated processing plants could serve as a source of employment for these people in the future.
5. *Initial lack of planting material.* There are no high-yielding industrial cassava varieties grown nearby, which means that the importation of large quantities of cassava stems from Java and Sumatra will be required. Initially, these were a mixture of many unidentified varieties, while later imports were mainly UJ-5 (= KU 50) from Sumatra. After planting an initial area of 300 ha, it was decided to stop further imports and use the planting material produced from this area to further extend the area to 3,000 ha and eventually to 30,000 ha.
6. *Lack of experienced local personnel.* Indonesia has only a relatively small number of cassava researchers, and these tend to be concentrated on Java and in southern Sumatra. While several researchers would be available for short-term consultancies, it is difficult to entice them to relocate to a relatively isolated area like Central Sulawesi. For that reason, most work is initially done with workers and technicians from China.

Genefields Inc. – USA

Objective: to evaluate cassava as a potential feedstock for production of fuel-ethanol in the US.
Starting date: June 2009
Trial site: Mercedes, Texas, USA
Major challenges:
1. *There is no source of planting material of cassava within the continental USA.* Since cassava is not a commercial crop in the US, there is no source of planting material, and importation of cassava stems is not allowed for phyto-sanitary reasons. The only alternative was to import sexual seed from Africa and Latin America and start selection from true seed, followed by multiplication of selected lines using 2-node cuttings etc.

2. Soils are alkaline. Around Mercedes, Texas, the soils tend to be alkaline, resulting in many micronutrient deficiencies, such as deficiencies of Fe, Mn and Zn. Application of foliar sprays with these three nutrients markedly improved the growth of cassava.
3. Few areas in the continental US have a suitable climate for cassava. Except for Hawaii, the US does not have any truly tropical climates that are suitable for growing cassava. The initial trials were therefore conducted in the southern tip of Texas, near the Mexican border, at latitude 26° N. While this area is warm enough to grow cassava, it is also an area frequently affected by hurricanes. In July 2010 a strong hurricane caused serious flooding of the cassava fields when plants were only six months old. Wading through waste-deep water, only a part of the cassava stems could be saved for future planting. The company decided not to continue further experimentation with cassava.

Phycal Sugar, Inc. – USA

Objective: to plant 4,000 ha of cassava in Hawaii to produce glucose to feed algae for the production of bio-oil.
Starting date: July 2010
Initial trial site: Dinuba and Wasco, California, USA
Final commercial site: Kauai, Hawaii and Oahu islands of Hawaii, USA
Major challenges:
1. Lack of planting material. Only small amounts of planting material could be saved from the flooded fields in Texas (from Genefields Inc.), so they had to start anew with sexual seeds imported from Africa and Latin America. These were planted in small plastic bags with potting soil in a greenhouse in Dinuba, CA; then transplanted to bigger bags, and finally to the field in May or June of 2011.
2. California has only a 6-7 month growing season. Dinuba is located in the very fertile Central Valley of California at 36° N. The climate is characterized by hot summers and fairly cold winters. Soil temperatures in the spring remain below 15°C until May, and already in Nov-Dec the night temperature may dip below 0°C, providing only a very short growing season. As a result, many cassava varieties showed symptoms of frost (or cold) damage in mid November after a growth cycle of only 5-6 months in the field. At that time the largest and oldest plants were harvested and the small woody part of the stems shipped to Hawaii for further multiplication. The plants remaining in the field in Dinuba were cut back to near ground level, but most died due to frost damage.
3. Land constraints in Hawaii. Located between 19 and 22° north of the equator, the climate on most of the Hawaiian islands is quite suitable for growing cassava. However, the topography of Hawaii is either mountainous or with rolling hills. It is difficult to find large areas of flat land that can be mechanized. The soils tend to be rather heavy and poorly drained when compacted, while P deficiency can be quite serious due to strong P fixation. At least on the Big (Hawaii) island, many areas are covered with lava rock due to recent volcanic eruptions. These areas are unsuitable for any agricultural activities.
4. High labor costs in Hawaii. Labor costs are high anywhere in the US but particularly in Hawaii, where the cost of living is higher than elsewhere as most consumer products and oil need to be imported. This makes it essential that all cassava production practices will be fully mechanized.
5. Wild pigs. At least in some parts of Hawaii wild pigs are a serious problem, as they can do great damage to any cassava plantation when roots are almost ready for harvest. The pigs are not deterred by electric fences, and other methods of control are either expensive or ineffective. Planting only very bitter varieties may be the best solution.

CassTech – Australia

Objective: to plant at least 6,000 ha of cassava for production of starch, protein extract from leaves and animal feed.
Starting date: 2005 for preliminary experimentation and development of suitable technologies; 2012 for commercial production
Location: Burdekin River Valley in northeast Queensland, Australia
Major challenges:
1. Need very high yields to be economically viable. The proposed location for the CassTech plantation combines many ideal factors for obtaining high yields: the area receives plenty of solar radiation; the soils are fertile; the land is almost perfectly flat, which will facilitate mechanization; water is available for supplemental irrigation; and the Casstech team has selected two high-yielding varieties that are currently being multiplied to provide good quality planting material for at least 600 ha. Still, due to high labor costs the company considers that root yields of 60-80 t/ha will be necessary, and co-products such as woody pellets from surplus cassava stems and foliage-derived animal feed will further enhance profitability. While yields of 60 t/ha can be obtained, it will still require a great deal of input of resources to increase this to 80 t/ha, and to obtain these high yields over a large area and on an ongoing basis.
2. Need supplemental irrigation. The Burdekin River Valley has a near ideal climate for irrigated crops like sugarcane, maize and cotton – as well as for cassava. Although cassava is much more drought tolerant than any of the other crops, it will require supplemental irrigation during at least 7-9 months of the year to obtain these high yields. The mean annual rainfall is 960 mm/year, of which about 70% falls during a short rainy season from Jan to March and only 5% during a 4-month dry season from July to October. Plenty of irrigation water is available from the Burdekin River. The company proposes to supply the water through a drip irrigation system using specially designed drip tapes that supply water at a uniform pressure throughout the entire drip tape network.

Because of the relatively short rainy season, the area receives plenty of solar radiation, having about 300 days of sunshine per year which will stimulate rapid growth; this is also promoted by a rather hot summer with mean maximum temperatures of 25-32°C, and warm winters with mean minimum temperatures of 12-23°C.
2. Some areas have sodic soils. The soils in the area are quite suitable for cassava as they are mainly sandy clay loams and sandy loams with a slightly alkaline pH (6.5-7.5) and with medium to high levels of P and K. However, the Na saturation is rather high for cassava, especially at 30 cm depth. To solve this problem, gypsum will be applied at rates of 5-10 t/ha by a precision applicator based on subsoil measurements of electrical conductivity. This will improve the soil's structure by replacing Na with Ca on the exchange complex, allowing the Na in solution to migrate down below the cassava rooting zone.
3. Labor is very expensive. As such, practically all operations have to be fully mechanized, from rock picking and planting, to leaf, stem and root harvesting. Land is prepared by plowing and disking followed by a rotovator that forms beds at 1.5 m between centers (corresponding to the wheel base of the tractors). It is proposed to plant a single row on each bed with 1.5 m between the rows and 40 cm between plants within the row. A drip tape can be rolled out and buried in the center of the bed at the same time as cassava is being planted.

The cassava planter has a very large hopper containing cassava stakes that were already cut into 20 cm stem pieces during the previous stem harvesting operation. Inside the hopper is an elevator system that moves the stakes to the top of each chute before the stakes fall down in a preformed shallow trench, with fertilizer and micronutrients being added at the same time; the stakes are then covered with soil and slightly tamped down with a rubber roller wheel. The planter can plant cassava simultaneously on three parallel beds; this requires only one operator and a tractor driver.

At time of harvest, the young tops with leaves are first cut off by a leaf harvesting machine, which then shreds the leaves, petioles and young green stems and deposits these in a big hopper; when full, the contents of the hopper are mechanically unloaded onto large trucks for transport to the processing factory. The leaf harvester is followed by a stem harvester which cuts the woody stems at ground level and then cuts these stems into 20 cm long stakes and deposits these in the large hopper of the planting machine which drives alongside. Finally, the clumps of roots are lifted out of the ground with a large blade mounted behind a tractor. The roots are pushed up onto an elevator belt, which shakes off most of the soil and then deposits the root clumps (with a small piece of stump still attached) in a trailer or truck traveling alongside the root harvester. The roots are then taken to the processing plant for further removal of soil and washing before the root clumps are either chipped for processing into dry chips, or are grated for processing into starch or ethanol. Using this fully mechanized cassava production process, CassTech expects to need only one person for managing each 100 ha, which is equivalent to about 3 mandays/ha for all operations from planting to harvest.

CONCLUSIONS

Large-scale cassava plantations have to face very different challenges from those faced by small-holder farmers, mainly due to the large land areas required, which can generally be found only in rather remote locations with deficient infrastructure and/or with serious soil or climatic constraints. The unavailability or high cost of labor makes it necessary to mechanize all or most field operations, while the lack of sufficient planting material slows the initial establishment of the plantation.

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DEVELOPING AN R&D STRATEGY FOR CASSAVA IN SOUTHEAST ASIA: FROM A CIAT PERSPECTIVE

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ABSTRACT

The cassava sector in Southeast Asia has developed into a large and quite complex production, trading, and processing sector. The size, productivity, geographic focus, market focus, and general uses for cassava have changed enormously in the last few decades, with the change in some countries being much more recent. From an initial focus on Indonesia, large areas of cassava have been planted in Thailand, then Vietnam and China, and more recently in Cambodia and other countries. On average, the yield has increased by 50 to 100% in most countries, which has paralleled the adoption of higher yielding and high starch varieties. The higher production and dynamic processing enterprises have helped shift the crop from a food crop to many other uses for food, for feed, and for a wide range of industrial processes based on cassava starch, which more recently has involved fossil fuel replacement by ethanol as a biofuel and by bioplastics.

Research has been a critical part of the development of new high yielding and high starch varieties. In addition, research on some aspects of improved agronomy and land management have resulted in a better understanding of the potential to improve production through management, although there has been comparatively little uptake of these improvements. These areas of research need to be continued and increased, along with some additional new areas. In breeding there is a need to broaden the focus on yield and starch content, to further develop starch qualities suitable for specified uses, as well as to include resistance to, or tolerance of, pests and diseases, and for other characteristics such as delayed post-harvest deterioration, different plant types, and herbicide resistance. There is much that needs to be done in both research and development of improved agronomy and land management, especially in relation to providing a more consistent supply of feedstock to the processing industries. As labor costs increase, there are increased possibilities to justify the use of other inputs, such as fertilizers, as the relative cost compared to labor declines. There is also a need to continue to improve post-harvest value adding by smallholder producers, to link producers more effectively to markets, and to work with the processing industries to improve processing of wastes.

Obtaining sufficient funding for CIAT and partners to undertake the required research has not been easy, although there has been much better support for participatory extension approaches to adapt research outputs to the needs of farmers. In Southeast Asia the cassava industry is a multibillion-dollar per year industry, with great potential for poverty alleviation, and yet the industry does not see their role in supporting research for development – this is seen largely as a role for governments. CIAT has experience in dealing with different models of funding for applied research for development, including public-private partnerships, for rice, beans, and cassava in both Latin America and Africa. These various models of organizing and funding cassava research and development will be discussed with respect to the needs and possibilities for similar support for cassava in Southeast Asia.

Key words: Cassava R&D, funding, Southeast Asia

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INTRODUCTION

The cassava sector in Southeast Asia is a large and quite complex multibillion-dollar per year production, trading, and processing sector. About 4 million hectares are harvested each year, producing about 80 million tonnes of fresh roots, which are then traded and processed into an increasingly wide range of products. Much of the production is traded internationally, both within and outside Asia, with the vast majority of internationally traded cassava products being from the region, particularly from Thailand and Vietnam.

Cassava remains an important snack, emergency food, and regular staple food in the region, but its role has increased greatly for use in processed foods, animal feed, starch for a multitude of pharmaceutical and industrial uses, and as a fossil fuel replacement, primarily as ethanol for use as a biofuel, and emerging as a feedstock for bioplastics. The impact on the lives of millions of smallholder farmers has been immense, in poverty alleviation and wealth creation, with a significant impact on national economies.

Changes in Cassava Production

The size, productivity, geographic focus, and market focus of the sector have changed enormously in the last fifty years. Some important changes occurred in the late 1960s and 1970s in a number of countries, most particularly in Thailand, with more recent changes since the late 1990s and 2000s in many other countries. National statistics from the Food and Agriculture Organization of the United Nations, FAO, provide good evidence of these changes (FAO, 2011), although it must be acknowledged that these data do have some problems. Generally, the quality of the FAOSTAT data has improved since establishment in the early 1960s, particularly as the value of the data for national planning has been realized. Despite this, there are problems with the cassava data, largely because the importance of the crop has been underestimated. In many countries the data on the expansion of planting are somewhat delayed compared to the real situation seen in the field. Despite these shortcomings, these data do provide a good indication of the trends in planting and production. The data discussed are for the ten cassava-producing countries in Southeast Asia, which includes the cassava-production areas in southern China, as well as data from India and Sri Lanka.

In the period from 1961 to 2010, the quantity of cassava produced annually in the region increased from less than 20 million tonnes to about 80 million tonnes (**Figure 1**) with the area harvested increasing from about 2.2 million ha in 1961 to approaching 4 million ha in 2010 (**Table 1**).

Indonesia has been a major producer throughout this period. Despite doubling production (**Table 2**), the Indonesian share of total production has dropped, from more than 60% to about one third, as production rose in other countries. The first major change in other countries producing cassava occurred in Thailand, with a dramatic increase in the area planted; doubling in the 1960s, increasing five-fold in the 1970s, and reaching a maximum of more than 1.5 million ha in the late 1980s before declining to the current level of about 1.1 million ha (**Table 1**), with similar changes in production (**Table 2**). Other countries experienced large increases in the areas planted to cassava, including Vietnam, China, and Cambodia. In Vietnam there was a large increase in the area planted in the late 1980s, followed by a decline, and then a doubling of the area planted from 2000 to 2010, although there is good evidence that current planting is significantly greater than the national statistics indicate. In China, the data indicates that the area cultivated has increased steadily over the period, with an overall trebling of the area harvested, but again provincial level data suggest that theses FAOSTAT data underestimate the current area planted. Cambodia provides another interesting case, with a massive tenfold increase in planting from 2000 to 2010, albeit from a very low base, and again, current information suggests that recent data may underestimate actual planting.

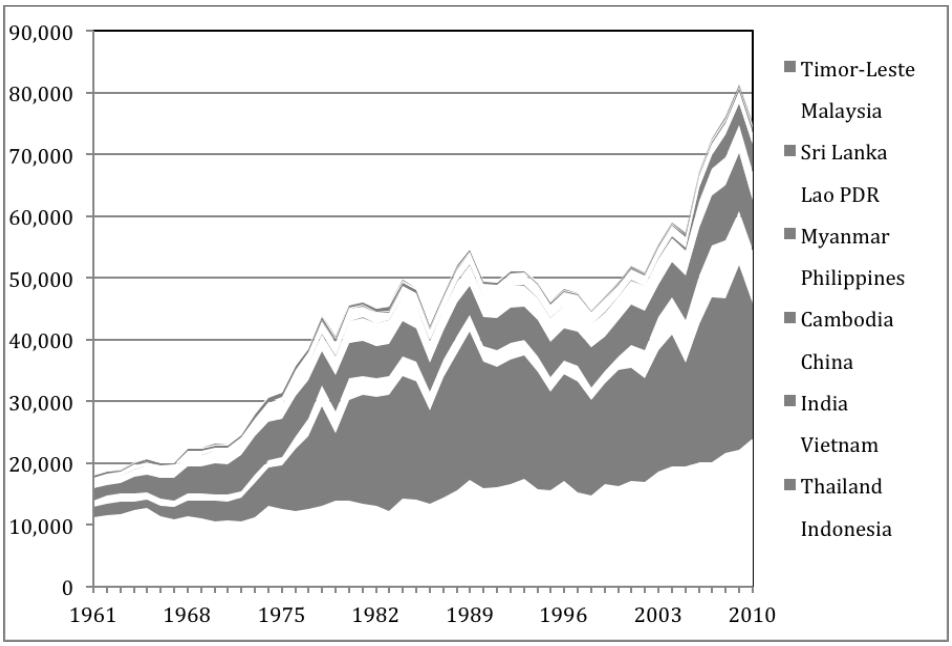

Figure 1. Cassava production ('000 t fresh roots) in Asia from 1961 to 2010.

In contrast to these countries that experienced large increases in the area of cassava production, the data from India is more similar to the situation in Indonesia. Of the countries under consideration, India had the second largest area under cassava in 1961 and by 2010, although there had been an increase in the area of production in the intervening period, the area had reduced by about 20%. With a similar decline in area, from 1961 to 2010, production in Indonesia more than doubled, while production in India increased by more than a factor of four.

While changes in the area of cassava harvested have influenced production, the productivity per unit land has also increased. Yields have increased (**Table 3**) by 50 to 100% in most countries, and much more in some, with the average increase across these twelve countries being 140%. The importance of increased productivity can be seen by comparing the relative changes in area, yield, and production for the region (**Figure 2**).

Over this 49-year period, the area cultivated to cassava increased by a factor of 1.7 while the yield increased by a factor of 2.4 (**Figure 2**). The net effect is a more than fourfold increase in production. The increase in area dominated the period up to the late 1980s, driven by the expansion of planting in Thailand. By contrast, yield increased quite steadily throughout the period, but with a sharper increase from the late 1990s, which resulted in a related sharp increase in production during the same period.

Table 1. Area of cassava harvested ('000 ha) in Asia from 1961 to 2010.

Country	1961	1970	1980	1990	2000	2010
Indonesia	1,478	1,398	1,412	1,312	1,284	1,183
Thailand	99	224	1,121	1,488	1,131	1,168
Vietnam	122	131	443	257	238	498
India	274	353	352	242	224	232
China	94	161	238	231	239	279
Cambodia	1	3	19	11	15	202
Philippines	100	83	204	214	210	218
Myanmar	1	1	3	5	8	45
Lao PDR	1	1	5	5	7	20
Sri Lanka	39	60	51	43	30	23
Malaysia	14	31	32	37	9	3
Timor-Leste	6	7	6	8	11	6
Total	**2,228**	**2,451**	**3,887**	**3,852**	**3,404**	**3,877**

Table 2. Production of cassava ('000 t) in Asia from 1961 to 2010.

Country	1961	1970	1980	1990	2000	2010
Indonesia	11,190	10,478	13,726	15,830	16,089	23,918
Thailand	1,726	3,431	16,540	20,701	19,064	22,006
Vietnam	965	945	3,323	2,276	1,986	8,596
India	1,969	5,214	5,845	4,962	6,014	8,060
China	1,166	1,908	3,485	3,216	3,822	4,694
Cambodia	14	30	152	60	148	4,247
Philippines	521	433	1,900	1,853	1,766	2,101
Myanmar	4	12	50	53	77	607
Lao PDR	10	15	68	65	71	500
Sri Lanka	297	354	499	379	249	283
Malaysia	125	288	330	360	120	37
Timor-Leste	18	18	22	35	50	28
Total	**18,004**	**23,127**	**45,941**	**49,789**	**49,457**	**75,077**

Table 3. Yield of cassava (t/ha) in Asia from 1961 to 2010.

Country	1961	1970	1980	1990	2000	2010
Indonesia	7.6	7.5	9.7	12.1	12.5	20.2
Thailand	17.4	15.3	14.7	13.9	16.9	18.8
Vietnam	7.9	7.2	7.5	8.9	8.4	17.3
India	7.2	14.8	16.6	20.5	26.9	34.8
China	12.4	11.9	14.6	13.9	16.0	16.8
Cambodia	11.6	10.8	8.0	5.5	9.6	21.0
Philippines	5.2	5.2	9.3	8.7	8.4	9.7
Myanmar	10.5	9.7	16.1	9.6	10.1	13.5
Lao PDR	10.0	13.6	15.1	12.8	9.7	25.1
Sri Lanka	7.7	5.9	9.8	8.8	8.4	12.1
Malaysia	9.3	9.3	10.3	9.7	14.1	13.4
Timor-Leste	3.0	2.6	3.5	4.2	4.8	4.6
Total	**8.1**	**9.4**	**11.8**	**12.9**	**14.5**	**19.4**

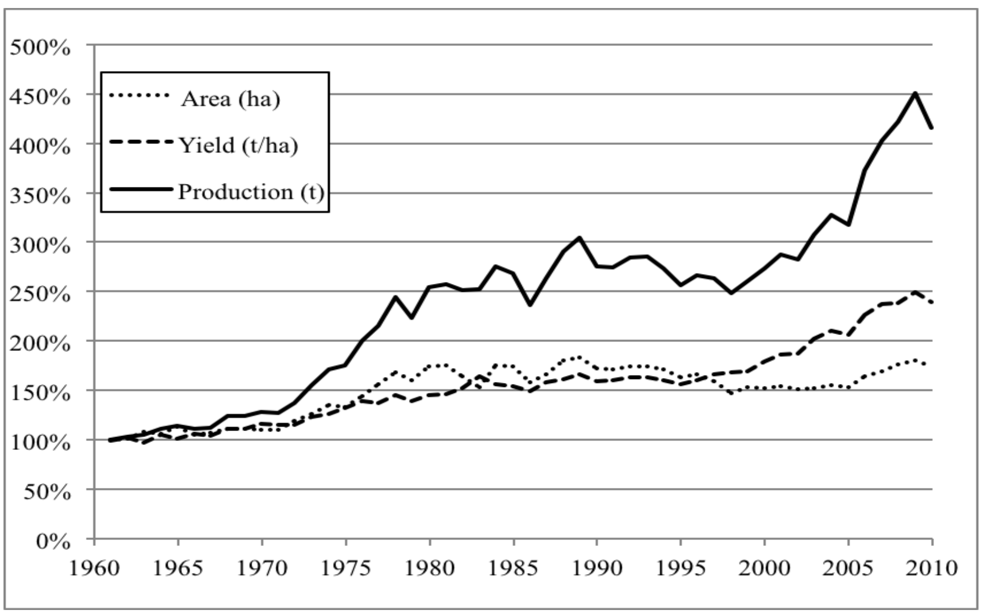

Figure 2. Relative changes in the area, yield, and production of cassava in Asia from 1961 to 2010.

The drivers of increased cassava production

Increases in yield can be driven by the availability of improved varieties and by better management. While it is hard to apportion yield increases to particular components, it is clear that a major factor in the increase in yield was the availability of new varieties, with high and stable yields and high starch content, yielding substantially higher starch yields per ha. The big advances in varieties became available from the beginning of the 1990s, first in Thailand and then across Southeast Asia. The replacement of areas planted to older varieties, particularly in Thailand, and the expansion of new planting with these new varieties, particularly in Vietnam and Cambodia, were a major component of the rapid increase in average yield and in production over this period from the late 1990s (**Figure 2**).

There has been a lot of applied research on improved management of cassava, particularly through better nutrient management of the crop, primarily through the addition of fertilizers, and the maintenance of soil fertility through minimizing soil erosion. Despite some excellent results and strong indications of the economic value of adopting improved fertilizer and erosion control measures, the adoption of new varieties has been more widespread than the adoption of better management.

It is clear that where good management has been adopted with good varieties then yields can be much higher. India has some of the lowest yields of cassava in the region, in the areas of Northeast India where cassava is grown in traditional cropping systems; however, in the two main states for cassava production, Kerala and Tamil Nadu, the combination of well-adapted varieties, excellent management, and relatively high inputs, has produced some very high yields. This combination of varieties and improved management resulted in the fourfold increase in production at the same time as the area cultivated declined by nearly 20%. Localized examples of high yields through a combination of good varieties and good management are seen in other areas, particularly in the south of Vietnam, especially in Tay Ninh province, in parts of Guangxi in China, in parts of Northeast Thailand, and on some of the larger cassava plantations in Sumatra in Indonesia. It is clear that the adoption of good agricultural practices (GAP) can result in significant increases in yield and more sustainable cropping systems and analyses of these systems shows significant returns on investments on components of GAP, such as improved fertilizer applications.

While the availability of stable and high yielding varieties with high starch content and improvements in management have made the increase in production possible, there have been a number of other factors that have driven the increase in production.

Over recent decades there have been major changes in the markets for cassava. The first major increase in cassava production, in Thailand in the 1960s and 1970s, was driven by the demand for dried cassava chips for animal feed in Europe. This market collapsed during the 1990s, resulting in a decline in production (**Figure 1**), but was rapidly replaced by demand, primarily in Asia, for cassava starch for a multitude of uses, and chips for animal feed and later for bioethanol. The broadening markets were reflected in good prices. Recent changes in the domestic price of fresh roots in Thailand, as well as the export prices for dried chips and premium grade starch, reflect the quite good and general trend of increasing prices, although with some significant variations over the period from late 2006 until mid 2011 (**Figure 3**). Good prices are a major incentive for farmers to start or expand cassava production, although unpredictable price variability can be a critical issue, especially for smaller and poorer farmers.

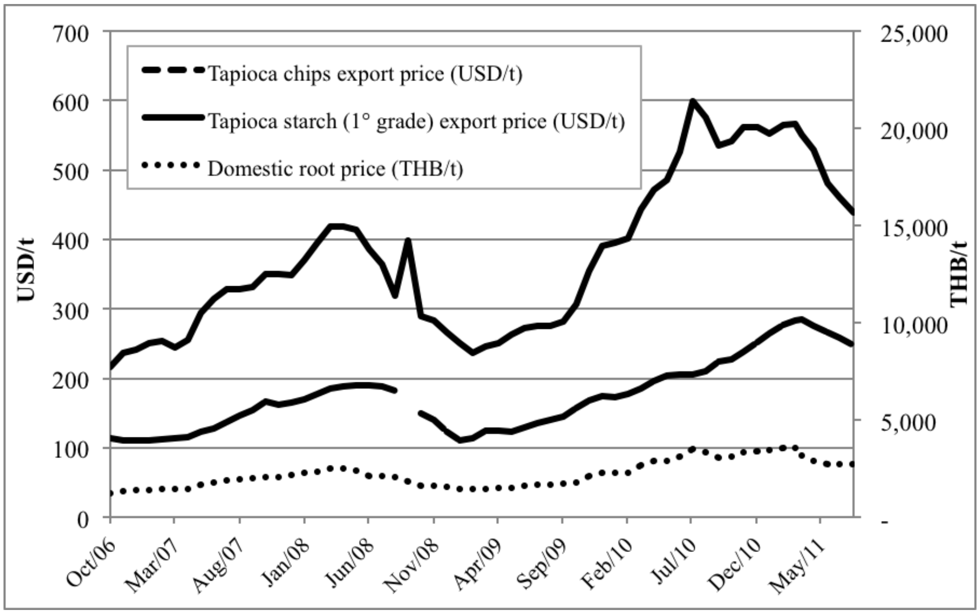

Figure 3. Price of fresh roots (domestic, THB/t), dried chips (export quality, USD/t), and cassava starch (premium export quality, USD/t) in Thailand from October 2006 to August 2011.
Source: *Thai Tapioca Development Institute, 2011. http://www.tapiocathai.org*

Another critical issue to drive the expansion of cassava production during this period across the region has been various forms of infrastructure. The rapid expansion of cassava production in Thailand in the 1970s was possible because of good and improving road access and the development in parallel of relatively simple facilities for drying cassava chips, in the form of large concrete drying floors and associated chipping equipment. Similar improvements in access have been seen across the region with greatly improved road networks. These improvements in road networks have been driven by the Greater Mekong Sub-region (GMS) plans for economic corridors developed and implemented by the Asian Development Bank and national governments of the GMS, primarily during the period from 1995 to 2015. In parallel with these improved road networks, there has been further development of feeder roads, which have increased the access to various markets and services for many marginalized communities, especially in the more isolated mountainous areas of the region.

The next wave of expansion, driven more by the demands of the local cassava starch industry, required the development of starch processing facilities. This started in Thailand, and was followed by rapid expansion across most of the upland provinces of Vietnam, and with large facilities in Indonesia and China. There was similar expansion in facilities for a wide range of processors, for modified starches, sorbitol, and more recently ethanol, as well as a steady increase in mills that used cassava chips as one of the feed stocks for animal feed production.

When environmental concerns around some of these processing facilities became an issue that could threaten the industry, there was a critical infrastructure response to reduce this threat. Improved waste management was introduced, which in many cases involved the processing of biogas that subsequently reduced the energy costs for processing. Increasingly, the residues from production were used in other processes, such as in animal feeds.

Of course, another driver in the expansion of cassava was the suitability of the crop to the different soils and climates across the region. The initial expansion of cassava in Thailand was driven by the demand for cassava chips for the animal feed industry, but it was in part made possible by the collapse of the kenaf industry. Kenaf (*Hibiscus cannabinus*), along with its related fiber crop, roselle (*Hibiscus* sabdariffa), is ideally suited to the conditions in northeast Thailand and was a major crop up to the 1960s. While these are drought tolerant crops, traditional methods of processing required large amounts of water. Problems of water availability, the pollution of water, and, perhaps most importantly, the collapse in the price and demand for kenaf as the fiber was replaced by man-made products, led to a rapid decline in the planting of kenaf. Ecological niche modeling, using the EcoCrop model, of the suitability of cassava to conditions in the Mekong sub-region indicates that while it is not quite as broadly suited to the conditions as kenaf, it is much better suited to these conditions than many other crops. The ability to survive in quite poor soils and the ability to tolerate drought conditions, once established, are important factors in the suitability of cassava in the region and the choice of cassava over other possible crops. Despite this tolerance of quite poor conditions, this cannot be confused with an inability to respond well to good conditions in terms of improved soils and good water management, as can be seen by the high yields where GAP is implemented.

Thus, the combination of a crop well suited to the area, the market demand for cassava and cassava products, and the transport, marketing, and processing support allowed millions of smallholder farmers to expand cassava production, in preference to other crops. This increased production of cassava has resulted in huge benefits in terms of household income and security, and in terms of national economic benefits, especially in export production.

The threats and challenges to cassava production

It is clear that cassava is well suited to the biophysical and socioeconomic conditions across much of the region, but one consideration is how well the crop will cope with the projected changes in climate. A preliminary analysis by CIAT suggests that there are very few areas across the world in which the growth of cassava will suffer as a result of projected increases in temperature and projected changes in rainfall. In fact, it appears that the area suited to cassava globally will increase. Research on heat tolerance may benefit some small potential areas of production, particularly in parts of India, but this does not cover areas currently important for production, and so, generally this is not considered an important line of research.

A bigger worry, as far as climate change is concerned, is the likely impact on pests and diseases of cassava as preliminary analysis suggests that the incidence and severity of outbreaks will increase with projected changes in climate. Southeast Asia has been very fortunate in that the massive explosion of cassava production, and associated economic benefits that has occurred in the last five decades was not matched by a parallel increase in the incidence of the pests and diseases seen in other cassava producing areas of the world, until recently.

In 2008, some outbreaks of the pink cassava mealybug (*Phenacoccus manihoti*) were noted in northeast Thailand, with increasing severity and range over the next few years, leading to major yield losses. While an initial response was through chemical approaches, including the spraying of plants and dipping of planting material, it was realized quite quickly that the biological control developed for outbreaks in Africa in the 1970s and '80s would be the best approach to adopt. In mid 2010 the biological control of the cassava mealybug was deployed in the field in Thailand through the mass raising and release of the parasitoid wasp *Anagyrus lopezi*. This should result in substantial reductions in the negative impacts of the mealybug, but these incidences have indicated the need to carefully monitor pest outbreaks, both for mealybug and for other potentially important pests, such as various mites (of which the green spider mite, *Mononychellus mcgregori*, is perhaps the major concern), and various whitefly species (and perhaps the major concern is for the spiraling whitefly, *Aleurodicus disperses*).

Diseases, which also have been of little concern in Southeast Asia in recent decades, are a further threat to production. Cassava Bacterial Blight (CBB) has been found in the region for many years, but with little impact, although this may be changing. Of more concern is the Cassava Witches Broom disease, which appears to be caused by a phytoplasma, has been found to reduce both yield and starch content, and has appeared recently in parts of Vietnam, Thailand, and Cambodia. So far there is no evidence of the important viral diseases that have caused major problems in Africa, namely Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD), except for the less serious strains of CMD in India and Sri Lanka. Clearly there is a need for increased monitoring of diseases, as well as more detailed understanding of the diseases, their causal agents and vectors, and control options.

The sustainability of cassava, as a crop and as part of cropping systems, is a major concern, for a number of reasons. Firstly, as cassava is known to survive on poor soils there has been a belief that the crop does not need fertilizers or other components of soil fertility management. Conversely, cassava has been seen by some as a destroyer of soils because once cassava has been grown then many consider that no other crop will grow. The offtake of most nutrients, other than potassium, is relatively low per kg of roots compared to many crops. As with any crop, however, with repeated removal of reasonable yields of roots there is significant removal or loss of all major nutrients, so a well-balanced application of nutrients is required. Although soil reserves of potassium may help to maintain yields for some time, depending on the soil, ultimately potassium needs to be applied in proportion to the amount removed in roots and so to yield. The application of other nutrients will depend on yield, but this also depends on other factors, such as how crop residues are managed and other components of the cropping system. As a large proportion of leaves senesce and drop in the field, some nutrients are returned. Nutrients will be removed in stems saved for planting material, but in most cases these will be returned to the field during the next planting. Moreover, when all of the leaves, petioles, and stems not used for planting material are left in the field and incorporated into the soil, or are left as mulch, the nutrients in them will also be returned, limiting the nutrient offtake only to those nutrients removed in the harvested roots. The relative nutrient efficiency of cassava means that well balanced applications of fertilizers can have large impacts on yield, and with high returns on investment.

The second major threat to the sustainability of cassava systems is from soil erosion. Many of the soils used for cassava production are light textured soils, which have quite high erosivity. In addition, with the wide spacing used for cassava and the slow establishment and early growth, it takes several months before the crop canopy is closed, so bare soils are at high risk of erosion. There are two main components of erosion reduction or prevention, namely avoiding the detachment of soil particles as a result of raindrop impact and avoiding entrainment of detached soil particles in runoff water. Protecting the soil surface from rainfall impact, with a biological or an artificial soil cover, can reduce detachment. Reducing the velocity of runoff water over the soil surface, by reducing the length or the steepness of the slope, can reduce entrainment. As such, for a particular set of soil types, topography, and rainfall quantity and intensity, there is a wide choice of steps that can be taken to reduce erosion. Helping farmers choose the right approaches to erosion control, for both biophysical and socioeconomic reasons, is key to implementing sustainable production.

Responding to threats and challenges to cassava production

An important component to tackling current and future threats to cassava production is through plant breeding. This has two broad components, namely the focus of the breeding efforts and the approaches to implementing varietal improvement. For some time, the focus has been on yield and starch content, and this focus has resulted in the current varieties with higher starch yields per hectare, and clearly this work needs to continue. More recently, as a stronger understanding has developed of the various traits within the cassava germplasm collection, other traits have been tackled. Two important traits that have been considered are waxy or amylose-free starch and high β-carotene materials. Other traits that have been considered or may be of interest are high amylose (low amylopectin) starch, reduced postharvest physiological deterioration, pest and disease tolerance or resistance, cold tolerance, herbicide resistance, high protein or other nutritional qualities, branchless architecture or other plant types, and more. On approaches to implementing varietal improvement, there have been technical developments, including identification of molecular markers, phenotyping to link to markers, investigation of the collection of cassava varieties, landraces, and wild relatives, development of double-haploids, and more. There are also changes in the approaches to implementing breeding programs, which hopefully will lead to greater integration of the breeding programs of international institutes, such as CIAT, and regional and national breeding programs. Increasingly it can be expected that national and regional programs will select the specific foci of their breeding programs and implement crosses and varietal selection, while CIAT will focus more on trait identification and developing breeding lines for use at the national and regional levels.

On pests and diseases, as these are emerging problems, there will need to be an increase in efforts in these areas, with a balance of monitoring, applied and pure research, capacity building, and implementation. It is likely that the focus will be on mealybugs, mites, whitefly, witches broom disease, and perhaps CBB, but with careful monitoring driving the specific focus or broadening the focus to other pest and disease problems that are identified. The approaches are most likely to be primarily on management and biological control, perhaps with some judicious use of chemical control, but ultimately moving to include breeding for tolerance or resistance through both conventional and molecular breeding techniques. An important component of pest and disease management, which will also help in the uptake of new varieties bred for a wide range of purposes, will be efficient propagation systems to provide clean planting material to large numbers of farmers. While an increase in the threats of pests and diseases is a great concern, and needs a great deal of effort to develop and implement mitigation strategies, it is possible, as has been found with other crops, that the need to better manage cassava because of pests and diseases will lead to better overall management of the crop with higher yields per unit of land, labor, and other inputs.

There are many aspects of crop management that can be improved, individually, or as a complete package of good agricultural practices. A good example of the benefits of combining improvements in genetics and management can be seen from the example of Green Revolution rice in Latin America (Jennings, 2007). The introduction of semi-dwarf rice in favorable environments resulted in a one-off increase in rice yield of about 2 t/ha, with average yields across the region increasing gradually as the new varieties were adopted. There were no major increases in yield with the subsequent release of a further 400 semi-dwarf varieties over the next 30 years. Despite this lack of change in average yields it was noted that some farmers in some areas had much higher yields and analysis of their management showed the importance of matching improved genetics with improved agronomy. By focusing on six critical factors, namely the time of seeding, the seeding density, seed treatment to control insect pests, good weed control, appropriate fertilizer use, and proper irrigation management, it was possible to obtain an additional 2 t/ha from good agronomy, so doubling the improvement from good genetics. So, combining the benefits of the Green Revolution with a Brown Revolution.

With average cassava yields in Thailand, Vietnam, and Cambodia now at between 15 and 25 t/ha we know that some specific sites in these countries, as well as in parts of Guangxi, are about double the national averages. India provides an example of combining good genetics with good management, with the national average yield of about 35 t/ha, driven by the situations in the two main production areas, in Kerala and Tamil Nadu.

There is now quite good information on many of the components of good management, particularly on soil fertility management, although the capacity for farmers or extension workers to select the most appropriate fertilizer recommendations for particular situations is comparatively poor. There is a great need to develop the capacity for appropriate site-specific fertilizer management. There is a similar situation for erosion control, although with the additional challenge that the benefits are not always immediately obvious, and even when there are major benefits good outcomes may be that soil health and yields do not decline, rather than a clear yield increase being observed, as with the adoption of a new variety or the application of appropriate soil fertility management.

Other important management issues are the quality of the planting material, the timing and density of planting, and seasonality in terms of when best to plant and to harvest, both for maximizing starch yield, but also maximizing economic returns by matching the demand for feedstock by processors, and thus the balance of yield and prices.

As the direct cost of labor and labor opportunity costs increase, so the interest in mechanization increases. In some situations all operations, including land preparation, ridging, laying of plastic mulching, weeding, harvesting and preparing planting stakes, harvesting and even mulching of tops, lifting of roots, and collecting roots have been mechanized. But this can only be justified where labor costs are very high. A more likely scenario will be the mechanization of some steps or the introduction of tools to help manual operations, such as the lever-based harvesting tool. Which steps are mechanized will depend on labor costs and labor availability at different times, the availability of equipment, and more. The biggest impacts will most likely come from mechanization of cultivation and ridging and then next from mechanization of harvesting, or at least lifting before manual collection of roots.

A critical issue with such a long-season crop as cassava is the cash flow and the delay between paying for inputs and receiving cash from the sale of roots. This will become even more of an issue if the greatest economic returns are received when the length of cultivation is extended beyond a year, to increase yield at the same time as to match high demand and so prices from processors. For many of these cases, in which improved management involves additional expenses, developing a cropping system with earlier returns is attractive. To this end, there appears to be significant scope for more work on intercropping systems. The intercropping of newly planted cassava with a faster-growing short-duration crop can produce significant benefits if the right intercrop is chosen and well managed. The right intercrop can result in rapid ground cover, so reducing the risk of erosion, improved soil fertility management, through biological nitrogen fixation and/or the addition of organic residues to the soil, and a harvestable product that can benefit household food security directly, through animal feed, or though income to cover the costs of inputs and to add to household income.

Although not related to cassava production directly, another issue is improved management of the links between the production of roots and the final product for sale. Much can and has been done to improve the links between smallholder producers, collectors, and the processors, in terms of appropriate contracts, price information, arrangements for transport and delivery to factories, payment regimes, and more. When working well, such arrangements can result in benefit to all stakeholders in terms of income, efficient use of time, and the matching of feedstock delivery to processing demand.

Postharvest management by smallholders or local traders is a further area that can be improved. Especially if access to collectors or processors is difficult, efficient and effective postharvest treatment of cassava roots can be important for more sustainable livelihoods related to cassava production. For instance, if roots cannot be reliably collected by or delivered to processors, then there is a risk that the value of the crop will be greatly reduced. One option is to undertake a degree of postharvest processing at or near the site of production. This could involve washing, peeling, cutting, and drying of quality chips, or even processing of roots through to small- or medium-scale wet starch processing for further value adding by noodle makers or other users of wet starch. Processing or partial processing of cassava roots near to the site of production has other important impacts. Firstly, there can be an energy efficiency component resulting from more efficient transporting arrangements. Secondly, there can be benefits in terms of waste management, with less concentration of residues at major processing sites, and thirdly there are increased options for the utilization of processing "wastes" nearer the site of production. As an example, the wastes of starch processing can be a useful component in animal feed rations. If the roots are processed near to the site of production, then the farmers can access the waste from the processing of their roots to use as animal feed, and so get closer to closing the nutrient and energy cycles from production to processing.

With high returns on investments for many of the components of improved management, the main challenges for adoption are the selection of which components to adopt and paying for the chosen components, which can be assisted greatly by the selection of an intercrop that yields well and has high economic returns. While identifying the component parts may be difficult, a "big data" approach to analyzing the current components in use across multiple locations presents an attractive option for developing site-specific recommendations.

Organizing the Responses by CIAT and Regional Partners

Clearly there is much to be done in terms of research, applied research, and extension to improve production, trading, and processing of cassava. In Southeast Asia, there has been international and national funding for participatory extension approaches, which has helped to get new varieties and technologies adapted and adopted by smallholder farmers, but there has been relatively limited funding for the development of new varieties and research on improved production and processing technologies. Substantial resources have been poured into international and national research efforts in the past, although obtaining funds for current and future research is not easy. Cassava is a multibillion-dollar per year industry in Southeast Asia with large involvement by the private sector in production and, more particularly, processing. Despite this, funding of research is seen by the sector as primarily the responsibility of governments, not of industry. Not surprisingly, national governments are more interested in funding national level research and extension, but this means international or regional efforts do not have significant access to these funds. International funding has focused more on extension and livelihood improvements, so there is a challenge at all levels to fund the required supporting research for development.

Besides funding there is the issue of how best to organize a coordinated regional research and development network of national and international organizations, be it a formal or informal arrangement that is funded or unfunded. CIAT has experience with a number of different models of R&D networks that may provide examples for a cassava R&D network in Southeast Asia. In Latin America, CIAT was involved in establishing CLAYUCA, the Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y al Desarrollo de la Yuca (the Latin American and Caribbean Consortium to Support Research and Development of Cassava). CLAYUCA was established and administrated by CIAT with funding by partner countries in proportion to the areas of cassava planted in each country. With many of these countries having comparatively weak research and extension services, some financial support from national governments for CLAYUCA was seen as an attractive way for them to access appropriate R&D. A somewhat similar approach in which CIAT has been involved has been used for irrigated rice in Latin America, through the Fondo Latinoamericano para Arroz de Riego (FLAR, the Latin American Fund for Irrigated Rice). On several occasions a proposal has been made to establish and fund an Asian Consortium for Cassava Research and Development (ACCORD), with funding based on various mixes of the level of production and the value of cassava imports, however, this proposal has never received strong endorsement from potential member countries, who understandably prefer to fund their own R&D efforts, rather than a consortium approach.

Another approach to the funding and organizing of R&D has been for CIAT involvement in RD&E on beans in Africa, through PABRA (Pan-Africa Bean Research

Alliance). This is a consortium across 29 countries, and includes investments from national government institutions, NGOs, and other partners, with strong and broad financial support by three major donors, and more specific support from other donors. It has worked very effectively, although with the more commercial aspect of cassava in Southeast Asia compared to a more food security focus for beans in Africa, plus the understandably greater interest of donors in Sub-Saharan Africa compared to Southeast Asia, a similar approach for cassava in Southeast Asia seems very unlikely.

Given the difficulties in developing a formal and funded cassava R&D consortium of international institutions and national stakeholders in Southeast Asia, perhaps the best option is for a less formal alliance of interested stakeholders, including CIAT and national R&D organizations. These stakeholders would be either self-funded or attract funding as individual institutions or small groups of stakeholders, probably for specific projects or activities, rather than as a consortium as a whole. Such an Asian Cassava Research and Development Alliance could undertake many of the RD&E activities outlined above. Some activities, such as the monitoring of pest and disease outbreaks and assessment of impacts, would require a highly coordinated multi-country approach to work effectively. Other activities, such as breeding for specific traits, would benefit enormously from the integration of R&D activities. Each country may have different priorities for breeding, but the sharing of information and of breeding outputs would likely lead to more rapid advances in the selection of germplasm adapted to the specific biophysical and socioeconomic conditions in each country and all based on breeding lines and approaches that involve CIAT. Similarly, with good agricultural practices, the countries are likely to have different possibilities, as dictated by biophysical considerations, labor costs, markets for inputs, and more, and yet common experiences will be valuable, with a larger set of data allowing much better analyses, even if the final selection of options and extension approaches is more country specific. Benefits will also flow from an alliance on issues of post-harvest management, from issues of collecting, pre-processing, processing, and marketing, especially when some of these issues cross borders, such as for Cambodia, where the majority of processing is undertaken in neighboring countries.

CONCLUSIONS

From a history of a largely forgotten crop, cassava is now firmly established and acknowledged as an important crop for the livelihoods of millions of smallholder farmers across Southeast Asia, as well as a critical processing industry and a sector that has important national and regional impacts. Despite this positive situation, there are threats for the sector. The sustainability of production systems needs to be improved in many locations, addressing issues of soil erosion, soil fertility decline, susceptibility to pests and diseases, cost effectiveness in terms of cost per unit of land, inputs and labor, and the production of relevant and desired products for the processing industry. Similarly, the processing industry needs to continue to improve waste management, focus on efficiency in terms of water use, labor, and more, and continue to respond to market opportunities and market signals. The link between the producers, processors, and the markets is also critical. Price instability is a major threat to small and marginalized producers and establishing appropriate cash flows, credit, and market access are critical, as maybe a shift to more post-harvest value-adding by producers or at least by local rural communities.

All of these options for improvements in the sector require, or at least will be assisted by, strong and coordinated international and regional approaches to research, development, and extension, with interactions between researchers, extensionists, industry, markets, and policy makers. There is a need for a strong alliance of stakeholders to foster and undertake such activities, and there is a clear collaborative role for CIAT in such developments and activities. Hopefully, the CGIAR Research Program on Root and Tuber Crops and Bananas (CRP-RTB), which is currently in development (CGIAR, 2011), will go someway to addressing these critical issues.

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