Cassava's Potential in Asia in the 21st Century:

Present Situation and Future Research and Development Needs

Proceedings of the Sixth Regional Workshop
held in Ho Chi Minh city, Vietnam. Feb 21-25, 2000

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Editors: R.H. Howeler and S.L. Tan

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R.H. Howeler
1. Farmers evaluating FPR trials in Thong Nhat, Phu Tho, Vietnam
2. Chipping cassava roots on drying floor in Wang Sombuun, Sra Kaew, Thailand

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II. Howeler, R.H. and S.L. Tan.
III. Centro Internacional de Agricultura Tropical.

PREFACE

The year 2000 marked the start of a new century and a new millennium. It also marked 25 years of close collaboration between CIAT/Colombia and cassava researchers in Asia. This collaboration started in 1975 with the arrival at CIAT of three cassava researchers from Kasetsart University in Thailand for an extended period of training in cassava varietal improvement, pathology and agronomy. This initial group was followed in 1976 by three Thais and three Malaysians, and in 1977 by another four Thais and one Indonesian. Many other cassava researchers from Asia have been trained at CIAT in subsequent years. Between 1978 and 1989 CIAT also organized four production training courses for Asian researchers in which a total of 86 persons participated. Over the past 25 years a total of 141 Asian researchers received training at CIAT/Colombia, while another 12 obtained MSc or PhD degrees with CIAT funding. This training not only increased people's knowledge about many aspects of cassava production and utilization, but also cemented a strong bond of friendship between cassava researchers at CIAT and those working in national programs in Asia. It was precisely this mutual trust and friendship which allowed CIAT to set up a Regional Cassava Office for Asia in Bangkok, Thailand, in 1983. The CIAT cassava breeder and agronomist stationed in Bangkok were thus able to work very closely with cassava researchers in many Asian national programs, with the common objective of improving the yield potential and starch content of cassava varieties, to widen the genetic base of cassava germplasm, and to improve the sustainability and productivity of cassava, with the ultimate goal of raising the standard of living of cassava farmers while protecting the soil resource base.

Shortly after the establishment of the CIAT Regional Cassava Office for Asia, CIAT organized the first Asian Cassava Workshop, held in Bangkok in 1984, to discuss the situation of cassava in Asia, its potential and research development needs. This workshop provided the blueprint for future collaboration between CIAT and Asian national cassava programs, focusing on cassava breeding and agronomy. With financial assistance mainly from the Japanese government, CIAT organized the second Regional Workshop in Rayong, Thailand, in 1987; the third in Malang, Indonesia, in 1990; the fourth in Trivandrum, Kerala, India, in 1993; and the fifth in Danzhou, Hainan, China, in 1996. Proceedings of these workshops have been published, and these provide a permanent record of the progress made during each three year period.

The sixth Regional Cassava Workshop was held in Ho Chi Minh city, Vietnam, from February 21 to 25, 2000. It was considered an opportune moment to pause and take stock, to review what had been done and achieved, to assess the present situation and the challenges ahead, and to discuss together how cassava can play an even more important role in the economic development of the countries in the region, and be a vehicle to improve the livelihood of cassava farmers, processors, traders and consumers. And, finally, to discuss again the need for future research and development to meet the challenges of a new era. Moreover, the Nippon Foundation supported project on "Improving the Sustainability of Cassava-based Cropping Systems in Asia", had finished the first phase (1994-1998) and had just embarked on a second phase (1999-2003). The sixth Regional Cassava Workshop was thus an opportunity to review the activities and assess the results of the first phase of the project, and to discuss how best to move forward to achieve the ambitious targets set for the second phase.

The Proceedings of the sixth Regional Workshop, entitled "Cassava's Potential in Asia in the 21st Century: Present Situation and Future Research and Developments Needs", thus reviews in detail the research done in Asia in the areas of cassava varietal improvement and agronomic research over the past 25-35 years and describes the major achievements attained; it also reviews the Nippon Foundation sponsored FPR projects in four countries as well as a similar FPR project conducted in India. A number of papers also assess the current situation of the cassava industry in each country and in the region as a whole, and describe new potential uses of cassava and how these products can play a role in opening new markets for cassava, in order to keep cassava competitive in an ever more globalized economy.

During the Workshop the Advisory Committee of the Asian Cassava Research Network met to elect new representatives from each country. These are:

Watana Watananonta	DOA, Thailand:	Chairman
Reinhardt Howeler	CIAT, Thailand:	Secretary
Li Kaimian	CATAS, China	
S. Edison	CTCRI, India	
Nasir Saleh	RILET, Indonesia	
Tan Swee Lian	MARDI, Malaysia	
Fernando Evangelio	PhilRootcrops, Philippines	
Pham Van Bien	IAS, Vietnam	

The Advisory Committee decided that the 7th Regional Workshop will be held in Thailand, probably at the end of 2002.

CIAT wants to take this opportunity to express its most sincere thanks to the Nippon Foundation of Japan for the generous financial support they have provided, not only in funding the FPR project in various countries over the past seven years, but also to contribute to the organization of the sixth Regional Workshop. Without this support it would be impossible to continue the Asian Cassava Research Network and to continue organizing the triennial Workshops.

CIAT also wants to thank the Vietnamese government, and in particular the Institute of Agricultural Sciences (IAS) of south Vietnam, for hosting the sixth Regional Workshop. The hard work of the organizing committee resulted in a highly productive and enjoyable meeting, and provided an opportunity for all participants to renew friendships, to exchange ideas about the latest developments in cassava research, and to experience the good food and the hospitality of the Vietnamese people.

R.H. Howeler
CIAT, Bangkok
September, 2001

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OPENING ADDRESS

STRENGTHENING INTERNATIONAL COOPERATION IN CASSAVA RESEARCH AND DEVELOPMENT PROGRAMS

Prof. Dr. Ngo The Dan
Vice Minister
Ministry of Agriculture and Rural Development of Vietnam

Good morning distinguished guests,
Ladies and gentlemen,

Today, scientists and distinguished guests from different countries in Asia, Latin America and Africa come to Ho Chi Minh City, the second largest city of Vietnam, and take part in the Sixth Asian Cassava Workshop. On behalf of the Ministry of Agriculture and Rural Development of the Socialist Republic of Vietnam, I warmly welcome all of you in the spring of the year 2000, the transitional year to the new century.

Vietnam ranks 13th in the world in terms of cassava production and 4th in terms of cassava exports. Exports of cassava starch are now reaching 100-180 thousand tonnes a year. Major markets of Vietnam's cassava exports are the P.R of China and Taiwan, Japan, Korea and countries in Eastern Europe. In the past ten years, cassava research and development in Vietnam have made significant progress. Cassava yield and production in several provinces has doubled, which has brought about the construction of new large-scale cassava processing factories, especially in the south of Vietnam. This has helped farmers to increase their income and generated more employment. This workshop provides an opportunity for scientists, educational instructors, extension workers, cassava producing and processing enterprises, businessmen and managers, to see and learn from each other, and to exchange experiences.

During the years 2000-2010, the production of food crops will remain the mainstay of Vietnam's agriculture, with the goals of: 1) to guarantee the security and stability of the national food supply, to increase food reserves so sufficient food is available for local consumption; 2) to produce an abundant supply of feed stuff for the development of livestock production with a growth of 8-10% a year, and sufficient raw materials for the processing industry; and 3) to increase agricultural exports with high efficiency and at competitive prices. Among the main food crops, the Vietnamese government focuses on the development of rice, maize, cassava, potato and sweetpotato in the most suitable regions and cropping seasons. Cassava plays an important role in livestock production and in the processing industry.

Research in breeding and selection of cassava varieties/cultivars that have high starch yields, in establishing sustainable and profitable pilot farms in cassava production, in providing a stable source of raw materials for processing, in diversifying of processed commodities, in finding and developing potential cassava markets, is all very important. I do believe this workshop will provide useful information on cassava research and development at present and in the coming years as well.

On this opportunity, I wish the workshop a good success, I wish all of you good health, and a pleasant and interesting stay in Ho Chi Minh City.

I have the honor to hereby declare the opening of the Workshop.

THE ROLE OF IMPROVED CASSAVA CULTIVARS IN GENERATING INCOME FOR BETTER FARM MANAGEMENT

Kazuo Kawano[1]

ABSTRACT

Cassava has been changing its role from a traditional fresh human food to an efficient crop for animal feed and starch production. Nearly all cassava is grown by small farmers. Harvested roots are sold to animal feed or starch factories, or are used for on-farm feeding of pigs to be sold at the market. Thus, cassava is an important source of cash income to small farmers in many parts of Asia.

International breeding efforts for higher root yield and starch content have been successful and the total area planted with the improved cultivars is now reaching one million ha in six countries in Asia. A substantial portion of economic gain generated by the improved cultivars is entering the household income of small farmers. However, cassava production often causes soil degradation when proper agronomic practices are not followed. Soil conservation is the prime issue in sustainable cassava production. While individual agronomic practices are important and indispensable components of soil management, a more fundamental requirement is to first upgrade the economic situation of farmers, in order to cut the vicious cycle of poverty and environmental mismanagement. Improved cassava cultivars is one of the most readily adoptable components for inducing better farm management by increasing feed or starch production leading to increased farm income.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is one of the most important calorie-producing crops in the tropics. It is efficient in carbohydrate production, adapted to a wide range of environments and tolerant to drought and acid soils (Jones, 1959; Rogers and Appan, 1970; Kawano *et al*., 1978; Cock, 1985). The major portion of the economic product, the root, is consumed as human food after varying degrees of processing. An estimated 70 million people obtain more than 2100 kj/d(500 kcal/d) from cassava, and more than 500 million people consume more than 420 kj/d(100 kcal/d) in various forms of cassava throughout the tropics (Cock, 1985).

In many parts of Asia cassava's traditional role as a fresh human food is rapidly changing to being an efficient industrial crop for factory processing. In Thailand, cassava for fresh human consumption has been completely replaced in the past three decades by cassava production for animal feed and starch processing. In Indonesia, Vietnam, China and the Philippines, while a considerable amount of cassava production is consumed as fresh human food or is used for the on-farm feeding of farm animals, the proportion used in producing value-added food, feed and industrial products is increasing. Thus, in this rapidly developing part of tropical Asia, cassava production for fresh human consumption is decreasing while its use for feed and industrial processing is rapidly increasing (Bottema and Henry, 1992; Kawano, 1995a).

Cassava as Animal Feed

In tropical America, the center of origin and diversification of cassava, cassava roots have been traditionally used as an energy source for humans as well as for farm animals. Research has shown that dried cassava can be added upto a certain proportion of

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the feed rations of broilers (Montilla, 1977), layers (Omole, 1977), swine (Khajarern *et al*., 1977), and ruminants (Devendra, 1977). A life-cycle swine feeding study indicated that fresh cassava roots of a so-called "sweet cultivar" were an excellent source of energy for swine feeding if properly supplemented with protein, vitamins and minerals, and it was concluded that a life-cycle feeding of pigs could be based on a high level (60-70%) use of cassava meal (Gomez, 1977). Bitter cassava roots in fresh form are not usually consumed by pigs because of their high content of cyanide.

In Vietnam and China, dried cassava roots are widely used for swine feeding. The remarkable increase of cassava production from the 1960s to the 1980s in Thailand was almost entirely based on the export of dried cassava chips and pellets (some 6-8 million t/year in peak years) mainly for swine feeding to the European Community. Now that the cassava pellet exports to the EU have diminished, the cassava harvest is effectively diverted to the domestic feed market and to starch production. Since the consumption of animal protein in Asian diets is expected to rise very significantly, increased production of energy sources for livestock feed is much needed. Cassava is a strong candidate for answering to this need.

Cassava Toxicity

Toxicity of cassava is caused by the presence of the cyanogenic glycoside linamarin, together with much smaller amounts of the closely related lotaustralin. These substances hydrolyze under the influence of the endogenous enzyme linamarase to liberate hydrogen cyanide (HCN). The quantities of toxic principle vary greatly between cultivars. Although so-called sweet cultivars are generally of lower toxicity than the bitter ones, the correlation is not exact. Variation in cyanogen content with ecological conditions during plant growth also occurs (Coursey, 1973).

A wide variety of traditional food preparation techniques are used for processing cassava in different parts of the world, and an important element in all of these is an attempt to reduce the cyanide content by liberation of the HCN, either by volatilization or dissolution in water. These processes involve drying, maceration, soaking, boiling, roasting, or fermentation of the cassava roots, or a combination of these processes (Coursey, 1973).

A series of studies in Africa revealed that while all toxic effects from cassava can be effectively avoided by sufficient processing, short-cuts in established processing methods are the underlying cause of cyanide exposure from cassava that can cause acute intoxications and chronic aggravations of goitre (Rosling *et al*., 1993).

There is a long list of insects that attack cassava plants (Bellotti and Kawano, 1980). Many of these are specialists (feeding only on cassava or closely related species) and are considered to have co-evolved with cassava since a long time ago. On the other hand, there are also generalist enemies, such as the cassava burrowing bug (*Cytomenus bergi* Froeschner, Cydnidae, Hemiptera), for which the high HCN content in cassava roots appears to function as a strong defense (Bellotti and Arias, 1993; Riis *et al*., 1995). This group of generalists includes rodents, wild boars, human thieves, and even elephants. They are considered to be newcomers to the evolution of cassava. Some practicing agronomists consider that the advantages of HCN in cassava outweigh the potential disadvantages.

It is the general understanding that for animal feeding cassava is an excellent energy source as long as it is properly processed (chipped and dried). Since the production of starch from cassava roots, no matter how crude it may be, includes the basic detoxification processes, such as maceration, soaking and drying, HCN toxicity from consumption of food products made of cassava starch is not heard of.

Yield Improvement Opportunities

A comprehensive cassava breeding endeavor, initiated by CIAT (Centro Internacional de Agricultura Tropical, with headquarters in Colombia) in 1973, and later involving a network of national breeding programs, is now witnessing the economic effects generated by the adoption of new cultivars (CIAT, 1995; Kawano, 1995b; 1998).

There have been three phases in the successful varietal improvement. The first phase corresponds to the evaluation of cassava germplasm and the generation of advanced breeding materials conducted at CIAT headquarters from 1973 to 1982. We attained in this phase a significant upgrading (90%) of physiological yield potential of the breeding population (calculated as the mean fresh root yield of selected clones to be used as cross parents for recycling in the hybridization program, in each year relative to the control) compared with the starting population which consisted of mostly traditional land races (**Figure 1A**). Of this process, enhanced (55%) harvest index (proportion of root weight in the total biomass) was the major factor (**Figure 1B**) (CIAT, 1976; 1983; Kawano *et al*., 1978).

The second phase corresponds to the Thai-CIAT collaborative cassava improvement program, conducted at the Department of Agriculture and Kasetsart University from 1983 onward. In this phase we accomplished, using the local materials and the advanced materials from CIAT/Colombia, a significant upgrading (50%) of dry root yield of the breeding population (**Figure 2A**). Of this process, enhanced biomass (25%, **Figure 2B**) and root dry matter content (15%, **Figure 2C**) were the major factors (CIAT, 1993; 1995; Kawano, 1998; Kawano *et al*., 1987; 1998)

The third phase corresponds to the selection of new cultivars, their release and dissemination by national programs. While Thailand naturally attains the largest acreage planted with new cultivars, Vietnam shows this varietal development success more dramatically than any other country. For the most part of the 1970s and 1980s, agricultural research in Vietnam was isolated from progress made outside the country. During this period, cassava varietal improvement in Vietnam was not much more than the maintenance and evaluation of local cultivars. The introduction into Vietnam of the best cassava clones from the Thai-CIAT collaborative breeding program started in 1989. This led to an immediate improvement (more than 100% eventually) of yield levels in the breeders' trials at the research stations (**Figure 3**), and similar improvements soon followed in farmers' fields.

The number of CIAT-related cassava cultivars officially released in Asian national programs has passed 35 in 1997 (Kawano,1998; and other unpublished communications). In Thailand, where hard data are available on the area planted with each cultivar from statistics of the Department of Agricultural Extension, the total area planted with five new cultivars was 376,250 and 622,000 ha in the 1995/96 and 1996/97 planting seasons, respectively (Rojanaridpiched *et al*., 1998). In Indonesia, new cultivars were planted in more than 110,000 and 136,000 ha in 1995/96 and 1996/97, respectively (Puspitorini *et al*.,

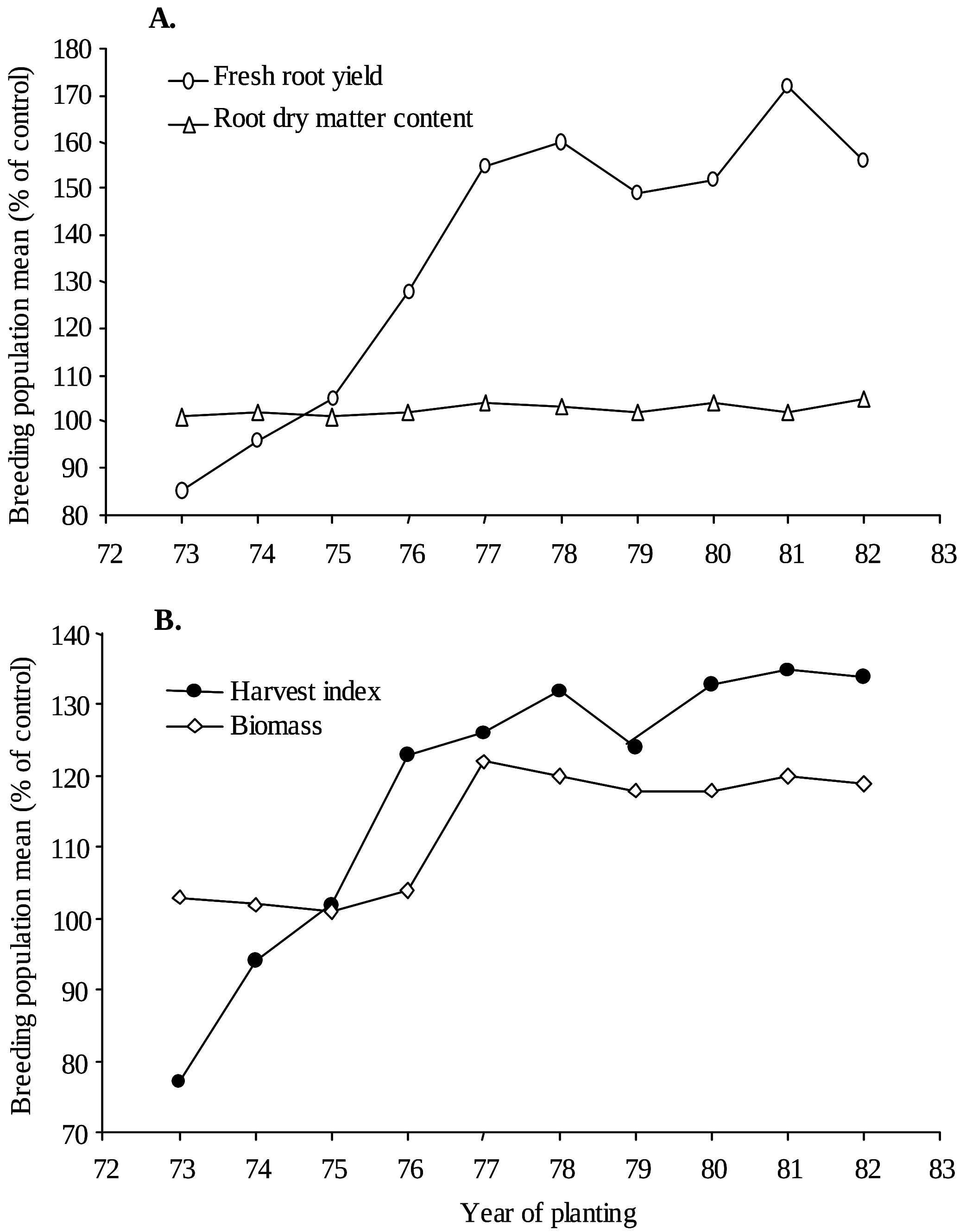

Figure 1. Change in yielding capacity (A) and harvest index and biomass (B) of the breeding population, given as the means of all entries in a yield trial for advanced clones to be used as cross parents for recycling in the hybridization program at CIAT Headquarters from 1973 to 1982.

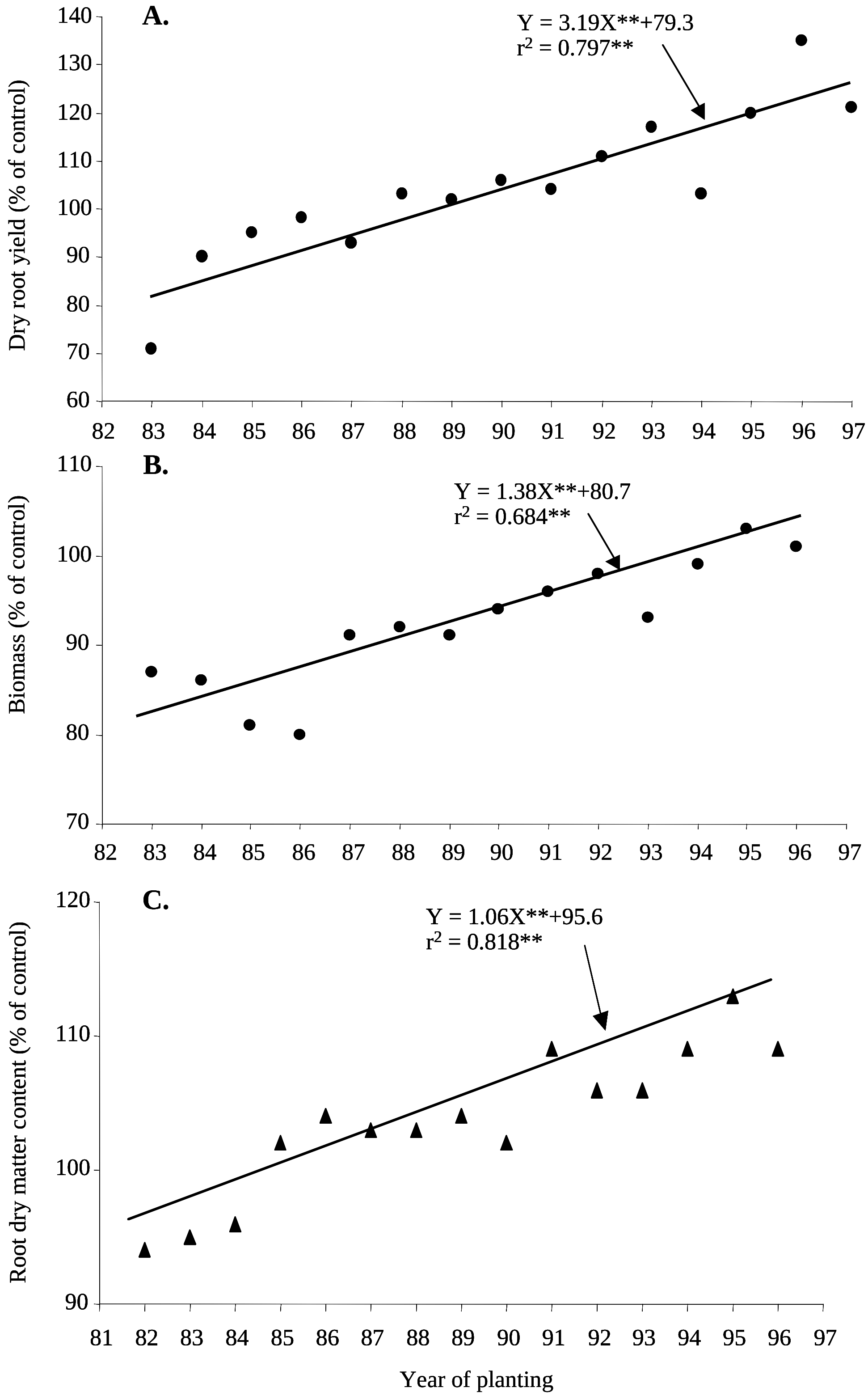

Figure 2. Yearly change in dry root yield (A), biomass (B) and root dry matter content (C) of the breeding population, given as the means of all entries in six regional yield trials for clones of official release condidates relative to control varieties in Thailand from 1982 to 1997.

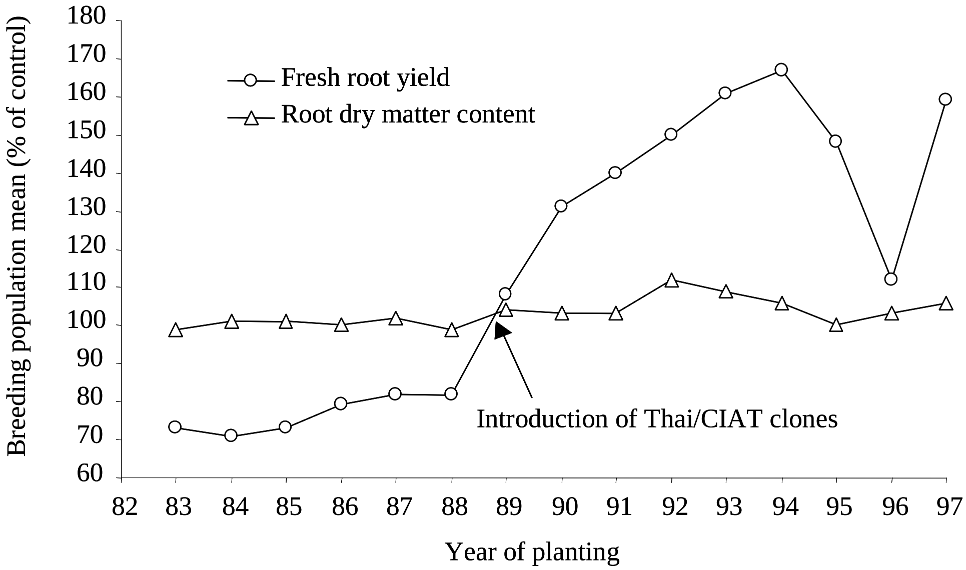

Figure 3. Change in yielding capacity and root dry matter content of breeding population, expressed as mean of all entries of yield trials for selected clones at Hung Loc Agric. Research Center, Vietnam.

1998). In Vietnam where the CIAT collabolation started much later but the progress is the fastest, the area planted with new cultivars is estimated to have passed 15,000 ha in the 1996 planting season (Kim *et al*., 1998). The adoption of new cultivars is also starting in the Philippines (Mariscal and Bergantin, 1998), China (Tian and Lee, 1998), and Myanmar (personal communication). Thus, the total acreage of CIAT-related improved cultivars in Asia is passing the one million ha this year.

Economic Effects Caused by the Adoption of Improved Cultivars

The results of hundreds of on-farm varietal trials indicate that in general farmers are getting 5 to 10 t/ha additional fresh root yield and the factories are enjoying an additional 3% (actual value) of root starch content by the adoption of the newest cultivars (Kawano, 1998; Kim *et al*., 1998). The additional economic effects caused by the higher starch content of the new cultivars in Thailand is estimated to be 87.6 million US dollars, and that caused by the higher fresh yield to be 42.4 million dollars for the 1996/97 season (Kawano, 1998; Rojanaridpiched *et al*., 1998). In Sumatra, Indonesia, the additional fresh root yield in the fields and the additional starch production in the factories caused by the new cultivars are estimated to have generated the economic gains of 32.6 and 44.7 million US dollars, respectively, for 1996/97 (Puspitorini *et al*., 1998). In South Vietnam, more money had been made by the sale of planting stakes of new cultivars than by the sale of fresh roots with higher starch content in the early years, but the benefits caused by the additional fresh root production and the additional starch production will probably surpass that from the sale of stakes from the 1996/97 season onward (Kim *et al*., 1998). The total economic effects due to the superior yield and quality of new cassava cultivars accumulated in the past ten years upto 1997 is estimated to be 693 million US dollars in Asia.

Benefits to Small Farmers

In Thailand virtually all the cassava production takes place in small farmers' fields and all the harvested roots are sold to processors. In Vietnam also, all the cassava is produced by small farmers and at present those advanced farmers who adopted the new cultivars sell all their harvested roots to processors (South Vietnam), or use them for feeding pigs to be sold at the market (North Vietnam). In Indonesia and the Philippines, some cassava production occurs in large plantations; yet, the majority of production takes place in small farmers' fields. Thus, we can assume that virtually all the additional economic effects generated by the higher fresh root yield of new cultivars are going directly to the pockets of small farmers.

How much of the additional profit generated by the higher starch content of new cultivars is shared by the farmers depends on what differential prices starch factories (or chipping plants) pay to the farmers. Large factories in Thailand, Indonesia and Vietnam are returning 55 to 100% of the value of additional starch production caused by the higher starch content of the raw material to the farmers. All in all, the scheme is not outrightly unfair to the farmers. We can safely assume that a substantial portion of the 693 million US dollars so far generated by the adoption of new cultivars has entered the household income of small cassava farmers.

The recent varietal dissemination in North Vietnam revealed that thousands of small farmers are adopting new cassava cultivars in their small plots (360-5000 m^2). Virtually all of them use the additional cassava production for on-farm pig feeding, which results in 50-600 kg additional pig sale (US$ 45-545) per family per year. The whole scheme is not as spectacular as the rapid varietal dissemination in South Vietnam or in other countries; yet, here is a scheme where a new technology is spreading thin and wide equitably, creating economic opportunities for overcoming rural poverty.

Is Cassava an Indefensible Villain?

Cassava is often considered as a crop that is conducive to soil degradation. Intensive research on cassava management and its effect on soil productivity (Howeler, 1991) revealed that:

1. Soil nutritional requirements of cassava per unit of dry matter yield are much lower than of most other crops, except for potassium. Actually, cassava is a very efficient user of soil nutrients (Howeler, 1991; 1995; 2001; Howeler *et al*., 2000).
2. The high nutrient absorption by cassava, especially of potassium, is a result of the crop's high productivity under sub-optimal conditions.
3. Continuous cassava production without fertilizer application inevitably induces soil nutrient depletion, but this can be prevented by appropriate fertilizer application (Howeler, 1991; 1995; 2001).
4. The slow rate of canopy formation and soil cover by cassava is due to the crop's low planting density, which in turn causes soil erosion; this may not only physically damage part of the cassava plantation but will also remove the most fertile part of the soil, including the nutrients contained in the eroded soil and in applied fertilizers (Howeler, 1995;1998; Howeler *et al*., 2000).
5. Contour ridging, closer spacing and appropriate fertilization are generally recommendable practices for preventing soil erosion (Howeler, 1995;1998).

Thus, cassava can be a very problematic crop if the cultural practices used are not appropriate, while it can be grown successfully, like any other well-managed upland crop, if the farmers adopt proper soil management procedures (Howeler, 1998; Kawano and Howeler, 1998).

Cassava Farm Management in Micro- and Macro-contexts

My recent experiences in North Vietnam, where thousands of farm families make their living on equally divided small farms, which typically comprise of 0.1-0.3 ha of paddy rice and 0.1-0.4 ha of upland cassava, offer a good opportunity for seeing soil management from many angles. We naturally start our sustainability concern by looking into soil management, for which we already have a comprehensive list of recommendable cultural practices. For any good method to give a result, it has to be adopted by the farmers. For this, farmers must be motivated and have extra cash for investment. Thus, soil management can not be separated from the more general development in farm management and farm income generation, which can not be sustained without a favorable market environment, which in turn is much dependent on the whole country's economic situation (**Figure 4**). After all, farmers' immediate interest is extra cash for tomorrow. Any technology that can not satisfy farmers' immediate needs has very little chance of being adopted.

In North Vietnam, pig production with new cassava cultivars is now well recognized as a new economic opportunity. Innovative farmers who plant new cultivars in larger plots and convert the extra production into more value-added products, such as piglets, can attain a US$ 500 level of additional income per year. As a consequence, many farmers are giving extra care to their upland cassava fields by applying more farm-yard manure and potassium fertilizer. Some are also making hedgerow plantings of *Tephrosia candida* or pineapple.

It is logical to start looking at the sustainability issue by defining each soil management component, but it is equally logical to handle this in terms of increased farmers' alternatives. Cutting the vicious cycle of poverty and environmental mismanagement is the most crucial factor. Among many technical components that constitute good farm management, improved cultivars may be the most readily adoptable component to induce good resource management.

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Soil management	*Farm management*	*Income increase*	*Socio-economic situation*
Contour ridging	Fresh cassava	Bicycle	Soil management
Intercropping	On-farm pig feeding	Color TV	Family economy
Farm-yard manure	Pig and poultry sales	2nd-hand motorcycle	Processing/mardetting
Chemical fertilizers	Cash for investment	New house	National economy
Hedgerows		New motorcycle	Sustainability across generations

Figure 4. Factors surrounding small cassava farms in North Vietnam.

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PRESENT SITUATION OF CASSAVA PRODUCTION AND THE RESEARCH AND DEVELOPMENT STRATEGY IN VIETNAM

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ABSTRACT

Vietnam produces annually more than 2 million tonnes of cassava fresh roots and is ranked 13th in terms of cassava production in the world. In Vietnam cassava has great potential both for domestic consumption and for export. In North Vietnam, cassava is grown for food and animal feed by small farmer households. However, in South Vietnam cassava has become a cash crop and is an important raw material for cassava processing factories, which have a total annual processing capacity of one million tonnes of fresh roots. The main constraints in cassava production in Vietnam are fluctuating prices as well as marketing problems, and slow adoption of new varieties and improved technologies in remote areas. Low soil fertility in cassava growing areas is also an important problem, as is the lack of processing facilities.

Cassava research in Vietnam has made remarkable progress since 1988 when Vietnam began its cooperation with CIAT and started taking part in the Asian Cassava Research Network. Further progress in cassava production was achieved when Vietnam established its Cassava Research and Extension Network, in close cooperation with starch processing factories, especially Vedan Vietnam Enterprise Corp. Ltd. New high yield cassava varieties (KM94, KM60 SM937-26, KM98-1, KM95-3, KM95) and more sustainable production practices (fertilizer application, intercropping or rotation with beans or peanut, erosion control and weed control) has increased the economic effectiveness of cassava production, especially in the Southeastern region. In order to transfer new technologies to cassava households, Farmer Participatory Research (FPR) was conducted in mountainous and hilly areas of North Vietnam. The first phase of this project was quite successful. Presently, the second phase has expanded into the Central Coastal and Southeastern Regions. The use of cassava roots and leaves for animal feed are also being studied. Biotechnology has initially been applied in lysine and modified starch processing.

Our cassava research strategy for the future consists of the following: further advances in cassava breeding and in production practices; improving soil fertility of cassava growing areas; planning and establishing production areas for processing factories; developing post-harvest technologies, and expanding markets for cassava products. The development of high starch and high yield varieties and the adoption of sustainable cassava production practices will help to maintain total cassava production while the growing areas can be reduced. This will create a strong incentive for the development of cassava industrial processing and diversification of end-products, in order to satisfy the increasing demand for cassava-based products by our people.

INTRODUCTION

During the past decade, 1991-2000, Vietnam's Cassava Program (VNCP) has achieved significant progress in four main aspects: 1) the network of cassava research and extension, set up in 1991, has expanded and has produced significant increases in production; 2) new cassava varieties, such as SM937-26, KM60, KM94, KM95, KM95-3 and KM98-1, are being grown in over 60,000 ha, resulting in a breakthrough in cassava production in Vietnam; and 3) pilot cassava farms of high productivity, high return and

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with soil fertility maintenance were studied and set up in various provinces, which has helped to increase the cassava growing area and provide raw materials for the processing industry; and 4) cassava processing factories with a total capacity of nearly 1 million tonnes of fresh roots per year have been established.

Three aspects in cassava research and development should be considered, evaluated and discussed: 1) cassava production in Vietnam: problems and prospects; 2) effectiveness of cassava research and extension in Vietnam; and 3) future needs in cassava research and development.

1. CASSAVA PRODUCTION OF VIETNAM: PROBLEMS AND PROSPECTS

At present, the annual production of cassava in Vietnam is about 2 million tonnes of fresh roots, ranking fifth in Asia, behind Thailand, Indonesia, India and China, and the thirteenth in the world (**Table 1**). However, yields remain very low. **Figure 1** shows that cassava was a minor food crop until 1975. Due to food scarcity after the reunification of the country the planted area and production increased markedly from 1975 to 1978, but then decreased gradually until the early 1990s, when production more or less stabilized due to the establishment of a cassava starch industry in south Vietnam and increasing demand for pig meat in north Vietnam. Yields remained rather stable between 7 and 9 t/ha.

Table 1. Cassava growing area, yield and production in the 13 major cassava producing countries in the world in 1998.

Region/country	Area (mil. ha)	Yield (t/ha)	Production (mil. tonnes)
Africa			
1. Nigeria	2.70	11.3	30.41
2. Congo, Dem R.	2.20	7.5	16.50
3. Ghana	0.63	11.4	7.17
4. Tanzania	0.69	8.9	6.19
5 Mozambique	1.02	5.6	5.64
6. Uganda	0.34	6.7	2.28
Asia			
7. Thailand	1.12	14.3	15.96
8. Indonesia	1.20	12.2	14.73
9. India	0.25	24.0	5.87
10. China	0.23	15.6	3.60
11. Vietnam	0.23	7.7	1.78
Latin America			
12. Brazil	1.58	12.4	19.81
13. Paraguay	0.24	13.9	3.30

***Source:** FAOSTAT, 1999.*

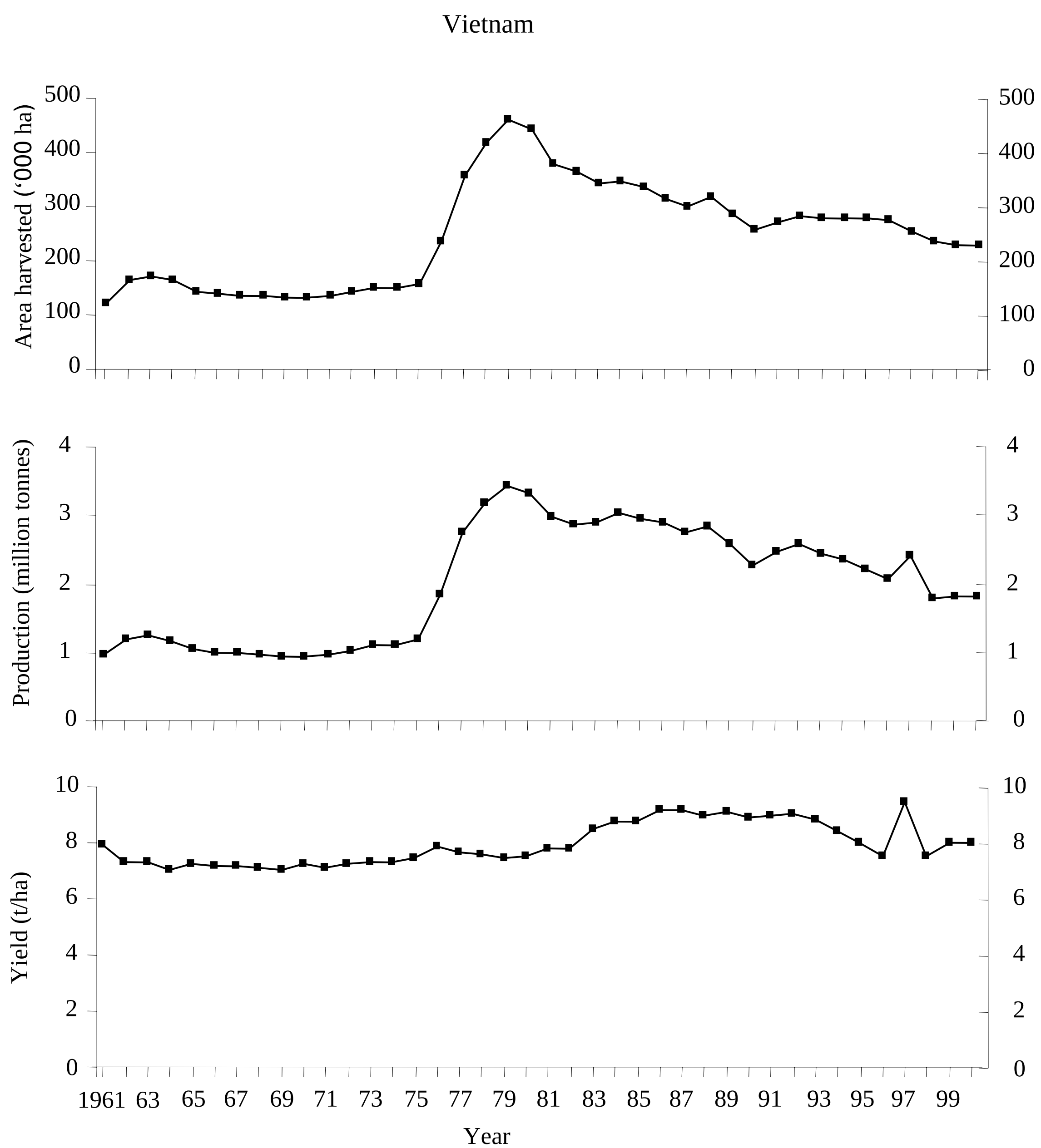

Figure 1. Cassava harvested area, production and yield in Vietnam from 1961 to 2000.
***Source:** FAOSTAT, 2001.*

In Vietnam cassava has a high potential for both export and local consumption. In terms of cassava exports Vietnam ranks fourth in the world, behind Thailand, Indonesia and China. The total amount of cassava exported from Vietnam was 30,000 tonnes a year during the period of 1992-1994, this increased to 150,000 tonnes in 1997 and reached over 200,000 tonnes in 1998. The cassava processing industry in Vietnam is still modest and cassava exports are limited. However, cassava production, processing and exports have a high potential due to its their ability to attract foreign investment into the production of cassava starch and monosodium glutamate (MSG) since the early 1990s. Vietnam has a good potential for cassava starch processing and export as compared with other countries in Asia (**Table 2**).

Table 2. World trade of cassava products (dried chips, pellets and starch) in millions of tonnes.

Market region	Average of 1983-1985	Average of 1992-1994	Average of 1995-1996	1998	1999	2000 prelim
Export	**7.0**	**9.8**	**5.9**	**4.4**	**5.8**	**5.7**
1. Thailand	6.4	8.3	4.6	4.0	5.3	5.2
2. Indonesia	0.4	1.1	0.6	0.2	0.3	0.3
3. China and Taiwan	0.1	0.3	0.4	-	-	-
4. Vietnam	-	-	0.1	0.2	0.2	0.2
5. Other countries	-	0.1	0.3	-	-	-
Import	**6.6**	**9.7**	**5.9**	**4.4**	**5.8**	**5.7**
1. EU	5.5	6.5	3.5	2.9	4.3	4.0
2. China and Taiwan	0.3	0.9	0.7	0.5	0.7	0.5
3. Japan	0.3	0.5	0.4	0.3	0.3	0.3
4. South Korea	0.2	0.7	0.3	0.4	0.1	0.1
5. Other countries	0.3	1.1	1.0	0.3	0.4	0.8

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

In South Vietnam cassava has rapidly changed its role from a food crop to a major source of raw material for starch processing and the animal feed industry. Cassava starch is an export product of high value. Cassava has been a crop giving a good cash flow with a steady market, and has become a main source of income of farm households in many areas. Cassava is a highly competitive commodity crop because it adapts well to a wide range of climates and soils, it is easy to grow, tolerant to low soil fertility and requires only low inputs (**Table 3**).

Table 3. Production costs and economic returns from growing cassava, cv. KM 94, on grey podzolic soils of An Vien village in Dong Nai province in 1998/99.

Items	Average farmers[1)]	Good farmers[2)]
Costs ('000 VND/ha)	**3169 (100.0%)**	**4397 (100.0%)**
1. Labor	1156 (36.5%)	1802 (40.9%)
2. Planting material [3)]	400 (12.6%)	450 (10.2%)
3. Fertilizers	1045 (33.0%)	1640 (37.3%)
4. Hired tractor	342 (10.8%)	380 (8.6%)
5. Land tax	116 (3.6%)	125 (2.8%)
6. Interest	23 (0.7%)	-
7. Others	87 (2.7%)	-
Output		
1. Yield of fresh roots (t/ha)	16.2	27.8
2. Farm gate price ('000 VND/tonne)	315	297
3. Gross income ('000 VND/ha)	5130	8257
Net income ('000 VND/ha)	**1934**	**3860**
Benefit/cost ratio	**0.61**	**0.88**

[1)]Mean of 80 farm households in An Vien
[2)]Mean of 9 good farmers in An Vien
[3)]Farmers supply their own planting material; cost estimated at 400,000 VND/ha

In North Vietnam cassava is a significant source of food and animal feed for small-scale farm households. Cassava is suitable for farmers in remote areas and for rural development programs in mountainous areas. In the food security policy of the Vietnamese government cassava is an important staple food in mountainous areas.

Four main constraints in cassava production in Vietnam are: 1) unstable prices and lack of markets; 2) low cassava yields in remote areas due to a limited adoption of new varieties and appropriate technologies; 3) low soil fertility in most cassava growing areas; and 4) limited diversification of products in processing. These are existing problems confronting the development of cassava production in Vietnam. The present situation of cassava production, processing and marketing in Vietnam was recently analyzed and reviewed in detail by Hoang Kim *et al*., 2000.

Vietnam has a high potential in cassava production and processing, due to: 1) increasing demand for cassava in the food, starch, animal feed and pharmaceutical industries and export; 2) currently, cassava yields are very low (8.3 t/ha), but they can be doubled by using high yielding varieties with high starch content, and by applying appropriate cultivation techniques; 3) Vietnamese farmers are laborious and willing to adopt new technologies; this will lead to a higher economic efficiency in cassava production; and 4) cassava growing areas can be extended into newly reclaimed soils, such as acid sulfate soils, hilly bare lands and sandy soils in the Central Coastal Region.

2. EFFECTIVENESS OF CASSAVA RESEARCH AND EXTENSION IN VIETNAM

Results of research on varietal improvement, cultivation techniques, processing, utilization, marketing and other economic aspects were presented in annual Vietnam Cassava Workshops. A review of cassava research in Vietnam has also recently been compiled by Hoang Kim *et al*. (2000). Cassava research in Vietnam has made significant progress since VNCP initiated its cooperation with the International Center for Tropical Agriculture (CIAT) and started taking part in the Asian Cassava Research Network in 1988. Major achievements in cassava production were obtained when the Vietnam Cassava Research and Extension Network (VCREN) was established and began its active collaboration with cassava processing factories, especially Vedan Vietnam Enterprise Ltd.

The effectiveness of cassava research and extension in Vietnam has been highly regarded after the release and dissemination of new varieties, such as KM94, KM60, SM937-26, KM98-1, KM95-3, KM95 and SM1447-7, and the adoption of improved cultivation techniques brought about a breakthrough in more sustainable cassava production, especially in the Southeastern Region. In recent years, cassava yields in Tay Ninh, Binh Phuoc, Dong Nai and Ba Ria-Vung Tau provinces have increased by 50-80%, due to the use of new varieties and the application of appropriate technologies (**Table 4**).

Table 4. Cassava area, yield and production in some provinces in the Southeastern Region.

	Area ('000 ha)			Yield (t/ha)			Production ('000 t)		
	1990	1994	1998	1990	1994	1998	1990	1994	1998
Tay Ninh[1)]	3.3	15.4	18.6	10.79	14.22	19.39	36.2	219.8	360.7
Binh Phuoc[2)]	(4.7)	(6.8)	9.8	(9.52)	(9.95)	21.07	(44.4)	(67.5)	208.2
Dong Nai	14.5	12.1	12.7	13.25	12.11	15.04	192.6	146.5	191.5
Ba Ria-Vung Tau	0.1	7.2		6.4	12.29		0.5	88.5	

[1)]Cassava in Tay Ninh in 1998 for industrial use 13,965 ha, for food 4,653 ha.
[2)]Data for Binh Phuoc in 1990 and 1994 are for the whole of Song Be province.
Source: *Vietnam Statistical Publishing House, 1990, 1994 and 1998.*

On acid sulfate soils and fallow lands of Tri Ton and Tinh Bien districts in An Giang province, a cropping system of cassava (8 months) rotated with Mua rice (4 months) has been very successful. In this area, even though the water supply is limited in the dry season, cassava gives a yield of 16-20 t/ha of fresh roots and provides farmers with an income of 2.4-5.6 million VND/ha. Agri-product Import-Export Company of An Giang (AFIEX) provides loans of low interest to farmers and buys cassava roots for starch processing. Cassava production and processing have increased farmers' income and generated more employment, especially in the dry season.

In North Vietnam farmers grow new cassava varieties on small areas of land (360-5000 m^2) and use the roots to raise pigs. Farmers practizing this system get 50-600 kg more live weight of pig, which are equal to 45-545 USD/household/year. The dissemination of new varieties is not as fast as in the South or in other countries, but the technology transfer process benefits many people, increasing farmers' income and generating more employment (Kawano, 1999).

The use of farmer participatory research (FPR) in the development and transfer of technologies for cassava production in mountainous and hilly areas of the North has been quite successful in the first phase (1994-1998) of the Nippon Foundation Project. In the second phase (1999-2003), this program is expanding to the Central Coastal and Southeastern Regions. On sloping lands, the intercropping of cassava with grain legumes such as peanut and black bean, and the planting of contour hedgerows of *Tephrosia candida* or vetiver grass are the best practices for soil conservation.

Long-term experiments on the application of NPK fertilizers for cassava on different soils show that on fertile soils the effect of P was still not significant after three years of continuous application; meanwhile, on grey soils of low fertility, N, P and K application gave positive effects already in the first year. Recommended N: P_2O_5: K_2O ratios for cassava for various soils are in the range of 4:2:4 and 3:2:4. The appropriate plant density is between 10-14 thousand plants/ha. Peanut, mungbean and maize can be intercropped with cassava on high-fertility soils, while on low-fertility soils peanut gives better results.

The utilization of cassava leaves and roots for feeding livestock is also being investigated. The development of cassava markets and marketing strategies are also being surveyed and studied. The application of biotechnology in lysine and starch processing has been initiated.

Even with a limited budget, VCREN has a good organizational structure and has frequently exchanged information on cassava production, processing and marketing, especially in the annual worshops. Therefore, research results, mainly new varieties and cultivation techniques, are now widely disseminated and applied in cassava production.

3. FUTURE NEEDS IN CASSAVA RESEARCH AND DEVELOPMENT

3.1 Determination of an appropriate strategy for cassava research and development

Agricultural development is still the focus of many Asian countries and Vietnam is no exception, even though there has been a trend towards urbanization and industrialization. In Vietnam, cassava is a major source of income for farmers in areas of low fertility soils and adverse climatic conditions. It is also a source of raw materials for starch processing and for the animal feed industry with a high commercial value.

Therefore, in the plan for the development of agriculture to the year 2010, the Ministry of Agriculture and Rural Development of Vietnam has emphasized the production of rice, maize and cassava.

3.2 Selection and dissemination of high yielding varieties with a high starch content

Emphasis will be on the making of crosses, the importing of hybrid seed and varieties from different sources, and on the application of biotechnology in the selection and dissemination of high yielding cassava varieties with a high starch content. Attention is also paid to the breeding and selection of multi-purpose varieties, which have a short growth duration, a prolonged harvesting period, and which are suitable for human consumption.

3.3 Transfer of appropriate cultivation techniques to farmers in different areas

In order to increase yield and to attain a sustainable cassava production system, more attention will be paid to fertilizer application on low fertility soils and to soil conservation measures on sloping lands.

3.4 Cooperation with processing factories in establishing areas with a stable source of raw materials

It is necessary to plan and stimulate the growing of cassava in certain areas, which will provide a stable supply of raw materials for processing factories, and to establish pilot farms where cassava gives high yields and where soil fertility is maintained, and to improve cultivation techniques with farmers' and factories' participation.

3.5 Research on the development of cassava processing technologies

Post-harvest technologies, diversification of processed products (instant food, fast food, animal feed, pharmaceuticals, textiles and paper) and the utilization of cassava for small-scale livestock production in remote areas, need to be studied and transferred into real production.

3.6 Structural improvement and development of the cassava extension network

3.7 Development of local and export markets of cassava

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PRESENT SITUATION AND FUTURE POTENTIAL OF CASSAVA IN THAILAND

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ABSTRACT

In Thailand cassava (*Manihot esculenta* Crantz) is considered one of the most important economic crops. Thailand has demonstrated the importance of cassava as more than a subsistence crop, and has developed a large and complex industrial system for processing and marketing of the crop. Production of cassava has steadily increased during the 1970s and 80s through expansion of the planted area, but has decreased again since the early 1990s. The national average yield has remained rather constant at about 14.5 t/ha. Major production problems are declining soil productivity, soil erosion and farmers' poverty. Since 1959, products obtained from cassava have been a major export commodity for Thailand, assisted by relatively easy market access to the EU. In a bid to meet the increasing demand, rapid growth in the industry also led to certain weaknesses.

Cassava roots are utilized for making dry chips, pellets, native starch, modified starch, MSG (monosodium glutamate), glucose, fructose, sorbitol, sago, citric acid, while starch is used in the paper, textile, and plywood industries. Of the products made from cassava, cassava starch and pellets are the only ones exported. Export companies are allocated export quotas of pellets to the EU market, but must seek new markets outside the EU to get a larger incentive quota for the EU. This helps to increase the farmers' income and reduce poverty.

CASSAVA PRODUCTION AND MARKETING

1. Cassava production

Cassava (*Manihot esculenta* Crantz.) is the third most important crop in Thailand. The root crop is known by many names in Thailand, but "cassava" and "tapioca" are the most widely used terms. Cassava was introduced into the southern part of Thailand from Malaysia during 1786-1840 (Cenpukdee *et al*., 1992) and was gradually distributed throughout the country within a few years. The main concentration of the crop is now found in the northeast of Thailand, especially in Nakhon Ratchasima province (**Figure 1**). Cassava has excellent drought tolerance properties and can be planted in almost all types of soil. Therefore, the planted area has rapidly increased. Cassava is grown by a large number of farmers, who own small plots of land (about 0.5-2 ha). No organized large-scale plantations have been established in Thailand, as this is prohibited by the land reform act. The total acreage of cassava, which peaked at about 1.6 million ha in 1988/89 is now reduced to 1.2 million ha (1998/99) (**Figure 2**). This trend is driven by a national agricultural policy promoting the reduction in planting area and increases in yields. Despite government promotion to improve yield, total production in 1998/99 was only 17 million tonnes or less than 70% of the peak of 24 million tonnes in 1988/89 (**Table 1**).

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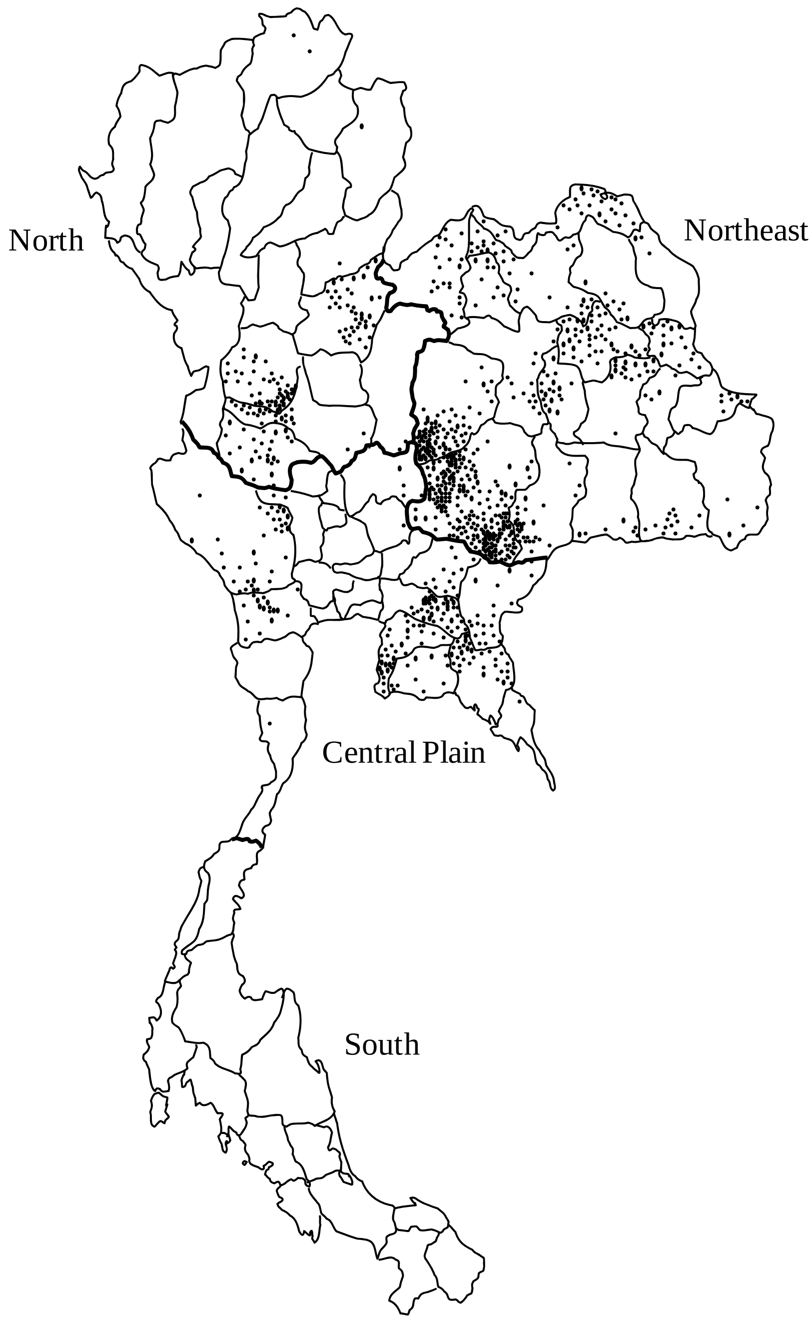


Figure 1. Distribution of cassava planted area in Thailand in 1995/96.
Each dot represents 1000 ha.
***Source:** DOAE, 1998.*

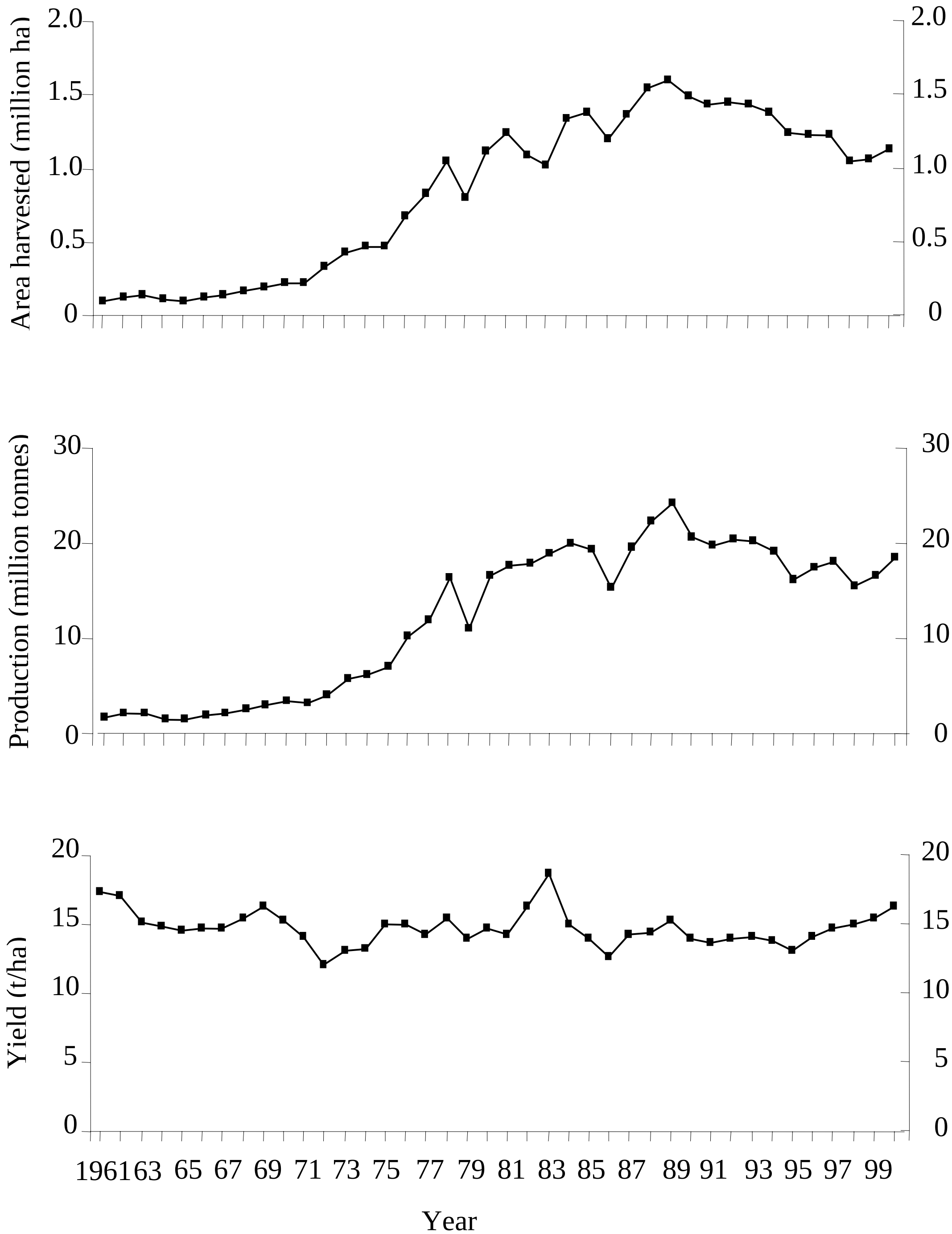


Figure 2. Cassava harvested area, production and yield in Thailand from 1961 to 2000.
Source: *FAOSTAT, 2001.*

Table 1. Planting area, production and yield of cassava in Thailand from 1988/89 to 1999/2000.

Year	Planting area (ha)	Total production (tonnes)	Yield (t/ha)
1988/89	1,593,164	24,264,026	15.23
1989/90	1,487,540	20,700,511	13.92
1990/91	1,433,579	19,705,040	13.75
1991/92	1,450,539	20,355,723	14.03
1992/93	1,438,017	20,202,897	14.05
1993/94	1,382,695	19,091,347	13.81
1994/95	1,245,157	16,217,378	13.02
1995/96	1,228,114	17,387,780	14.16
1996/97	1,230,381	18,083,579	14.70
1997/98	1,119,096	15,968,474	14.27
1998/99	1,172,374	17,315,554	14.77
1999/00	1,095,631	16,930,190	15.45

Source : *Office of Agricultural Economics, 1991-2000.*

2. Varieties

Until the early 1990s the most popular cassava variety was the local variety. A selection of this local variety was named Rayong 1, and was the first variety used as a source of industrial raw material. The cassava breeding program has continued progressively at:

- Rayong Field Crops Research Center (RAY-FCR), Department of Agricultural (DOA), Ministry of Agriculture
- Sriracha Research Center of Kasetsart University (KU), Ministry of University Affairs, and
- Research and Training Center of the Thai Tapioca Development Institute (TTDI) Foundation.

The goal of cassava breeding in Thailand is to increase yields and root starch content, as well as the crop's adaptability to a wide range of growing conditions. Starch yield is a function of starch content and root dry matter yield. There has been no systematic institutional breeding of cassava for improved cooking quality in Thailand. Of the many varieties developed and released only a few are now widely adopted, mainly Kasetsart 50, Rayong 5 and Rayong 90 (**Table 2**).

Table 2. Recommended cassava cultivars in Thailand.

Cultivar	Year released	Parents	Main features
Rayong 1	1975	From local cultivars	High yield
			Good adaptability
Rayong 3	1983	MMex 55 x MVen 307	High root DM
			Low cyanide
Rayong 60	1987	MCol 1684 x Rayong 1	Early harvest
			High yield
Rayong 90	1991	CMC 76 x V43	High root DM
			High yield
Kasetsart 50	1992	Rayong 1 x Rayong 90	High root DM
			High yield
			Good adaptability
Rayong 5	1994	CMR 27-77-10 x Rayong 3	High yield
			High root DM
			Good adaptability
Rayong 72	1999	Rayong 1 x Rayong 5	High yield
			Relatively high DM
			Adapted to Northeast Thailand

***Source :** Limsila et al., 1996; Sarakarn et al., 2001.*

3. Production Costs and Net Income

Production costs (**Table 3**) are mainly dependent on the time of planting and environmental conditions during growth. For example, the first planting period (Feb-Apr) and the second planting period (Nov-Jan), known as early and late rainy season plantings, respectively, need different levels of weed control and inputs. Variable costs account for about 85% of the total costs. Major components of production costs (in descending order) are labor, materials and land rent (**Table 3**). Net income per rai varied from 355 to 1,794 baht during 1995/96 to 1999/00. In 1997 there was an oversupply of roots, which depressed the root price to 0.69 baht per tonne (TTTA, 1998). The Ministry of Commerce, in an attempt to protect the farmers, intervened in the purchasing cycle by providing soft loans to starch factories to encourage them to purchase roots at 1,000 baht/tonne. This situation was short term, as a few months later environmental conditions, mainly drought due to El Niño, led to a sharp reduction in cassava yields. Indonesia was particularly affected and the country had to import cassava products from Thailand to supplement this shortfall. The root price in Thailand increased to 2.22 baht per kg resulting in an average root price for 1998 of 1766 baht per tonne (TTTA, 1999) (**Figure 3**).

The low root price in early 1997 also led to a reduction in the area planted to cassava that year, which in turn resulted in a high price of roots in 1998 (up to 2500 baht). Aggravating the situation of cassava was the new exchange rate in July 1997 (from 25 to 42 baht/dollar). The crop harvested in late 1999, was not effected by a high price as in the previous year. The cassava root price in Dec 1999, was about 0.92 baht/kg.

The current world economic crisis is reflected by a reduction in meat consumption and surplus of cereals, especially of maize, driven by reduced demand from the feed sector. This has depressed the current maize and maize starch prices, and as cassava products (pellets, starch) have to compete directly with maize, this has substantially reduced the price of these cassava products (**Figure 4**).

Table 3. Variable and fixed costs of cassava planting in Thailand, 1995/96 to 1999/00.

	1995/96	1997/98	1999/00
Variable costs (baht/rai)	**1,229**	**1,535**	**1,743**
1. Labor costs	*918*	*1,082*	*1,238*
Land preparation	203	236	270
Planting	119	135	176
Weed control	292	353	387
Harvesting	284	331	372
Transportation	20	27	33
2. Material costs	*214*	*347*	*363*
Planting material	95	137	158
Fertilizers	52	120	120
Herbicides	36	58	51
Others	31	32	34
3. Miscellaneous costs	*97*	*106*	*142*
Reparation	0	0	0
Interest	97	106	142
Fixed costs (baht/rai)	**208**	**281**	**281**
Land rent	188	261	261
Depreciation	20	20	20
Production costs (baht/rai)	**1,437**	**1,816**	**2,024**
Production cost (baht/kg)	0.65	0.78	0.77
Yield (kg/rai)	2,205	2,329	2,643
Price (baht/kg)	1.38	1.55	0.90
Gross income (baht/rai)	3,043	3,609	2,379
Net income (baht/rai)	1,606	1,794	355

[1)] 1 rai = 0.16 hectare
[2)] 1 US$ = 25 baht until July 1997 and about 40 baht thereafter
fresh root price in Jan of year of harvest (TTTA, 1999; 2000).
Source: *Office of Agric. Economics (OAE), 2001.*

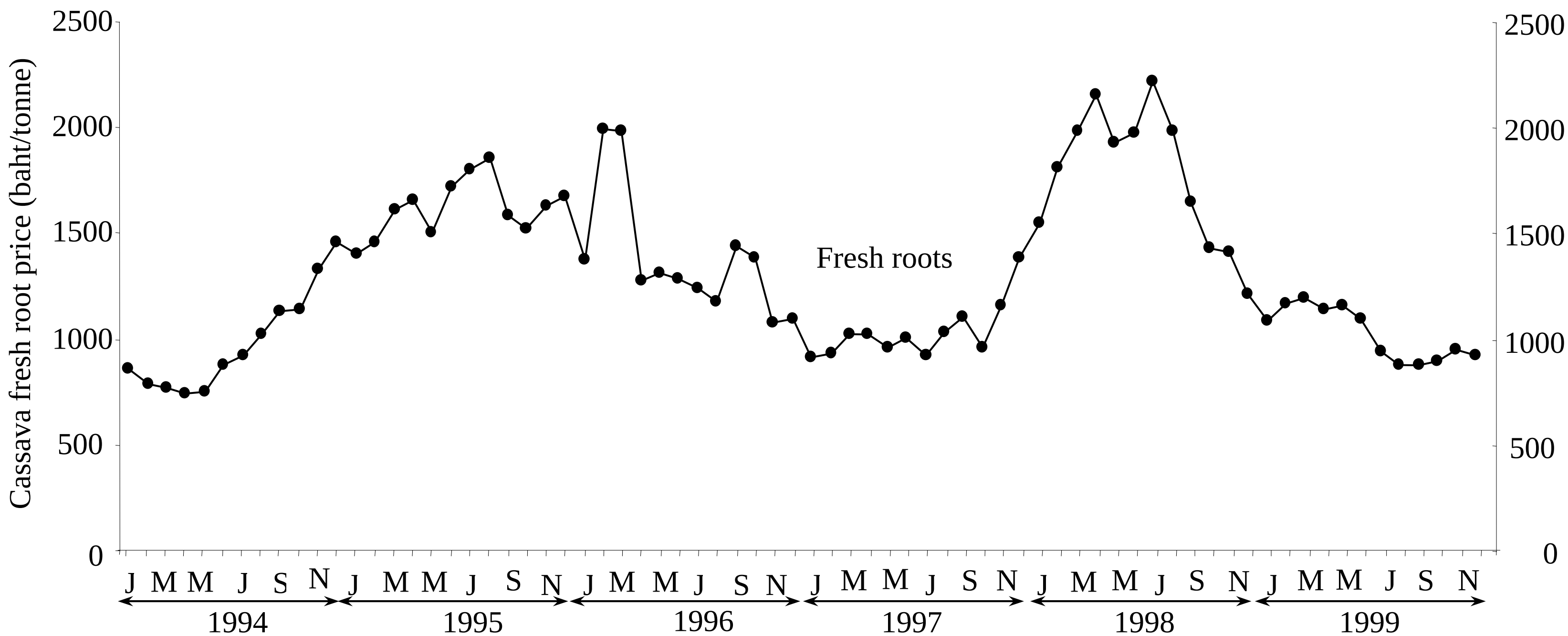


Figure 3. Monthly trend in the price of fresh cassava roots (at 30% starch content) in Nakorn Ratchasima province of Thailand from 1994 to 1999.

Source: *Thai Tapioca Trade Assoc. (TTTA), 2000.*

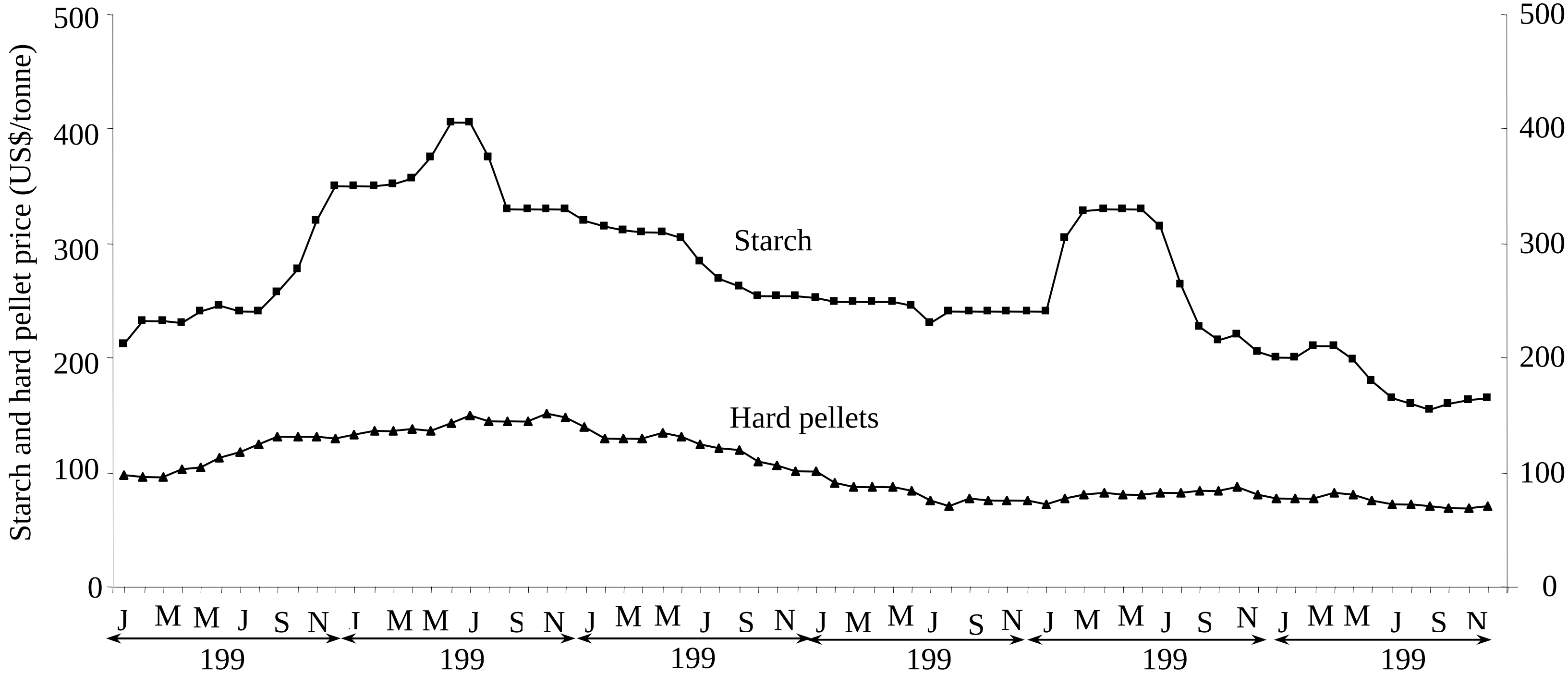


Figure 4. Monthly trend in the price (FOB Bangkok) of cassava starch and hard pellets from 1994 to 1999.
Source: *Thai Tapioca Trade Assoc. (TTTA), 2000.*

4. Cassava Marketing

The structure of the cassava market in Thailand is depicted in **Figures 5** and **6**.

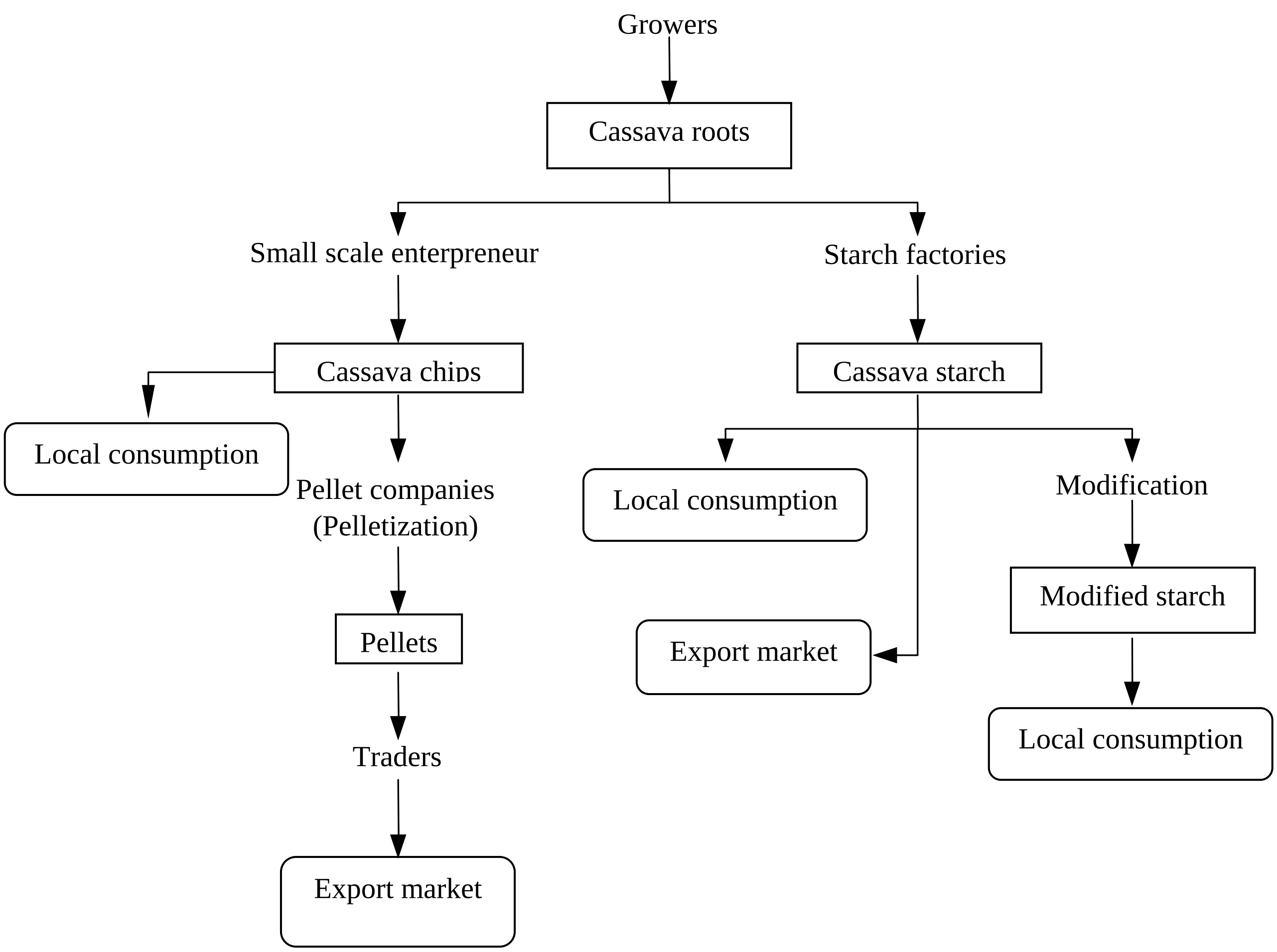


Figure 5. Marketing structure of cassava in Thailand.

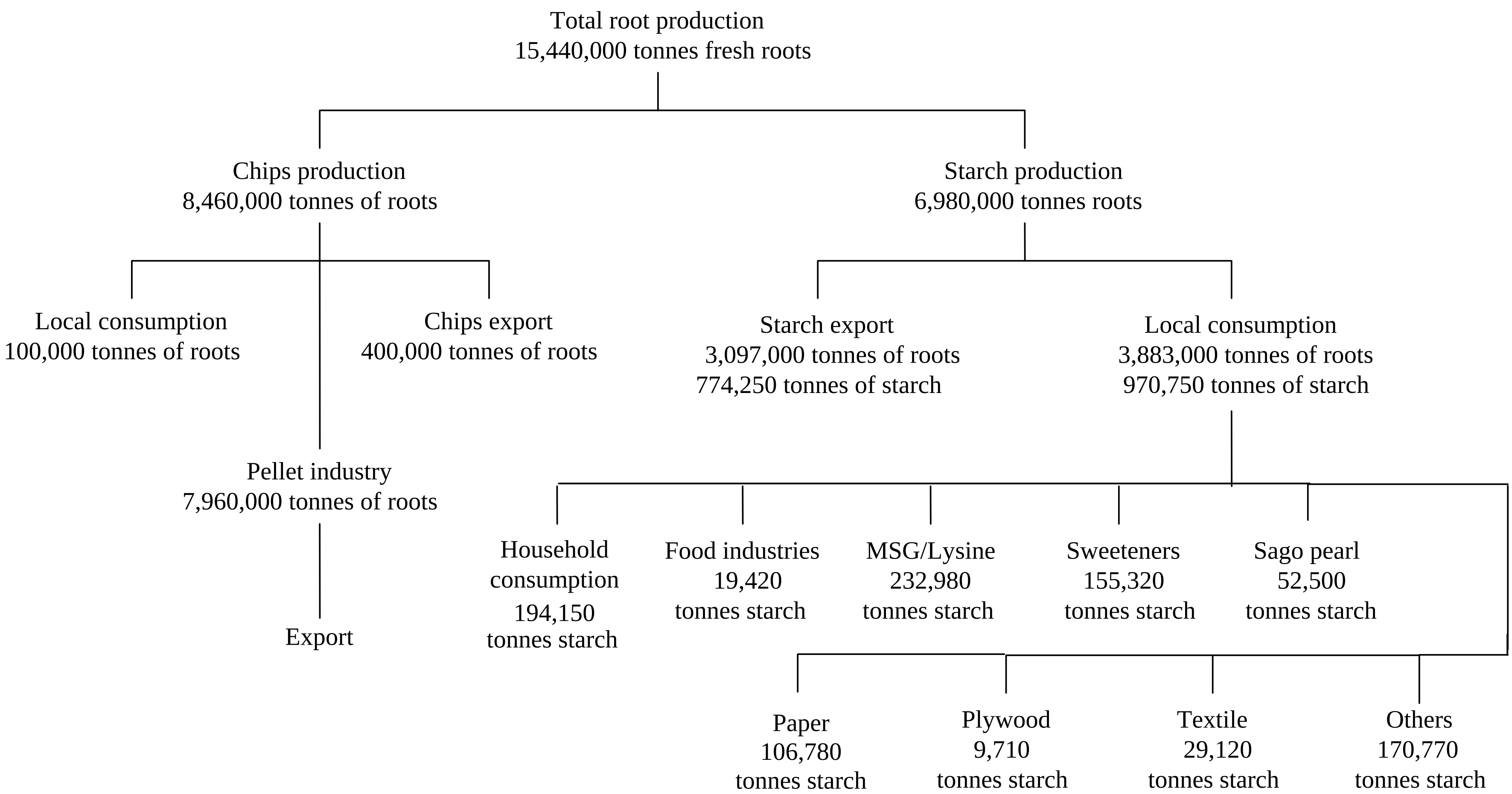


Figure 6. Distribution of cassava roots for industrial processing in Thailand in 1998.
Note: *Modified starches are partially distributed over export, food, and the paper, textile and plywood industries.*
Source: *Modified from TTTA, 1999.*

5. Government Policy

The Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, formulates cassava policies. Considered in the formulation and amendment of this policy are recommendations by the Common Agricultural Policy (CAP) of the EU. The cassava policy for 1994-1998 is laid out as follows (Office of Agricultural Economics, 1994):

(a) Limitation of cultivation

Since 1983, only cassava planting in certain areas has been promoted. Twenty-three provinces (17 in the northeast and 6 in the east) were announced as economic zones for cassava. In 1987, registration of cassava growers was started. This policy was not monitored, thus the registration of all the growers has not been realized.

(b) Substitution crops

An attempt to persuade cassava growers to plant intercrops and partially replace cassava with high value crops, such as maize, mungbean, peanut, jute, sesame, and castor bean, was started in 1983/84.

(c) Rubber plantation

With financial support from the EU (1990-1997), a group of cassava growers was trained and plants of new varieties of rubber were distributed to three provinces in the northeast of Thailand (the main cassava planting area). Fruit orchards were also established and supported with EU funding.

(d) Marketing incentive

Traders or companies who export cassava chips and pellets were allocated export quotas to the EU market, but were required to seek new markets outside the EU to receive incentive quotas (in proportional figures to exports to non-EU countries).

CASSAVA PROCESSING

1. Cassava Chips Industry

Cassava chip factories are small-scale enterprises and most have no formal company registration. The manufacture of cassava chips is recognized as an agricultural activity; factories belong to farmers or small business men and are located in close proximity to the growing area. The chipping factories are installed with simple equipment, consisting mainly of a chopper. Roots are loaded into the hopper of the chopping machine by tractor; after chopping into small pieces, the chips are sun-dried on a cement floor. The chips are spread to a specific density (kg/m^2), ensuring a consistent final moisture content. During drying, which typically requires 2-3 days, a vehicle with a special tool for turning over the chips is used to ensure uniform drying. Economic loss occurs as a result of weight loss of the chips, caused by wind that blows the dry particulate matter; this is also a major problem leading to air pollution. **Figure 7** presents a pictorial representation of the chipping process.

When it starts raining, chips must be quickly pushed into piles and covered with plastic. This prolongs the drying time and inevitably results in lower chip quality. The final moisture content should be below 14%. Normally it takes 2.00-2.50 kg of fresh roots (with 25% starch content) to produce 1 kg of chips (14% moisture content).

(a)

(b)

(c)

(d)

Figure 7. Chips processing : (a) Root transportation (b) Conveyor and chopper (c) Drying area and (d) Turning chips by tractor

The Market: Chips are sold to pelleting manufacturers who either directly export the chips/pellets or sell to traders. In most cases, the small chipping factories sell their products to large factories that in turn sell a consolidated consignment to pellet manufacturers. Time from purchase of chips to their sale is rapid. Factories in Thailand do not have silo facilities for storage, and all transactions are direct; middlemen or brokers are not involved. Nakhorn Ratchasima province has the highest chip and pellet production in Thailand, and the pellet price in this province is the standard trading index to set the Bangkok market pellet price.

Local consumption of chips: The quantity of cassava chips used locally for animal feed in 1996 was around 100,000 tonnes; this is estimated to increase to 1,000,000 tonnes in 2000, equivalent to 2.5 million tonnes of fresh roots. The uncertainties of unstable prices and supply of maize and soybean cake, used for animal feed, are mirrored by the cassava chip market.

Export markets: Cassava chips are exported mainly to non-EU countries, either directly by pellet manufacturers (but not chip factories), or by export companies. Since 1981, Thailand has exported to the EU mainly hard pellets rather than chips (**Table 4**). In this form, less dust is created, lowering the impact of environmental pollution during the loading and unloading of ships at the port.

Table 4. Quantity (tonnes) of cassava products exported from Thailand from 1966 to 1999.

Year	Chips	Pellets	Hard Pellets	Starch	Total
1966	521,328	-	-	173,671	694,999
1967	506,169	97,096	-	204,153	807,418
1968	417,282	314,788	-	143,568	875,638
1969	87,844	773,908	-	124,772	986,524
1970	22,620	1,061,065	-	142,914	1,226,599
1971	8,706	966,278	-	146,368	1,121,352
1972	3,905	1,109,363	-	124,453	1,237,721
1973	23,908	1,508,598	-	179,929	1,712,425
1974	105,713	1,924,647	-	254,967	2,285,327
1975	67,989	2,036,110	-	141,676	2,245,775
1976	63,721	3,252,439	-	241,200	3,557,360
1977	104,786	3,564,529	-	122,466	3,871,781
1978	312,598	5,727,531	-	135,028	6,275,157
1979	202,844	3,677,204	-	123,409	4,003,457
1980	256,212	4,452,579	-	148,483	4,957,274
1981	413,122	4,978,137	608,212	109,724	6,309,195
1982	487,247	5,214,592	1,479,856	125,632	7,607,327
1983	266,157	2,391,530	1,637,827	174,194	4,669,708
1984	155,775	2,893,327	2,905,316	464,875	6,419,293
1985	127.161	1,102,432	5,386,950	497,370	7,113,913
1986	68,662	251,161	5,508,254	459,048	6,287,125
1987	97,078	18	5,653,244	369,056	6,119,396
1988	368,328	18	7,183,239	555,746	8,107,331
1989	120,391	-	9,032,918	645,529	9,798,838
1990	269,150	-	7,285,423	656,291	8,210,864
1991	142,472	-	6,044,973	707,051	6,684,228
1992	320,643	-	7,724,387	750,425	8,576,686
1993	71,566	-	6,635,439	653,276	7,360,281
1994	9,909	-	4,732,643	923,561	5,716,113
1995	169,607	-	3,127,525	845,006	4,141,599
1996	2,700	-	3,604,411	893,365	4,500,476
1997	138,586	-	4,016,106	1,140,377	5,295,069
1998	237,162	-	2,961,486	770,096	3,968,744
1999	222,058	-	4,118,549	931,923	5,272,530

Source: *Thai Tapioca Trade Association, 2000.*

China, Korea and Japan still import cassava chips from Thailand, but for purposes other than feed, such as for ethanol fermentation. The high carbohydrate content of cassava chips is of value for biotechnological conversion; this utilization will secure a continued future for the cassava chips industry.

2. Cassava Pellets Industry

The pellets industry began a few years after the start of cassava exports to the EU (around 1967). Development of this product was stimulated by a need to improve the uniformity in shape and size of cassava chips required by the compound feed producers/users. In addition, during transportation, loading and unloading of chips dust generation caused serious air pollution, placing pressure on the importers in Europe to improve the nature of cassava products handled by the ports. Production of pellets involves pressing chips, and extrusion through a large die. The heat and moisture in the chips helps in the formation of a pellet-like shaped product, known as a soft pellet. Later process developments involved grinding of chips followed by steam extrusion; this created strong pellets upon cooling, known as hard pellets. Exports of hard pellets began in 1981; by 1987 hard pellets dominated pellet production in Thailand and by 1989 these were virtually the only pellets exported to Europe.

The raw material (cassava chips) for pellet manufacture, is purchased from chip drying yards; pellet factories do not produce chips. The purchase price is directly dependent on the export price of pellets in Bangkok. Quality of the chips is also an important consideration. The standard quality of chips is:

Moisture content = max. 16%
Sand = max. 4%
(The sum of the two factors should not exceed 20%)

Moisture content exceeding 16% results in a price penalty, but no reward is given if the moisture is less than 16%.

Competition for raw material by the pellet factories favors those with a large capacity and these always occupy a large proportion of the export quota; these factories can offer a higher price for chips.

There are approximately 200 pelleting factories in Thailand with a total capacity of about 10 million tonnes per year. However, the EU quota is only 5 million tonnes and this is the sole market for this product. The factories are therefore working only at 50% of their capacity (3-4 months per year).

The manufacturing process for pellets is shown in **Figures 8** and **9**.

3. Cassava Starch and Starch-based Industries

At the time that cassava was introduced into the southern part of Thailand (1786-1840), a cottage-scale industry for production of cassava meal or cassava flour was adopted from neighboring countries, Malaysia and Singapore.

Conversion of fresh cassava root, by grating, mixing with water followed by sedimentation and sun-drying (or conductive heating) produces a product traditionally

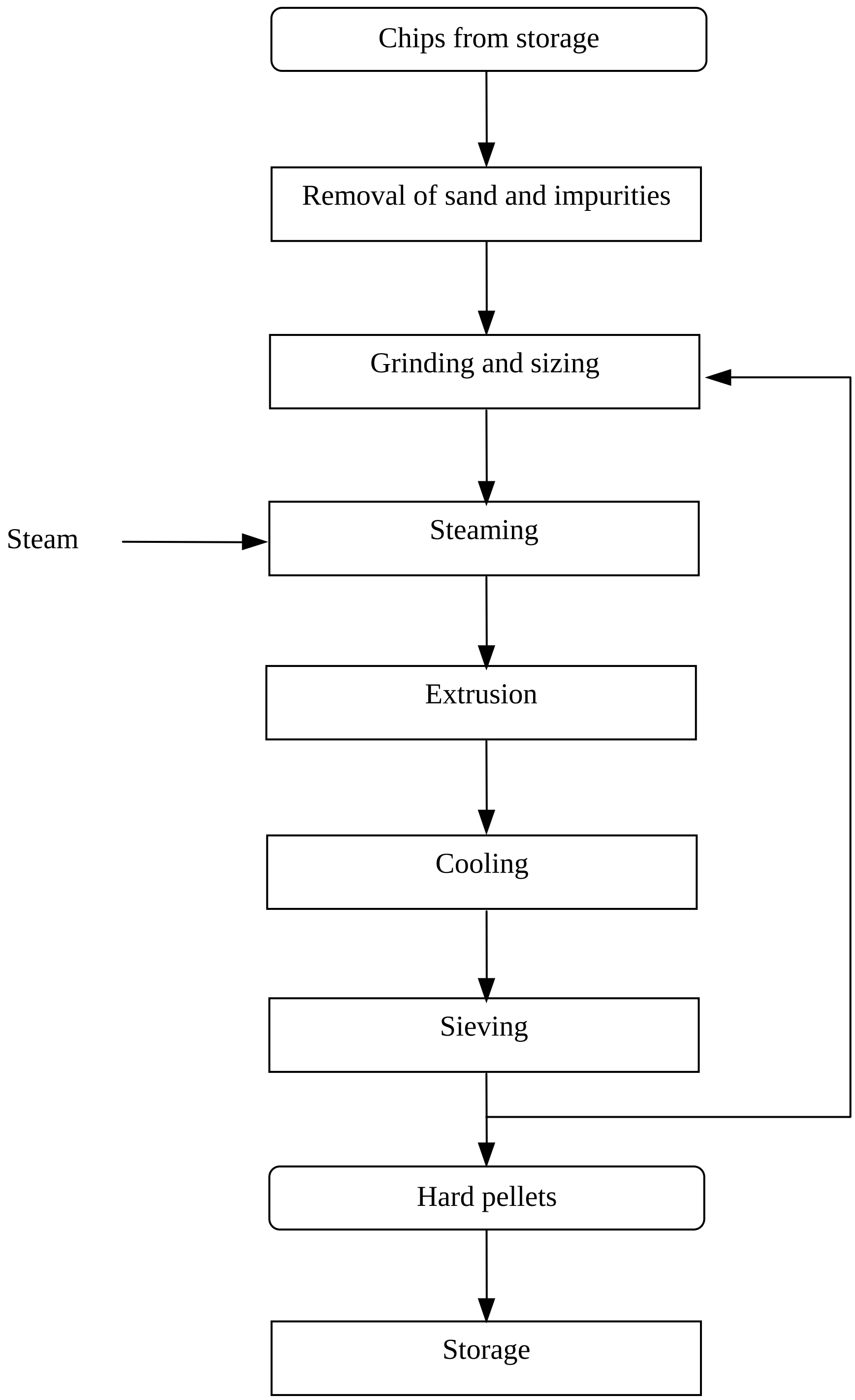
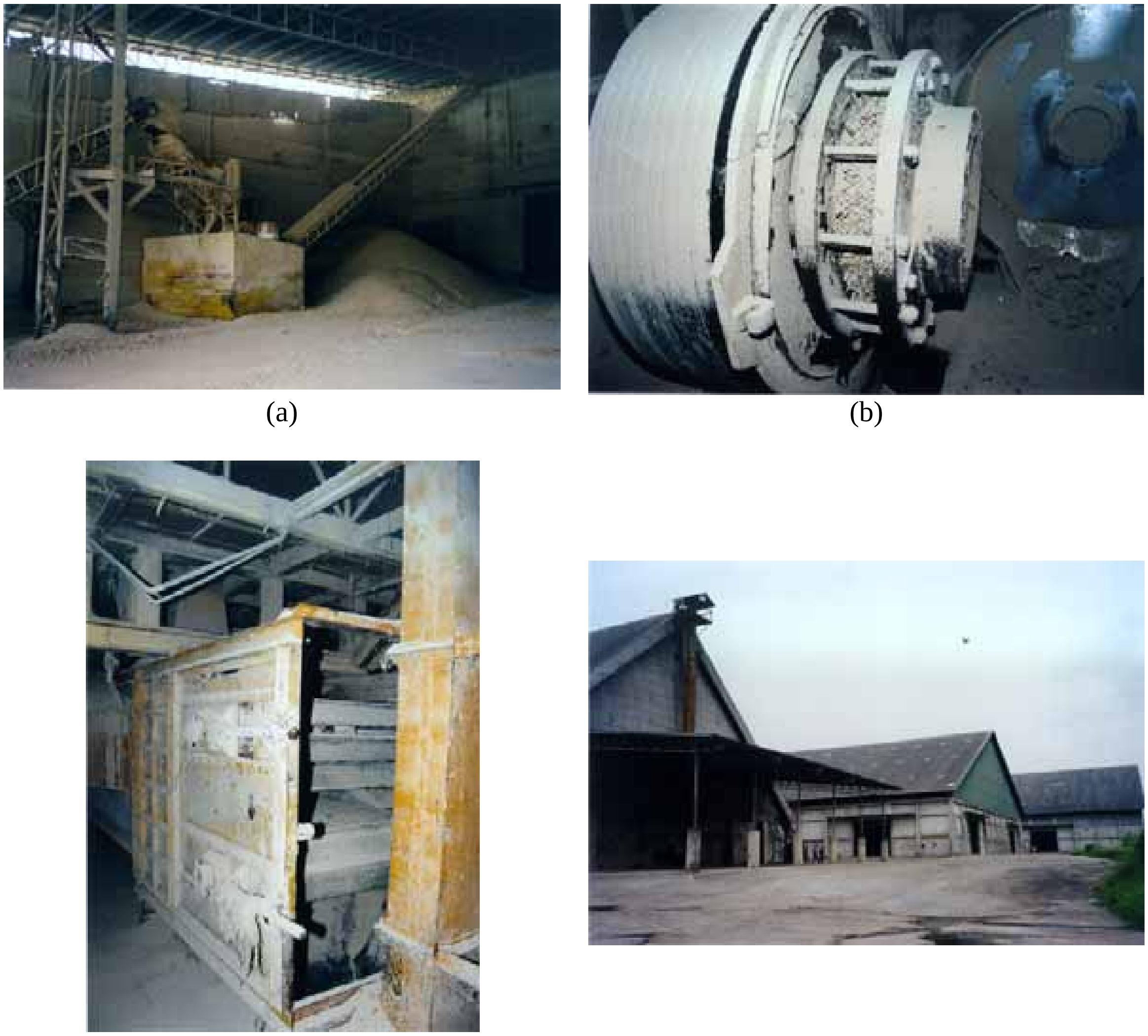


Figure 8. Process for production of cassava hard pellets.



(a) (b)

(c) (d)

Figure 9. Pellets processing : (a) Grinding of chips by hammer mill (b) Extrusion (through a die press) (c) Cooling chamber and (d) Storage of pellets

called "cassava flour" but now called "cassava starch". Cassava starch may be further processesed to make sago pearl, which is a traditional dessert for the people in the southern part of Thailand.

Demand for cassava starch increased dramatically and this led to the development of the modern starch manufacturing process in the 1970s. A survey conducted in 1996 indicate that at that time there were 41 modern factories registered to the Thai Tapioca Flour Industries Trade Association. These factories were working with modern separation and drying processes. The processing time (from the grating of fresh root to dried starch) is estimated to be less than 30 minutes. Presently, factories using the sedimentation process do no longer exist in Thailand.

The process for production of cassava starch manufacturing is essentially the same for all factories, and is shown in **Figure 10**. About 4.75 tonnes of fresh roots produce one tonne of dry starch.

About 40% of cassava starch, i.e. 600,000-800,000 tonnes, is used domestically and 60% i.e. 700,000-900,000 tonnes, for export (**Table 5**) (The Thai Tapioca Flour Industries Trade Association, 1999).

Distribution from factories is by three outlets; 1) direct sale for general consumption and local factories, 2) sale to intermediary dealers for domestic retail and export, and 3) direct export.

Table 5. Production and export(tonnes) of cassava starch from Thailand, 1991-1998

	Domestic		Export		Total	
Year	Starch	Root	Starch	Root	Starch	Root
1991	559,000	2,795,000	860,681	4,303,405	1,149,681	7,098,405
1992	615,810	3,079,050	946,749	4,733,745	1,562,559	7,812,795
1993	680,358	3,401,790	1,041,422	5,207,110	1,721,780	8,608,900
1994	754,004	3,770,020	936,390	4,681,950	1,690,394	8,451,970
1995	723,269	3,435,527	857,852	4,074,797	1,581,121	7,510,324
1996	759,434	3,607,311	905,136	4,299,396	1,664,570	7,906,707
1997	770,000	3,657,500	1,155,738	5,489,755	1,925,738	9,147,255
1998	650,000	3,087,500	784,835	3,727,966	1,434,835	6,815,466

Source: *The Thai Tapioca Flour Industries Trade Association, 1999.*

3.1 Domestic market (see Table 6 and Figure 6)

Monosodium glutamate (MSG)/lysine: Highest consumption of cassava native starch is by the MSG (four factories) and lysine (one factory) industries. Starch consumption for production of these products is in the proportion 80:20 by the MSG and lysine industries, respectively. Production of commercial MSG in Thailand utilizes only two carbohydrate sources for inoculation: molasses and cassava starch. To produce one tonne of MSG, factories need either about 2.4 tonnes of cassava starch or 7.0 tonnes of molasses.

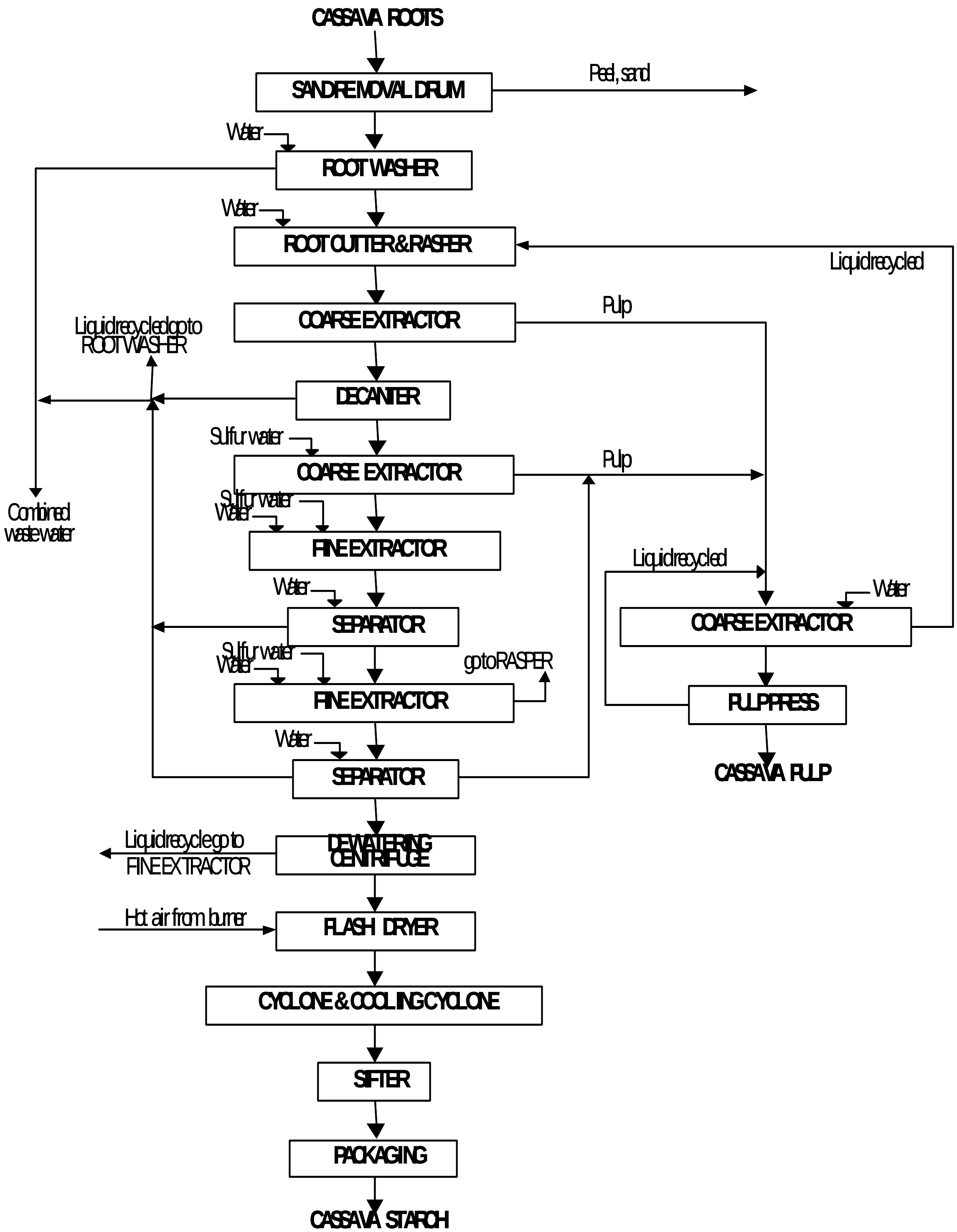


Figure 10. Example of the cassava starch manufacturing process in Thailand.

Table 6. Annual demand for cassava starch for the production of sweeteners and MSG/lysine in Thailand.

Products	Quantity of starch used (tonnes/year)	Product (kg/kg of starch)
High fructose	60,000	1.00
Glucose syrup	45,000	0.90-0.95
Dextrose monohydrate	20,000	1.75
Dextrose anhydrous	500	0.50
Sorbitol	30,000	1.20
MSG/Lysine	232,980	0.42

***Source:** Sriroth, 1998.*

Sweeteners (glucose/fructose/sorbitol): There are 14 factories manufacturing glucose syrup (two also produce sorbitol) and two large international sorbitol producers (Ueno Co., Ltd., Japan, and Lucky Chemical Co., Ltd., Korea). In 1998 there was only one factory producing high fructose syrup (about 60,000 tonnes per year).

Food/sago industry: Cassava starch is widely used by the food industry, especially for canned products. Properties of cassava starch as a binding and thickening agent play important roles in many products such as ice-cream, noodles and puddings. It is also used as a filler in wheat flour to control protein content. The amount of starch used in the sago industry is 6% of total domestic cassava starch consumption.

Paper/textile/plywood: Cassava starch has the properties of gel formation and retrogradation. For this reason it is widely used in the paper industry for surface treatment (sizing). In the textile industry it is used for yarn treatment and in the plywood industry for its binding properties. Starch consumption in paper, textile and plywood industries are 11, 3 and 1%, respectively, of total domestic cassava use (The Thai Tapioca Flour Industries Trade Association, 1999).

Citric acid: There are only two factories manufacturing citric acid in Thailand. One uses cassava pulp from starch factories as the raw material (about 5-6 tonnes/day) for its solid state (surface) fermentation. The other, recently established, uses cassava chips as raw material for its submerged fermentation process. About 40 tonnes of chips are needed to produce 6 tonnes of citric acid per day.

4. Export/International Market

Of the various cassava-based products mainly cassava starch and pellets are exported (**Table 7**). In the future, the export of cassava starch will be more significant in both value and volume. Thailand exports not only native cassava starch but also the modified products, for example, chemically and physically modified starch, sago, seasoning powder, sorbitol and liquid glucose.

Table 7. Quantity (tonnes) and destination of cassava products exported from Thailand during 1998 and 1999.

	Chips		Hard pellets		Starch	
Country	1998	1999	1998	1999	1998	1999
Africa	-	-	-	-	11,432	13,838
Australia	-	-	-	-	13,223	11,993
Bangladesh	-	-	-	-	3,668	7,034
Belgium	-	-	27,165	73,148	77	94
Brazil	-	-	-	-	263	410
Canada	-	-	-	-	8,623	2,779
China	182,100	155,261	-	-	28,412	61,555
France	-	-	-	-	4,555	3,863
Germany	-	-	3,500	-	924	384
Hong Kong	-	-	-	-	39,702	48,043
Indonesia	-	-	-	-	65,079	41,725
Italy	-	32,277	-	26,616	-	-
Japan	-	-	20,886	16,603	204,152	234,007
Laos	-	-	-	-	1,769	205
Malaysia	-	-	-	-	46,936	80,195
Mexico	-	-	-	-	660	234
Netherlands	-	24,720	2,486,686	3,409,728	13,816	14,526
New Zealand	-	-	-	-	1,289	465
Norway	-	-	-	-	902	689
Philippines	-	-	5,500	-	13,612	19,710
Poland	-	-	-	-	-	-
Portugal	-	9,800	52,125	57,125	-	-
Saudi Arabia	-	-	-	-	53	45
Singapore	-	-	-	-	41,826	46,382
Spain	-	-	194,075	535,329	-	-
Sri Lanka	-	-	-	-	525	1,158
South Korea	55,040	-	171,549	-	4,031	6,113
Sweden	-	-	-	-	1,906	1,680
Switzerland	-	-	-	-	560	6,397
Taiwan	-	-	-	-	212,676	277,761
U.K.	-	-	-	-	2,555	1,563
U.S.A.	-	-	-	-	39,086	38,199
Other	-	-	-	-	7,784	10,876
Total	**237,162**	**222,058**	**2,961,486**	**4,118,549**	**770,096**	**931,923**

Note: starch data only for Jan-Nov, 1999.
Source: *Thai Tapioca Trade Association, 2000.*

Future exports of cassava starch are expected to increase, as under the new GATT agreement the Thai government has agreed to maximum market access of cassava starch and modified products with the European Union (EU), South Korea, and Japan (The Thai Tapioca Flour Industries Trade Association, 1994; 2000).

1) EU will grant market access for Thailand's cassava starch upto 10,000 tonnes per year. The current tariff rate is 170.59 ECU per tonne; and the tariffs for import above the quota of 10,000 tonnes is 260 ECU per tonne; this will be reduced to 166 ECU per tonne by 2000.

2) Japan will reduce the tariff for cassava and related products within two years, as follows:

- Flour and meal for animal food production will be exempt; for others the current rate of 25% will be reduced to 15% in 2000.
- Cassava starch: in 1995 the tariff was 140 yen per kg; this will be reduced to 119 yen per kg in 2000. In addition, Japan is also committed to improve market access of dextrins and esterified starch by reducing the tariff from 8% in 1995 to 6.80% in 2000.

3) South Korea will grant market access for Thailand at an annual import volume of 1 million tonnes of cassava pellets with a 3% tariff, and a volume of 2,400 tonnes of cassava starch with 9% tariff.

CONCLUSIONS

Since 1959, cassava-based products have been a major export commodity for Thailand, assisted by relatively easy market access to the EU (until 1992). In a bid to meet the increased demand, rapid growth in the industry also led to weaknesses.

Productivity and demand: Enormous increases in cassava production in the past, with rather low yields, required a large planting area. The current reduction in demand for cassava will result in a large amount of land becoming available, but being unsuitable for other crops without large investments.

Policy: Systems for rewarding contracts to companies involved in the cassava industry are not yet fully in place to cope with a reduced export demand. The government needs to implement procedures that will grant fair access to as many companies as possible.

Thailand has demonstrated that cassava can be more than a subsistance crop, and that a large-scale and complex industrial system can be developed around this crop. Value addition to cassava has been a gradual process, and one that is still under way. Long term survival will necessitate that higher-value starch-derived products be developed from cassava and that appropriate markets be created. Thailand is unique in that despite the large scale of the cassava products industry, primary raw material production systems have remained small-scale. Farmers livelihoods have not been compromised as the range of products required by export markets has created competition between root buyers. This situation may not be maintained in the long term as Thailand becomes dependent on a narrower range of products and quality requirements of export markets well become more demanding.

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PRESENT SITUATION AND FUTURE POTENTIAL OF CASSAVA IN INDONESIA

Nasir Saleh[1], Koes Hartojo[1] and Suyamto[2]

ABSTRACT

Cassava (*Manihot esculenta* Crantz.) in Indonesia can be considered as a controversial crop. This crop has a tremendous yield potential of almost 100 t of fresh roots/ha, but official data show that its actual productivity is only 10-20% of its biological potential. It is considered to have multiple end uses, such as food, feed, raw material for industry and export. Very often, however, cassava farmers complain about the low and unstable price they receive for their product. A longer list can be developed concerning the contradictory nature of cassava. This in turn should be perceived as a special challenge to those who are more concerned about the improvement of people's living standards rather than the crop itself.

Starting from 1973, the cassava production system in Indonesia has shown a declining annual growth rate for the harvested area (-0.41%), but an increasing rate for both production (1.53%) and yield (1.93%). Since the standard deviation of the rate is much greater than its average, values of the rate and its sign (positive and negative) should be considered as a trend indicator only, and they can not be used for prediction purposes. At present, cassava in Indonesia is harvested from around 1.2 million ha, producing around 15-17 million tonnes of fresh roots, as the yield is only about 12-13 t/ha.

Most cassava is produced by small farmers that are weak in resources endowment, either in economic or social terms. Little purchased inputs, especially chemical or inorganic fertilizers, are applied, and as a result cassava production is frequently blamed as the cause of soil degradation. The crop is mostly grown in upland areas with undulating topography. Since its planting time should be compatible with the distribution of rainfall, the flexibility in planting and harvesting time is limited. As a consequence, the existence of a peak in planting and harvesting time is difficult to avoid. Abundance of cassava roots during the peak harvesting time results in low prices.

From an individual farmer's point of view, his income is determined by his productivity level. Logically, any improvement in productivity should increase farmer's income. However, this rarely happens, because the price is governed by the total amount of roots produced. As price fluctuation is the result of supply and demand imbalance, any decrease in price can be perceived as an indicator of limited demand. There is a belief that cassava farmers, especially the low-income groups, are trapped in a vicious cycle: changes in yield-planted area-production, are countered by changes in prices which go up and down. This condition in turn prevents farmers from improving their income.

If the opinion that demand is the most important limiting factor for production growth is true, the best solution should be a demand-led strategy. Demand for cassava in Indonesia is mainly in the areas of food, industry (mainly processing of starch and starch-based products), export and feed. Future prospects for using cassava as food will depend mainly on: (1) rice availability, since rice is the most preferred staple food for Indonesian people; and (2) cassava product development activities, as the social bias against cassava as being a food for the poor is strong and real. The existence of starch processing and starch-based industries, especially on a large scale, have been present for some time, but their role in improving farmers' welfare should be questioned. The growth in cassava exports will face two barriers: first, strong competition from Thailand, and secondly, the domestic price. Demand for cassava as a raw material for production of feed will depend on its price in relation to that of maize.

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It can be concluded that from the grower's view point cassava is a cash crop rather than a subsistence crop, and therefore the crop is a source of income rather than a source of food. As a consequence, every effort to improve the crop's performance should strife to ensure an increase in the grower's welfare. In addition, there has to be a significant increase in net income for individual farmers, due to a correct balance between production and demand. In fact, economic and social issues are the principal constraints. Unfortunately, these two issues are beyond the farmer's control. Concerted efforts among farmers, government and non-government organizations, research and development agencies, and others are urgently needed. While technical expertise should continuously be improved, much is known already to help increase the present productivity level towards its full yield potential.

INTRODUCTION

In Indonesia, cassava is classified officially as a food crop, so its development should be under the responsibility of the Department of Agriculture. Almost all cassava roots and their derivative products (e.g. chips, pellets, starch, food, feed and chemicals) are traded or processed in other sectors, outside the jurisdiction of the Ministry of Agriculture. As trading and/or processing activities affect the cassava grower, directly or indirectly, any attempt to resolve cassava production problems by only focusing on its cultural practices will fail. A holistic view and approach through integrating all related parties concerned (cassava growers, traders, processors, and consumers) as a continuum is unavoidable.

Cassava is grown mainly by small farmers who use labor-intensive methods. Due to its wide adaptability, cassava can be grown over a wide range of soil and climatic conditions as well as levels of management. However, most areas allocated to cassava are uplands, characterized by marginal soil fertility, with sloping or undulating topography, under-developed infrastructure (especially transportation), and a number of other relatively unfavorable circumstances. There are cassava plantations owned by private companies, as well as "illegal" farmers on the other end of the scale; however, their existence does not necessarily have a positive effect on the legitimate small farmers.

Even though well-known as a subsistence crop, most cassava is sold or traded outside the farm where it is produced. Cassava is sometimes considered as an undesirable food because it contains mostly carbohydrate. While it is considered to be of low value or a cheap commodity, cassava is the only food crop which contributes towards the net foreign exchange through export. Growing cassava is frequently considered a poverty indicator, but its produce and products create wealth for the wealthy.

The livelihood of millions of people depends on cassava, directly or indirectly, with great gaps either in social or economic status, beginning from the grower up to the exporter. It is becoming clear that the merits of cassava are not only limited by its physical or economic values, but go beyond that. Cassava can be a means of fulfilling our social obligations.

CHARACTERISTICS OF CASSAVA PRODUCTION IN INDONESIA

Three performance indicators of the production system are harvested area, production, and yield. **Figure 1** and **Table 1** show the trend in the cassava production system in Indonesia from 1961 to 2000, while **Figure 2** shows the trend in area for the four major cassava producing provinces.

Harvested area is directly related to the number of growers, because the average farm size for upland areas is approximately one hectare. Based on the assumption that family size is about

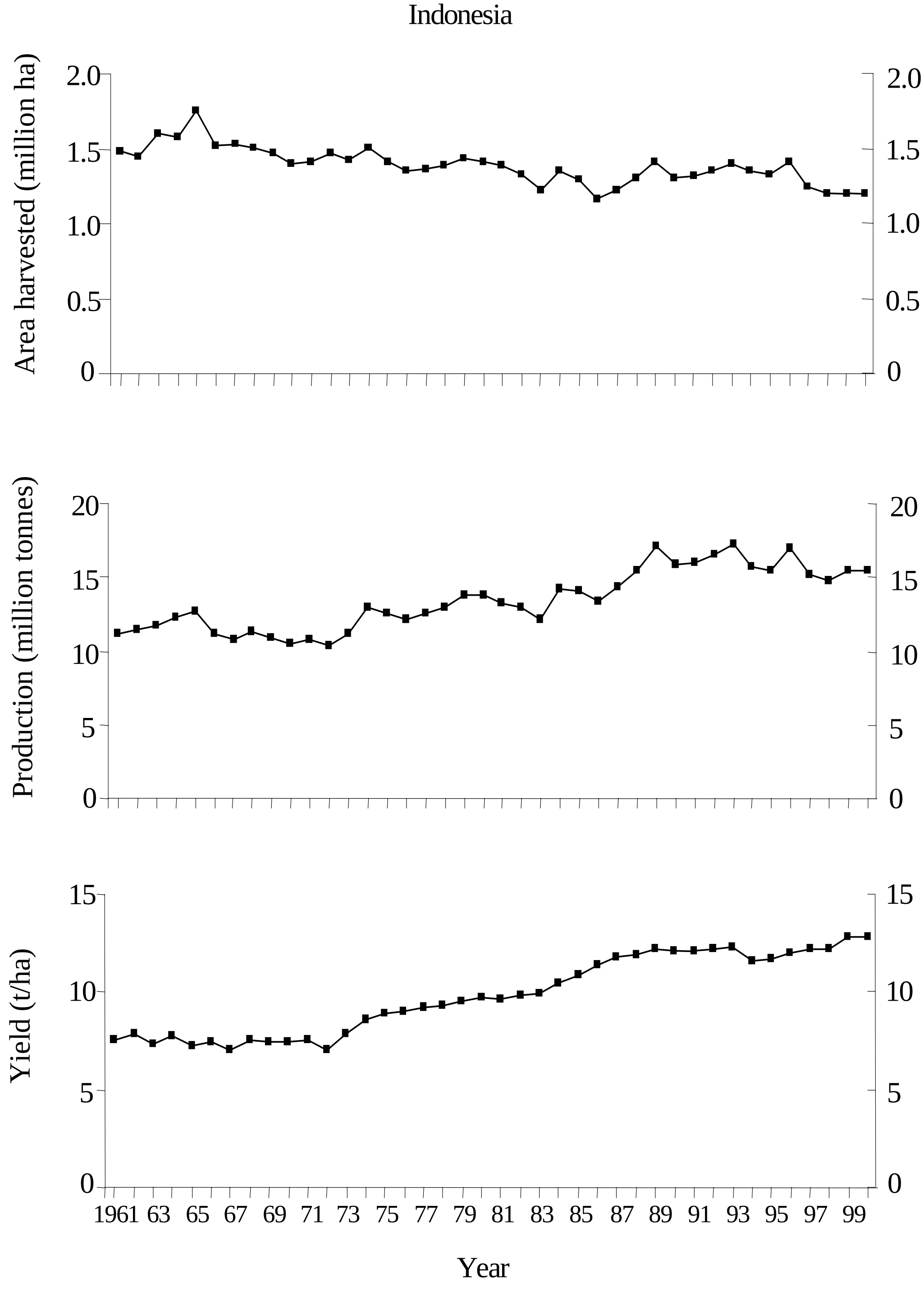

Figure 1. Cassava harvested area, production and yield in Indonesia from 1961 to 2000.
Source: *FAOSTAT, 2001.*

four, then the livelihood of not less than 4 million people will be influenced by either good or bad
crop performance. Productivity or yield is a quantitative measure of the farmers' welfare, depending on its financial value or root price. The farm-gate price for roots is also highly dependent on the distance between the farm and the market place.

Table 1. Cassava production in Indonesia from 1973 to 1998.

Year	Harvested area (ha)	Production (tonnes fresh roots)	Yield (t/ha)	Annual growth rate[1] (%)		
				Area	Production	Yield
1973	1,428,913	11,185,592	7.829	-2.7	7.7	10.7
1974	1,509,440	13,030,674	8.633	5.6	16.5	10.3
1975	1,410,025	12,545,544	8.897	-6.6	-3.7	3.1
1976	1,351,289	12,190,728	9.022	-4.2	-2.8	1.4
1977	1,367,535	2,487,664	9.132	1.2	2.4	1.2
1978	1,386,246	12,902,011	9.307	1.4	3.3	1.9
1979	1,441,748	13,750,767	9.538	4.0	6.6	2.5
1980	1,413,328	13,773,778	9.746	-2.0	0.2	2.2
1981	1,390,461	13,300,911	9.566	-1.6	-3.4	-1.8
1982	1,322,305	12,987,891	9.833	-4.9	-2.4	2.7
1983	1,219,066	12,102,733	9.928	-7.8	-6.8	1.1
1984	1,350,448	14,167,090	10.491	10.8	17.1	5.7
1985	1,291,835	14,057,027	10.881	-4.3	-0.8	3.7
1986	1,169,886	13,312,119	11.379	-9.4	-5.3	4.6
1987	1,222,151	14,356.336	11.747	4.5	7.8	3.2
1988	1,302,581	15,471,111	11.877	6.6	7.8	1.1
1989	1,407,880	17,117,249	12.158	8.1	10.6	2.4
1990	1,386,482	15,829,635	11.417	-1.5	-7.5	-6.1
1991	1,319,093	15,954,467	12.095	-4.9	0.8	5.9
1992	1,351,324	16,515,855	12.222	2.4	3.5	1.0
1993	1,401,640	17,285,385	12.332	3.7	4.7	0.9
1994	1,356,580	15,729,232	11.595	-3.2	-9.0	-6.0
1995	1,319,627	15,321,062	11.610	-2.7	-2.6	0.1
1996	1,415,101	17,002,455	12.015	7.2	11.0	3.5
1997	1,243,366	15,134,021	12.172	-12.1	-11.0	1.3
1998	1,211,871	14,888,793	12.286	-2.5	-1.6	0.9

[1] growth rates calculated in comparison with previous year.
Source: *Statistical Yearbook of Indonesia (various issues).*

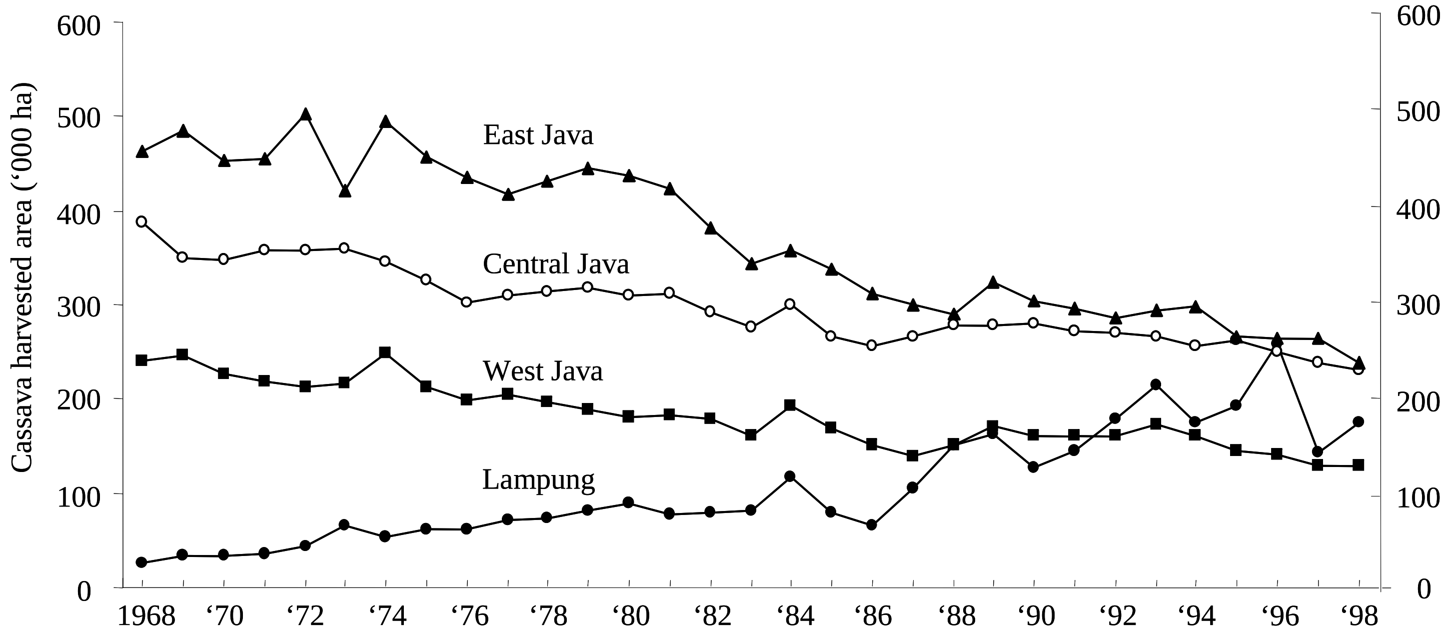

Figure 2. Trend in cassava harvested area in the four major cassava producing provinces of Indonesia from 1968 to 1998.

Source: CBS, 1999.

Due to its wide adaptability, cassava is grown in all the 26 Indonesian provinces, but the spatial distribution of cassava varies widely. Java island, with about seven percent of the country's agricultural area, accounts for about 50% of the national cassava harvested area and more than 50% of national production, because the yield level there is slightly higher than in the other islands. The wide-ranging archipelago of Indonesia creates specific problems, such as transportation systems and costs.

Fluctuations in harvested area over time suggest that there were changes in the number of farmers who grow cassava, or there was a change in the planted area per farmer. The former is a more likely explanation. There is no data on the actual number of cassava farmers at any one time. Since fluctuations in harvested area are much less than those of production volume or yield, it may be deduced that the farmers who start growing cassava and those who quit are more responsive to price changes, while those who continuously grow cassava are totally dependent on price fluctuations.

Trends among the three performance indicators can be seen clearly in **Figure 1**. Production appears to be mainly a function of yield. This conclusion is statistically valid, but the graph tells nothing about farmer characteristics. Koes Hartojo (1999), using national data over a shorter period from 1986 up to 1996, and Koes Hartojo and Wargiono (1999), using certain provincial data over a much shorter period from 1995 up to 1997, came to contradictory conclusions. Production was a function of harvested area, whereas yield was not related to production at all. It was suggested that for the purpose of prediction or developing programs for the future, the use of shorter period data (e.g. over the last three years) as well as long-term trends may provide more accurate results.

It is hoped that in the future cassava production will be a function of yield, but with very strict prerequisites. Productivity should be distributed normally with a very narrow base and a very sharp peak. This means that yield variability among farmers should be as small as possible. Since the natural conditions of cassava-growing areas vary widely, there is a need for a wide range of environment-specific technologies to be developed. That is the challenge to be faced by cassava researchers.

Even though the level of yield might be the most important key factor, the role of the other two indicators cannot be overlooked. This is because they are essentially linked to the grower's welfare. All three indicators are mutually related, but not necessarily in the same direction. What frequently happens is that any factor's increase or decrease is at the expense of the others. For example, an increase in yield (leading to higher production) should not go beyond the market capacity; otherwise, it will result in a price decline. For bulky and perishable products like cassava, the rate of price decline is much faster than the rate of productivity increase under over-supply conditions. Therefore, the hope of getting more money by selling more roots is unlikely to be fulfilled.

Price is determined by total production, which is the level of supply, and this is not possible to be predicted by the individual farmer. Thus, the existence of an early warning system, which can provide signals or information on both the planted area or the yield, would be very useful in order to match supply with demand. Such a system is totally absent at present. Without this system, farmers' response to price fluctuations is often too late.

It can be concluded that cassava is still a crop in demand, and that the number of people who depend on this crop for their livelihood is relatively stable, but unlikely to increase.

Productivity will continue to increase, but whether this also results in an increase in the grower's income is still uncertain. The agricultural sector has been growing at a higher rate than before the economic crisis of 1997. Even at the height of the economic crisis, the agricultural sector grew at a rate of more than 2% per year. Production will therefore always increase, which means that cassava growers will be providing more raw materials, jobs, or wealth to others.

SPATIAL AND TIME DISTRIBUTIONS OF CASSAVA PRODUCTION PARAMETERS

Cassava is grown in all the provinces of Indonesia, and is characterized by wide variations in both harvested area and production, and slightly less variability in yield. As previously stated, harvested area is indicative of the number of people who grow cassava; thus, a larger area will mean more farmers. However, this is not always true when comparing Java with the other islands, because average farm size in Java is smaller than in the other islands. It can be expected that for the same harvested area, the number of farmers growing cassava in Java will be greater than in Sumatra. The number of cassava growers is a yardstick for measuring the number of beneficiaries of any program or activity in production development.

The largest harvested area and production during the last five years were achieved in 1996, i.e., more than 1.4 million hectares, producing more than 17 million tonnes of fresh roots. About 88% of the harvested area and production were distributed within ten provinces only, which are considered as the main cassava production areas (**Table 2**). Nevertheless, among the main cassava-producing provinces, the variability in both harvested area and production is very large. Harvested area and production in East Java province, is about 7-8 times higher than the harvested area and production in North or South Sumatra.

Table 2. Cassava production in the main cassava growing provinces of Indonesia in 1996.

Rank	Province	Area (ha)	Yield (t/ha)	Production (t)
1.	East Java	263,799	13.4	3,546,260
2.	Lampung	257,417	11.3	2,898,667
3.	Central Java	250,841	13.3	3,344,715
4.	West Java	141,637	12.8	1,816,487
5.	East Nusa Tenggara	93,720	9.1	849,606
6.	South Sulawesi	62,473	10.9	681,256
7.	Yogyakarta	58,430	11.9	695,488
8.	Maluku	46,493	11.9	554,909
9.	South Sumatra	35,506	11.9	403,063
10.	North Sumatra	35,246	12.0	421,460

Source: *Statistical Yearbook of Indonesia, 1997.*

The geographical conditions as well as the distance among the provinces determine whether or not one province is dependent or independent of another. Even though East Nusa Tenggara and Maluku provinces are main producers, since these two provinces consist of many separated islands their production will not significantly affect those of other provinces. By contrast, there is a strong dependency between Lampung and East Java. Many industries located in East Java utilize starch produced in Lampung. Any increase or decrease in starch processing in East Java will affect the level of starch demand from Lampung, which in turn will affect the cassava price and production in Lampung.

Spatial distribution of cassava availability also determines the required policy for development and its effectiveness. Fresh roots have two components. First, the dry matter content which consists of starch and non-starchy materials. Second, the moisture content, which, from an economic stand-point, can be considered the undesirable part because of its effect on perishability and costs. Since the weight of the undesirable part is twice as large as the weight of the desirable part, then the further the distance of transportation the lower will be the price of the desirable part. Consequently, fresh roots should be processed near the place where cassava is grown. Based on these features, it is suggested that there should be specifications on what products should be produced (starch, chips or pellets) as well as the scale of the processing enterprise (household, small, medium or large) in accordance with natural, economic and social circumstances. Furthermore, the development of spatial distribution should be based on the principles of competitiveness and comparative advantage.

Most likely, certain provinces will be centers of starch production, while other provinces will be centers of other cassava products. Ideally, there should be a balanced demand for the various products. Otherwise, competition among the products will happen, leading to a reduction in total potential. Besides spatial distribution, the development of an enterprise will be based on time distribution.

Cassava is available all the time, but the supply is unevenly distributed (**Table 3**). In general, cassava is available more evenly in Sumatra (North and South Sumatra, Lampung) and the western part of Java (West Java) compared with the availability in Central Java, Yogyakarta and East Java. Since this fluctuation in cassava supply is caused by natural conditions, especially rainfall, a change towards a steady supply situation is not likely to occur. Consequently, the type and the scale of the enterprise, which is expected to create a demand for fresh roots, should be planned in accordance with the supply capabilities of the region.

Ideally, any enterprise, especially a big one, should operate for as long as possible. To be secure in its investments, it is very likely that the demand level will be fixed below the average or even at the lowest availability level. Consequently, there will be certain periods or months when supply is larger than demand. Such a condition will result in two possibilities. First, the root price will automatically decline. Second, by prolonging the transaction time the price will also decrease due to an increase in cost as well as a decline in quality. In the case of starch processing, the trucker who has to queue longer will charge more (Erwidodo and Hadi, 1999). That is one of the defects of big enterprises. A big enterprise with large investments, especially fixed costs, may have high-tech infrastructure but will not necessarily offer a high root price. In fact, the opposite may be true. Household or small-scale starch processors usually offer higher prices than big factories; however, their capacity is very limited.

Table 3. Monthly proportions of cassava harvested area in several selected provinces of Indonesia in 1996.

Province	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total (ha)
	Proportions of harvested area by month (%)												
1. East Java	2.66	2.46	1.91	1.76	3.27	6.08	**16.41**	**29.20**	**18.36**	11.23	4.29	2.30	263,799
2. Lampung	8.05	8.73	7.76	8.55	6.16	6.10	6.87	**11.26**	**13.24**	**10.46**	7.73	4.92	257,417
3. Central Java	3.22	2.81	3.25	3.37	5.29	6.24	**13.27**	**32.23**	**13.76**	9.29	3.71	3.56	250,841
4. West Java	6.16	5.15	5.20	5.38	7.88	10.88	**13.67**	**15.50**	**11.94**	8.53	5.36	6.31	141,637
5. East Nusa Tenggara	2.25	2.14	2.15	2.59	2.68	4.91	11.64	**16.60**	**19.19**	**24.79**	8.54	2.51	93,720
6.South Sulawesi	1.96	3.30	2.31	2.41	3.26	5.74	**11.11**	**24.44**	**28.96**	9.08	3.28	4.16	62,437
7.Yogyakarta	0.39	0.51	0.75	0.43	1.04	**4.78**	**49.05**	**36.11**	4.44	1.24	0.96	0.32	58,430
8.Maluku	9.27	8.80	**11.44**	9.12	10.30	10.12	**11.84**	**12.55**	7.68	1.12	7.39	0.37	46,439
9.South Sumatra	**10.55**	7.44	5.66	6.60	8.25	**11.89**	**13.89**	8.87	5.82	9.36	6.03	5.64	35,506
10.North Sumatra	**12.50**	**13.34**	6.44	5.14	5.95	8.08	**14.52**	4.90	7.46	9.07	4.75	7.84	35,246
TOTAL	4.86	4.74	4.34	4.44	5.13	6.87	**14.10**	**21.79**	**14.52**	10.32	5.25	3.54	1,245,472

Source: *Calculated from Statistical Yearbook of Indonesia 1997 (three highest months shown in bold print).*

Big enterprises are not only suspected of causing lower prices, but are also frequently believed to pollute the environment significantly. Big enterprises may buy roots at low prices because they have monopolistic power when buying fresh roots, while they are also monopolistic when selling their products (Gunawan, 1997). However, there are arguments against this suspicion which come mainly from the big factory owners. They usually claim that their factory operates much below the designed capacity. Regardless of which argument is true, there is something wrong which needs to be corrected. In the case of environmental pollution, starch processing has the potential of producing serious pollution regardless of the scale of operation (Howeler *et al*., 2000). As the awareness of the need for environmental conservation is growing, waste treatment, either solid wastes or waste water generated by the starch processor, should be improved.

Based on the above explanations, it is clear that both the spatial and time distributions of cassava availability are uneven. Spatial distribution will characterize what are the most appropriate products to be produced from cassava, whereas the time distribution will determine the scales of the processing enterprises. Nevertheless, alternatives in processing can be many, as long as they are complementary to each other. At present, coordination between cassava growers and consumers is almost absent. The processors (as consumers) are not usually concerned with the farmers' problems. Despite farmers being the first link in the chain of cassava-based economic activities, they struggle by themselves. Without cassava farmers it is unlikely that the cassava processing industry as well as its trade will be as big as it is at present.

CHARACTERISTICS OF CASSAVA FARMERS

The existence of millions of people involved, directly or indirectly, in cassava growing is an undisputable fact. However, Lynam (1987) noted that they are an invisible group especially to policy-makers. Lynam's statement was based on the fact that there was an inbalance between the farmer's role and government support. Possibly, that inbalance still exists even today.

Most of the 1.4 million hectares of cassava area is cultivated by small farmers characterized by either small capital or low technical capabilities. Unfortunately, they face considerable constraints and uncertainties for a better life. Limited capital and technical capabilities frequently force them to practice "inappropriate" cultivation techniques, even though from their point of view these are the best choice they can make. For example, on sloping land most farmers grow their cassava along up-and-down ridges rather than on contour ridges. The reason is they believe that yield is higher with the former practice, even though they are aware that such practices will cause severe soil erosion. Most poor farmers are faced with a dilemma; either to maximize productivity in order to sustain their present life style or to conserve their land for the future. Limited capital coupled with low marketing capabilities make matters worse. Sales of standing crops are commonplace, indicative of the weak bargaining position of cassava farmers. As a result, their farm-gate price is about 50% of the factory or consumer price. Consequently, only a small part of their income will be used to conserve their natural resource, especially to maintain land quality. It is believed that many farmers are trapped in a "vicious cycle" (**Figure 3**).

Most farmers respond to price signals, either an increase or a decrease, through their subsequent planting schedule. Such a response is due to the absence of coordination among farmers, and more importantly, there is no advance communication between farmers and consumers. A decline in harvested area in response to a price decline is usually accompanied by a lower level of technology, whereas a price increase will result in the use of better technology as well as an increase in planted area. Indeed, the vicious cycle cannot be broken by the individual farmer, as the possibility of a price increase depends on the conditions that demand is larger than supply. Better communication between farmers and consumers is urgently needed.

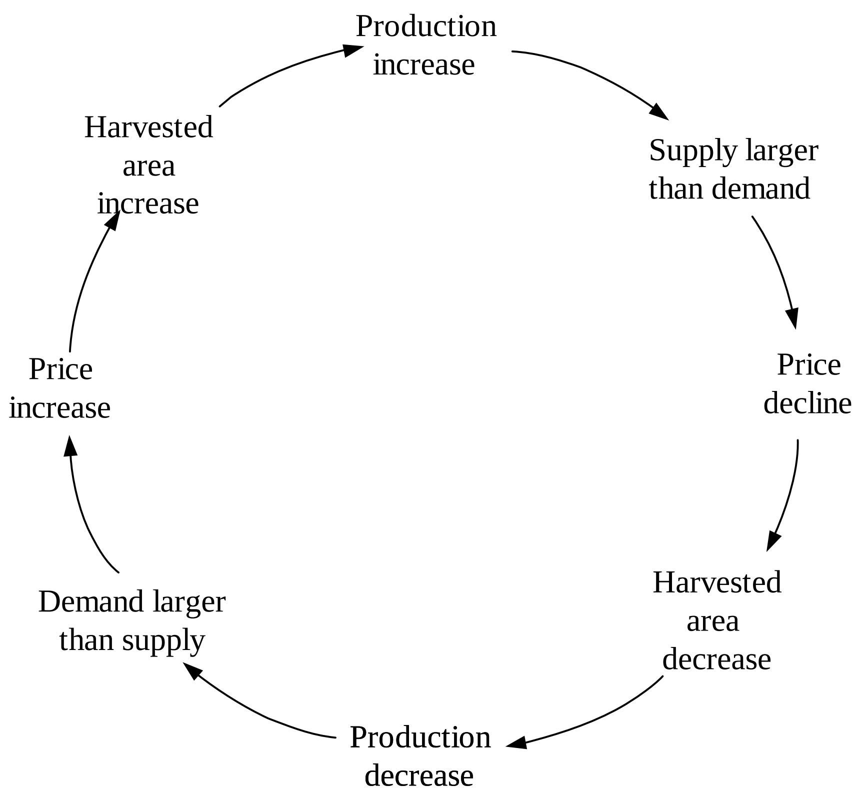

Figure 3. Hypothetical vicious price cycle which prevents farmers from reaping benefits from increased production.

FUTURE NEEDS AND POTENTIAL

What the cassava growers really need is an improvement in their living standard. If a better life can be accomplished by higher incomes, the higher income can be realized through sustainable farming practices. Sustainable farming practices can increase yield, while a yield increase can fulfill consumer demand. This consumer demand should drive a balanced production, which will benefit the farmers; but a better life is not so easily achieved.

Economic incentives to cassava farmers are low. Gunawan (1997) stated that the income of cassava farmers per unit time was the lowest among food crops farmers. For a long time it was believed that low farmer income stemmed from low productivity; hence, increasing productivity was considered the best strategy. Furthermore, the prospect of increasing yield is very promising since the gap between actual and potential yields is very wide. Unfortunately, this option has not always been successful.

The wide gap between actual and potential yields is true but increasing yield will raise income only on the condition that demand is larger than supply. Theoretically, price is a result not a cause: a price decline is indicative that supply is larger than demand. Limited demand itself can be expressed in terms of limitations in financial capability or capacity to process or to consume cassava. Since increasing farmer income is the main objective, expanding demand is urgently needed.

Cassava is in demand either for domestic use (food, feed or industry) or export. Cassava is consumed both as fresh roots and in dried forms. There is a marked regional variation in consumption patterns of both fresh and dried forms. Fresh and dried cassava consumption, at least in rural areas, increases markedly with increasing income at low income levels; consumption levels off at medium income levels, and declines at high income levels. In general, total cassava consumption tends to decline when income increases. As cassava is considered as an inferior food commodity, the prospect of expanding demand through direct consumption depends highly on the number of the poorer income groups who substitute cassava for rice (more highly preferred). Furthermore, rice prices have a very marked effect on cassava consumption.

Based on the overall tendency that cassava for direct human consumption will decline with an increase in income, the prospect of using direct consumption as a means to expand demand is dubious. As trends in direct consumption are related to the type of products as well as to the preparation methods for cassava, the future hope rests upon product development activities. Availability of more cassava-based products will make more people willing to accept cassava, and not only as an alternative food when rice is in short supply. Integrating cassava into the overall food policy through government support is essential.

Two main cassava-demanding industries are starch processing and the manufacture of starch-based products. The structure of the cassava industry is characterized by great diversity. Starch factories are scattered throughout Java and Sumatra, with a significant range in plant size as well as processing techniques and scale. The future potential of this demand locus is expected not only to absorb more cassava but also to generate social benefits such as employment. The local government of Lampung province launched a special program "called the Community-owned Cassava Starch Industry "since 1998. It is expected that the demand for cassava will increase with this program, stabilizing cassava prices as well as farmers' income. However, there are still many constraints, mainly in marketing the starch and in capital availability. The prospect of industry being a focus of demand expansion is promising. However, it should be based on mutual benefits for farmers and processors. A good example has already been implemented by one of the private enterprises located in Lampung province.

In an attempt to get a sustainable supply of cassava, the private enterprise has implemented a joint venture scheme with farmers. The company provides technology and loans for working capital, while farmers provide their land and labor. By this scheme, more productive technologies can be implemented and a fair price can be paid. Since providing technology and loans for working capital is an investment, the company also actively supervises farmers' cultural practices. Many advantages can be achieved by such a scheme.

Another source of industrial demand, which has potential but is not yet sufficiently tapped, is the animal feed industry. Constraints which handicap the use of cassava in the feed industry should be identified. Government support is required, since some feed components are still imported. The future prospect of this demand is expected to be high, because trends in demand for poultry, dairy and other animal products are increasing, while most of these products are still imported. Cassava chips and pellets can be used as one of the components in feed manufacture. In addition, exporting feeds which contain cassava as one of their components will be another good alternative. Again, government support is required, because large investments, either from domestic or foreign sources, are necessary. There are good possibilities of creating either unilateral or multilateral joint ventures.

The above discussion shows that demand is required to trigger an increase in farmer productivity within the farmer's capability. Without expanding demand, there is limited hope for an increase in farmer income. Farmers need support, not only in technological expertise but also in economic expertise. The simplest expression of their most basic need is: "please tell us how to sell cassava in order to get a reasonable price". Of course, the availability of more productive and efficient technology is undoubtedly required. However, availability of other necessary measures which enable farmers to employ more productive technologies should come first.

CONCLUSIONS

1. Cassava remains an important crop, involving the lives of millions of people either directly or indirectly. At least four million people, the growers, are directly affected by either high or low cassava production, which in turn affects price.
2. Most of the cassava growers cultivate their crop under relatively unfavorable circumstances. They are dependent on rainfall which is usually unpredictable. The topography of their land is mostly undulating, and is therefore susceptible to soil erosion and degradation.
3. Most of the cassava roots are traded outside the farm, and cassava is more likely to be a source of income rather than a source of food. Low price at harvest discourages farmers from using productive cultural practices. As a result of the relatively low income obtained from cassava farming, only a small fraction of the farmer's income is allocated to conserving his land.
4. Since the role of the crop is more likely to be a source of income, the best measure for the effectiveness of a development program should be a change in farmer income. The best way for farmers to increase their income is to increase their yield. While the potential for increasing farmer income through increased yield is high, it can only be realized if other determinants, such as demand and distribution, operate in a complementary fashion.
5. Increasing demand is crucial to absorb the greater production as a result of higher yields. Improving the efficiency in distribution is essential in order to reduce the marketing margin and allow a more equitable price for the farmers.
6. Demand can be expanded through product development which will lead to more people consuming cassava-based products as well as through higher consumption by each person. Product development should be supported by government policy which encourages the integration of cassava into the overall food policy. Industrial demand,

mainly starch and starch-based industries, is expected to grow. Demand for cassava by the feed industry, which is still insignificant at present, has a huge growth potential.

7. All these prerequisites are beyond the farmer's control. Without these preconditions in place, the farmer's future is unclear. Of course, farmers themselves will try to develop their own mechanism to adapt to the difficulties/problems they encounter.

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PRESENT SITUATION AND FUTURE POTENTIAL OF CASSAVA IN INDIA

S. Edison[1]

ABSTRACT

Cassava (*Manihot esculenta* Crantz.) is cultivated in India in about thirteen states (out of 32 states and union territories) with major production in the South Indian states of Kerala (142,000 ha) and Tamil Nadu (65,700 ha). It is now a major industrial crop in Tamil Nadu and is also gaining importance in Andhra Pradesh. The area and production trends of cassava in India and the major constraints to cassava production are highlighted in this paper. The emerging trends in cassava production, like the true cassava seed program, organic manuring, mycorrhizal technology, etc., and the strategy adopted in India to contain cassava mosaic disease, are briefly discussed. The efforts made to popularize high yielding varieties in traditional areas, and to expand cassava cultivation to non-traditional areas where the poverty stricken rural people make up a major share of the population, are also detailed. The transfer of cassava production technology is done through specific outreach programs of the Institute, namely the Lab-to-Land Programme, Institute Village Linkage Programme and Farmers Seminars. A special program, called "Testing and popularising cassava varieties", is currently undertaken in Tamil Nadu. The production and processing technologies are also transferred through consultancies, as in the case of Project Uptech (in Andhra Pradesh … 21,000 ha of cassava), in which a partnership is established with the State Bank of India.

The technological advancement made in the field of cassava utilization and the diversified value-added products that can be made from cassava are described. Realizing the industrial importance cassava is likely to attain in the next 20 years, priorities for future development have been identified. While attempting to augment internal demand by developing and marketing value-added products and increasing the use of cassava in poultry and fish feeds, opportunities for export markets need also to be explored. Some of the imminent problems faced by the cassava starch industry, and efforts being made to address these issues, are narrated. The need for setting up rural agro-enterprises based on cassava as well as organized marketing channels for the roots to ensure a reasonable income for producers, human resource development through international collaboration, the role of participatory research in solving farmers' problems, etc. are also discussed.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), which was introduced into India by the Portuguese during the 17th century as a food crop, is gradually changing its role as an industrial raw material. The importance of cassava as a food crop was well recognized in Kerala, south India during the 20th century, when famine struck India at the time of the Second World War. The crop integrated well with the traditions and culture of the people of Kerala. Adaptability to poor soils, an ability to establish in high as well as low rainfall areas, and relative resistance to pests and diseases are a few of the factors that helped to anchor cassava in India. With increasing availability of cereals and other food materials, the food value of cassava gradually diminished. Meanwhile, cassava spread to the neighboring states of Tamil Nadu and Andhra Pradesh, where it serves mostly as raw material for starch extraction. The phenomenal growth in the starch and sago trade over the years has also helped in creating rural employment in Tamil Nadu.

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PATTERN OF GROWTH IN CASSAVA CULTIVATION

Asia stands second among the cassava-producing continents in the world. Approximately 13% of Asian cassava production comes from India. **Figure 1** shows the trend in cassava area, production and yield in India during the past four decades. Cassava area and, particularly, production increased steadily from 1963 to 1977, after which both declined. Production has been maintained at about 5.5 million tonnes due to a steady and remarkable increase in yield, from 7 t/ha in 1963 to 24 t/ha in 2000.

Although cassava is cultivated in about 13 states of India, major production is from the southern states of Kerala and Tamil Nadu. As a result of changing life-styles, the influx of money sent home by Indians working in the Gulf states, and a shift to cultivation of cash crops like rubber and plantation crops, the area under cassava in Kerala has gradually decreased over the past 30 years (**Figure 2**). Cassava, which was planted in an area of 297,000 ha in 1967/68 was cultivated in only 142,000 ha in Kerala in 1996/97. The industrial potential of cassava, however, has led to a rapid spread of cultivation in Tamil Nadu, and complementary factors for its growth have been the cheap labor available in that state and the organized marketing channels for the products. While the total production in Kerala declined to 2.59 million tonnes in 1996/97 from 4.2 million tonnes in 1967/68, in Tamil Nadu cassava production rose to 3.04 million tonnes in 1996/97 from 0.42 million tonnes in 1967/68 (**Figure 2**). The remarkable increase in production in Tamil Nadu is due to the very high productivity of cassava in that state (about 46.32 t/ha in 1996/97), which is the result of adoption of high-yielding cultivars like H-165 and H-226 as well as better management of the crop through the use of irrigation (**Table 1**). The shift in focus of the crop from Kerala to Tamil Nadu is also evident from the percentage contribution of the two states towards national cassava production over the past thirty years. Kerala, which accounted for 86% of the total area and 91% of total production in 1967/68 contributed only 61% and 45%, respectively, towards area and production in 1996/97 (**Figure 2**). By contrast, Tamil Nadu which had only a meager area (13%) and production (9%) in 1967/68, contributed 29% of the total cassava area and 52% of total cassava production in 1996/97. Based on statistical projections, the production of cassava in Tamil Nadu is expected to reach 6.08, 6.76 and 7.44 million tonnes, respectively, by the years 2000, 2010 and 2020.

Considering the population growth rate, India needs to produce as much cassava roots as 12 million tonnes by the year 2020; this calls for R&D strategies to meet the requirement. The present productivity of 22.5 t/ha is projected to rise to 26.95, 32.57 and 38.20 t/ha by the years 2000, 2010 and 2020, respectively.

SWOT ANALYSIS

SWOT analysis is an important tool which analyzes the *strengths*, *weaknesses*, *opportunities* and *threats* of any enterprise while formulating development strategies for that enterprise. The salient points from a SWOT analysis on cassava in India are furnished below:

Strengths

1. Potential to produce a large amount of food per unit area
2. Excellent adaptability to a wide range of ecosystems
3. Relatively free from pests and diseases
4. Strong cassava research base available
5. Strong technology base
6. Capability in providing food security and contributing towards livelihood.

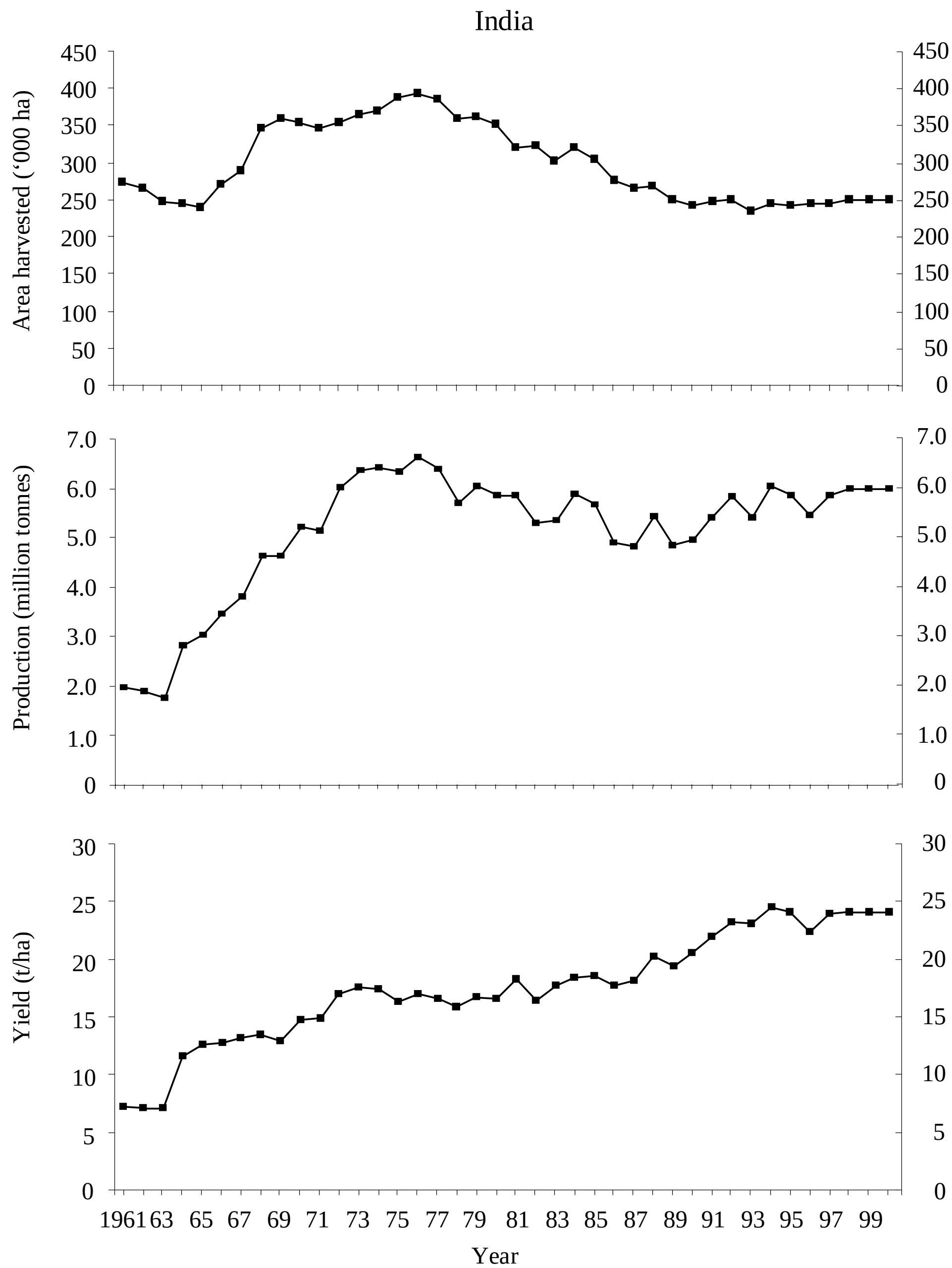

Figure 1. Cassava harvested area, production and yield in India from 1961 to 2000.

Source: *FAOSTAT, 2001.*

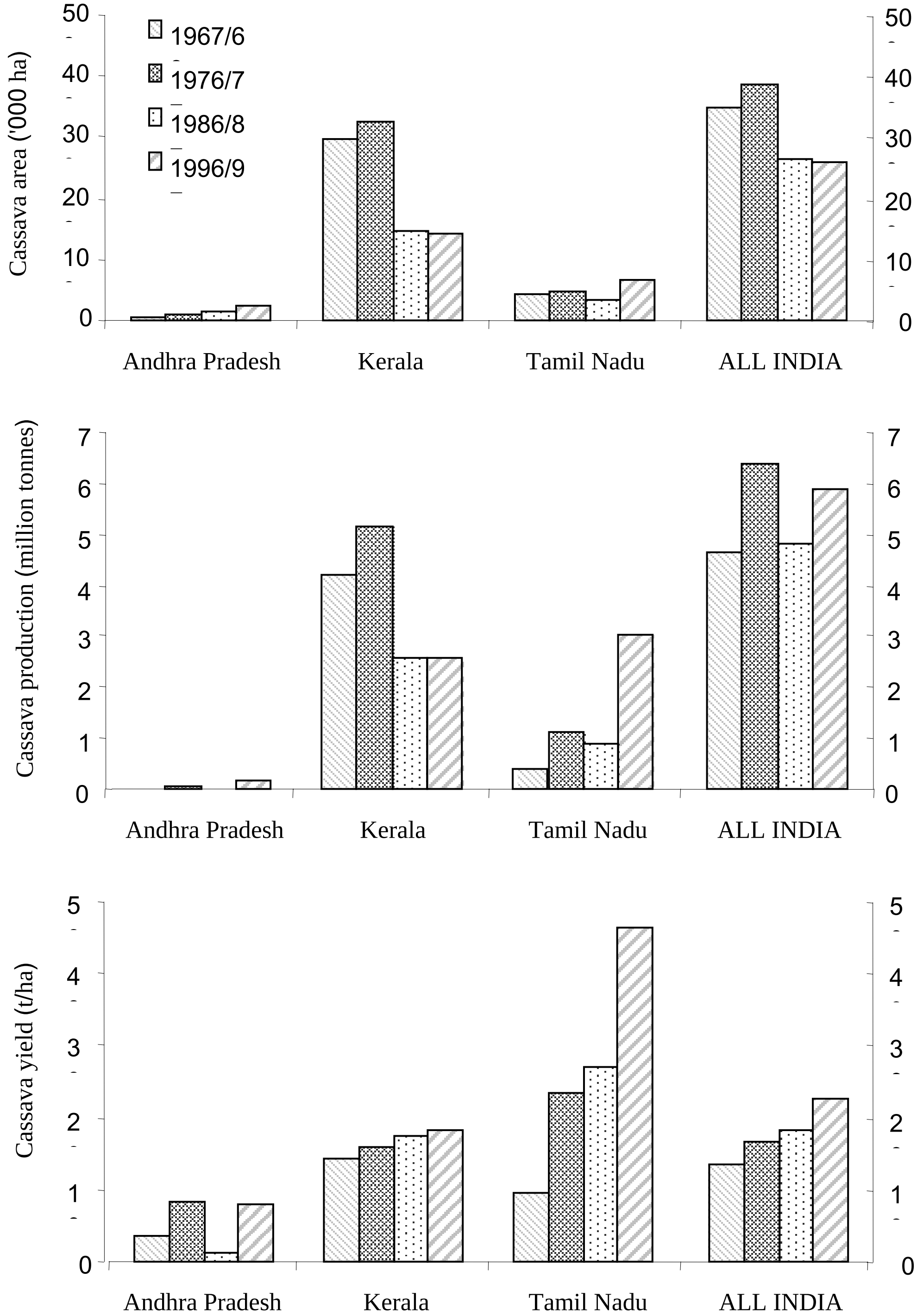

Figure 2. Changes in cassava area, production and yield in the main cassava production states of India from 1967/68 to 1996/97.

Table 1. Area, production and yield of cassava in India (1967/68 to 1996/97).

	Area ('000 ha)				Production ('000 t)				Yield (t/ha)			
State	'67/68	'76/77	'86/87	'96/97	'67/68	'76/77	'86/87	'96/97	'67/68	'76/77	'86/87	'96/97
Andhra Pradesh	3.40	9.00	12.50	22.00	12.20	74.10	15.20	174.50	3.59	8.23	1.22	7.93
Assam	2.10	1.30	1.78	2.40	9.60	5.40	7.50	11.50	4.57	4.15	4.24	4.79
Karnataka	0.60	1.20	1.50	0.90	4.10	16.60	14.60	7.10	6.83	13.83	9.73	7.89
Kerala	297.60	323.30	146.95	142.00	4198.40	5125.50	2576.10	2588.30	14.11	15.85	17.53	18.23
Meghalaya			4.00	3.90			23.30	21.50			5.83	5.51
Nagaland			0.30				0.60				2.00	
Rajasthan			0.20				0.50				2.50	
Tamil Nadu	43.40	48.00	33.80	65.70	419.40	1128.20	913.40	3043.20	9.66	23.50	27.02	46.32
Tripura		0.20	0.50			0.60	2.15			3.00	4.30	
A & N Islands			0.20				0.80				4.00	
Arunachal Pradesh			3.20				10.00				3.13	
Mizoram		0.10	0.10			0.30	0.50			3.00	5.00	
Pondicherry		0.70	0.50			13.40	9.90			19.14	19.80	
ALL INDIA	**347.10**	**386.00**	**265.00**	**260.80**	**4643.70**	**6375.00**	**4814.00**	**5868.30**	**13.38**	**16.52**	**18.17**	**22.50**

Source: *Lakshmi et al., 2000.*

Weaknesses
1. Cassava is not given due recognition in agricultural development policies of the government
2. Lack of extension programs
3. Lack of organized marketing
4. Disproportionate increase in the labor wage and root price
5. Lack of information base
6. Poor resource base

Opportunities
1. Role in food security
2. Scope for area expansion
3. Product diversification
4. Suitability for use in various cropping systems

Threats
1. Decline in area
2. Product *cum* price competitiveness
3. Competition from other exporting countries

CASSAVA PRODUCTION

While the average world cassava yield is only 10 t/ha, the yield in India is currently 22.5 t/ha. This has been possible mainly through the introduction of high-yielding cassava varieties, released by CTCRI, and the adoption of improved production practices. Despite this, there are a number of biological constraints to cassava yield improvement. These include a low multiplication rate, bulky planting material required for cultivation, rapid drying out of stakes, and incidence of cassava mosaic disease (CMD) and root rot. It is important to address these issues through properly oriented research programs, so that the high productivity can be sustained. One of the most fascinating strategies to overcome the low multiplication rate and bulkiness of planting material is the true cassava seed program (TCSP). Work on TCSP was initiated in India almost a decade ago, and has advantages such as a 150 times increase in propagation rate, longer viability of seed, and non-transmission of mosaic virus through seed. Cassava mosaic disease is gradually reaching alarming proportions in the cassava-growing states of India. The integrated disease management strategy adopted to overcome this biological constraint includes production of disease-free material through meristem culture, multiplication of planting material in vector-free zones, mass multiplication of healthy planting material through farmer participation, etc.

The shift in focus of cassava from a food to an industrial crop has led to a change in the breeding strategy for cassava as well. For the industrial zones of Tamil Nadu and Andhra Pradesh, importance is being given to develop high starch varieties with CMD tolerance, early harvestability and better post-harvest storage life.

Management strategies to improve cassava production include agronomic interventions, such as the development of low input and mycorrhizal technologies, natural resource utilization and water management. As a management strategy for CMD, branching types are also preferred due to better canopy spread with consequently lower yield reduction from the disease. Testing and popularization of cassava varieties through outreach programs like the Lab-to-Land Program (LLP), Institution-Village Linkage Program (IVLP) and on-farm trials (OFT) are another approach for enhancing cassava production.

PROCESSING AND UTILIZATION

Cassava offers immense scope as a food, feed and industrial raw material. An overview of the global product use of cassava indicates that the roots are the source of a number of fermented food products in Africa and Latin America as well as non-fermented food products in Asia. Even though substantial proportions (>30%) of cassava are used for on-farm pig feeding in Vietnam and China, its use as cattle feed in India is still very limited. More than three and a half decades of cassava research at CTCRI has led to the development of several utilization technologies. Some of these are the production of alcohol, cold water soluble starch, biodegradable plastics, food products like *rava* (semolina) and porridge, glues and adhesives, as well as *in situ* utilization as ensiled cassava for cattle, microbial techniques to enhance starch recovery, and starch factory waste-based broiler feed.

Starch and sago are the two cassava products that have revolutionized cassava cultivation in Tamil Nadu. There are a number of lessons that can be learnt from the experience of Tamil Nadu, where cultivation and organized marketing channels have raised the hopes of cassava farmers. The fact that cassava can offer sustainable incomes to farmers has encouraged them to cultivate the crop even by using irrigation to obtain good returns. About 80% of the national demand for starch and sago is met by approximately 1,100 starch factories in Tamil Nadu, which produce 150,000 tonnes each of starch and sago from 1.5 million tonnes of roots. The remaining quantity of roots goes mainly for cassava chips, flour, cattle feed, wafer production and for consumption of raw tubers for human consumption and animals. Starch/sago production has now spread to the adjoining state of Andhra Pradesh as well, where the production is about 25,000 tonnes of sago and 5,000 tonnes of starch. Starch and sago production from India is projected to reach 0.4 and 0.3 million tonnes, respectively, by the year 2020.

Expansion of cassava cultivation to non-traditional areas is an alternate strategy adopted by CTCRI to enhance cassava production in India. As a part of this strategy, a novel project termed UPTECH was launched in Andhra Pradesh in 1998 with the collaboration of the State Bank of India. The technical support extended under this program includes preparation of a feasibility report on the modernization of starch/flour industries, consultancies for process development, treatment of waste water, and refinement of agro-techniques.

PRODUCTS OF FUTURE POTENTIAL

In order to maintain equity in the food production systems, secondary crops like cassava have to be retained in the cropping systems of marginal farmers. This necessitates the creation of awareness of the scope of cassava for *in situ* production of several food products through rural processing units. A number of products like wafers, chips, *pappads*, *rava*, noodles and dried chips for animal feed can be made with low technological and financial inputs. Converting harvested cassava to products with better storability will help farmers reduce postharvest losses and ensure economic returns. Stable quality value-added products made from cassava can also open up export avenues for cassava.

Starch and sago will continue to be the major industrial products from cassava in India. Nevertheless, the commercial success of any industry depends on the diversified products generated. Realizing this, two hi-tech starch factories have recently been established in the Erode and Dharmapuri districts of Tamil Nadu to start manufacturing several modified starches from cassava. These include pre-gelatinized starch (for the paper and oil industries), acid-modified thin boiling starch (for the confectionery and textile industries), oxidized and cationic starches (for the paper industry), textile grade modified starch with good tensile and adhesive strength (for the textile industry), and paper grade starch with ink water resistance. Such products, besides augmenting internal demand, are likely to improve export potential also.

Although, cassava-based products were exported by India to European countries from 1958 to 1964, these exports stopped subsequently when internal demand increased. In 1996, India exported 31,000 tonnes of cassava products earning Rs 141.30 million of foreign exchange (**Tables 2** and **3**). Irregular demand and an inability to compete with international prices did not allow this trade to catch momentum. With a view to promoting the export potential of cassava-based products, CTCRI has launched programs such as market assessment and export demand assessment. Extruded food products and white pelleted starch conforming to international quality standards are products of future potential for India. Strengthening the research base to produce modified starches with stable viscosity, freeze-thaw stability, film-forming properties, better suspension characteristics, etc. to suit many food applications (Satin, 2000) will further enhance the prospects of cassava in India.

A number of problems were faced by the cassava cultivators of Tamil Nadu when the crop was introduced into the state. Lack of market avenues and poor post-harvest storage life of roots dismayed their aspirations. Realizing this, an industrial cooperative society, called SAGOSERVE, was established by a group of entrepreneurs. This cooperative is at present monopolizing the starch and sago trade in the state. In addition, it has also substantially enhanced rural employment opportunities, resulting in around 0.6 million people making a living from cassava. The marketing channel for cassava in Tamil Nadu is well organized with a central role being played by SAGOSERVE. The lack of such an organization was felt by the producers of Andhra Pradesh, and an industrial cooperative society of a similar nature to SAGOSERVE was launched in the state in February, 2000. Exploitation of farmers by middlemen and processors can be controlled to a large extent through the intervention of such societies.

PRIORITY ISSUES AND FUTURE NEEDS

The declining importance of cassava as a food crop in India, shrinkage in cultivated area, long crop duration, diseases like CMD and root rot, necessitate alternative research strategies to diversify the scope of cassava utilization and to sustain its production and productivity in India. Germplasm enrichment through exchange (in tissue culture) can help introduce root rot resistant, drought resistant and high starch cassava varieties from Brazil, or early maturing and high dry matter clones from countries like Thailand. Proposed research collaboration with CIAT is expected to make available true seeds of elite high starch clones and to facilitate the generation of sustainable production management practices in India. Human resource development through training programs with the active participation of international agencies is also necessary to strengthen the research base to tackle vital issues related to production and product development.

The cropping pattern scenario has witnessed change, especially in Kerala where plantation crops have started gaining prominence in upland production. This necessitates cassava to be integrated into alternative cropping systems, such as lowland and multi-tier systems. Thus, there is a need to develop management practices for cropping systems involving cassava in upland and lowland production systems.

Cassava is grown under many complex and diversified production systems where technology preferences are multifarious to suit different socio-economic production systems and objectives. It is necessary to have technology assessments under a wide range of agro-climatic situations through farmer participatory research.

Table 2. Exports of cassava and its products from India during 1996/97.

Cassava Product	Importing country	Quantity exported (tonnes)
Cassava flour and meal	Australia	3.0
	Baharain IS	1.8
	Bangladesh	685.8
	Canada	0.3
	Hongkong	0.1
	Kenya	19.0
	Kuwait	15.5
	Mozambique	1.0
	New Zealand	0.8
	Oman	2.3
	Saudi Arabia	8.7
	Sri Lanka	3.0
	Tanzania Rep.	0.5
	UAE	23.0
	UK	28.0
	USA	41.4
	Zambia	1.0
	China P Rep	196.0
	Malaysia	294.0
	Sri Lanka	138.2
	Total	**1,463.7**
Cassava starch	Bangladesh	977.4
	Malaysia	598.8
	Russia	20.0
	Sri Lanka	533.8
	Thailand	18.0
	UAE	0.4
	USA	4.0
	Total	**2,152.5**
Cassava (tapioca) & substitutes prepared from cassava starch	Bangladesh	705.8
	Belgium	4,810.0
	Italy	22,500.0
	Singapore	5.0
	South Africa	84.5
	Sri Lanka	60.0
	UAE	72.5
	Total	**28,238.3**

Source: *Directorate of Commercial Intelligence and Statistics, 1997.*

Table 3. Quantity (tonnes) of starch and sago marketed in India.

Commodity	Year	Marketed through SAGOSERVE	Direct sales	Total
Starch	1997/98	75,654	18,913	94,507
	1998/99	72,000	18,000	90,000
Sago	1997/98	105,767	43,203	148,970
	1998/99	112,500	42,750	155,250

Note: Direct sales make up 25% of SAGOSERVE's sales per annum in the case of starch and 20% in the case of sago in Tamil Nadu, plus 22,050 tonnes per annum of sago from Andhra Pradesh.
Source: *SAGOSERVE, 1998.*

In view of the global development strategy for cassava initiated a couple of years back, there is also a need to start an Asian Cassava Production and Processing Network (ACPPN) to identify the needs of Asian countries, their strengths and weaknesses, as well as to strengthen mutual development. It can also help coordinate the research activities of member countries. For example, low genetic diversity is a major hurdle in cassava improvement for countries like Vietnam and China. By contrast, India has a rich germplasm collection of cassava which can be made available to these countries. Diversification technologies developed in India can also benefit countries like Thailand, which has had to increase internal starch demand in recent years due to a decline in export markets. The wet starch technology of Vietnam and that of pelleted cassava of Thailand can in turn help India expand the utilization potential of cassava in the industrial and animal feed sectors. Network collaboration seems to be the right choice for Asian countries to widen the prospects of cassava in the coming decades.

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PRESENT SITUATION AND FUTURE POTENTIAL OF CASSAVA IN CHINA

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ABSTRACT

In China, cassava is planted mainly in the southern provinces of Guangxi, Guangdong, Hainan and Yunnan. The annual total area and production is about 400,000 ha and 6,000,000 tonnes of fresh roots, respectively. Guangxi is the main cassava producing province with more than 60% of both cassava growing area and production. Following the success of research on cassava product development and the development and dissemination of promising varieties, the cassava yield in the province has increased substantially during the last ten years.

The cassava processing industry is mainly concentrated in Guangxi and Guangdong provinces. Of the approximately 525,000 tonnes of cassava-based products processed annually in China, 73% comes from Guangxi, about 20% from Guangdong, 6% from Hainan and 2% from Yunnan. About 95% of these products are starch or modified starch. Considering the natural resource conditions and the rapid development of the cassava industry in Guangxi, it is clear that the present status and future potential of the cassava industry is more favorable in this province as compared to other provinces. Especially since the beginning of the 1990s, the cassava industry in Guangxi developed very fast. In view of the great potential to further develop this crop, the government of Guangxi has organized a group of experts to work out a future plan of cassava development in Guangxi for the next 20 years. Other cassava producing provinces have not yet developed similar plans.

INTRODUCTION

China is a very big country with a large population. There is no doubt that all kinds of products have a huge market. This is the same for cassava-based products. For example, China has now an annual per capita starch consumption of about 4 kg, which is only 1/15 of that of Americans, 1/10 of the Japanese and 1/4 of the Thais. It is clear that the future Chinese starch market will be very large. Although maize starch is the most commonly used starch, cassava starch also plays an important role in the market, especially in the southern part of China and in some specific industries (**Table 1**).

In China, 99% of the cassava growing areas are in the southern provinces of Guangxi, Guangdong, Hainan and Yunnan. The annual planting area is about 400,000 ha, with a total production estimated at 6,000,000 tonnes; Guangxi province accounts for about 60% of both the planted area and production. Of the 6,000,000 tonnes of fresh roots produced in China, it is estimated that about 49% is used in the processing of starch, alcohol and various other chemical products, 22% for animal feed processing (compound feed), 21% for on-farm pig feeding, 6.2% for human consumption (mostly for subsidiary foods), and 1.7% is waste (**Table 2**).

Cassava processing in China is mainly concentrated in Guangxi and Guangdong provinces, and the main cassava-based products are native starch, alcohol, modified starch and MSG (**Table 3**). During the 1990s many cassava-based chemical products were

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developed and are now produced on a large scale; these have become the raw material in many industries.

Table 1. Annual production ('000 tonnes) of starch and starch-derived products from various sources in China in 1998.

Total production (100%)	4,030	-modified starch	300
		-MSG	500
		-Others	NA
-maize starch (82.3)	3,320		
-cassava starch (11.7%)	470[1)]	-Guangxi (70.2%)	330
		-Guangdong (21.3%)	100
		-Hainan (6.4%)	>30
		-Yunnan (2.1%)	10
-sweetpotato starch (2.4%)	96		
-wheat starch (2.4%)	96		
-potato starch (1.2%)	48		

[1)] In addition, more than 100,000 tonnes of cassava starch were imported from Thailand.
Source: *Guangxi Starch Association, 2000; Zhao Jixiang, 2000.*

Table 2. Estimated annual cassava root production ('000 tonnes) and utilization in China in 1999/2000.

Total production (100%)	6,000
-starch and starch derived products (49%)	2,940
-compound feed (22.3%)	1,340
-on-farm pig feeding (20.8%)	1,250
-human consumption (6.2%)	370
-waste (1.7%)	100

CURRENT STATUS OF CASSAVA IN CHINA

Table 4 shows the trend in cassava area, production and yield in the three principal cassava producing provinces of China since 1954. Area, production and yield increased gradually during the 1960s, 70s and 80s, reaching a plateau of about 400,000 ha in the early 1990s. After that the area continued to increase in Guangxi but declined in Guangdong province. Yields were very low in the 1950s and 60s but increased gradually to about 13.0 t/ha in 1993; in 1998 yields are estimated to be about 15 t/ha[4].

[4] FAOSTAT shows the cassava area for China in 1999 to be 235,045 ha producing 3,750,658 tonnes and a yield of 16.0 t/ha. However, these data do not correspond at all with locally produced estimates of 400,000 ha and a production of 6 million tonnes.

Table 3. Estimated annual cassava root production and utilization ('000 tonnes) in China in 1998.

Total production (100%)	6,000		
-Guangxi (62%)	3,700	-starch + starch derived products (50%)	1,850
		-chips for compound feed (20%)	740
		-on-farm pig feeding (20%)	740
		-human consumption (8%)	300
		-waste (2%)	70
-Guangdong (24%)	1,450	-native starch (34%)	500
		-modified starch (14%)	200
		-sweeteners (3%)	46
		-compound feed (23%)	~334
		-on-farm pig feeding (21%)	~300
		-human consumption (3.4%)	~50
		-waste (1.4%)	~20
-Hainan (7.5%)	450	-native starch (>33%)	>150
		-chips for compound feed (30%)	133
		-alcohol (16%)	72
		-on-farm pig feeding (15%)	68
		-human consumption (<4%)	18
		-waste (2%)	9
-Yunnan (6.7%)	400	-on-farm pig feeding (35%)	140
		-chips for compound feed (34%)	136
		-native starch + alcohol (30%)	120
		-human consumption + waste (1%)	4

Source: *Adapted from Guangxi Starch Association, 2000; other sources.*

1. Guangxi Province

Presently, Guangxi is the most important cassava producing province in China. Before 1995, the cassava area and production in Guangxi comprised about 40% of that in China, always being less than in Guangdong province (**Table 4**). After 1995, Guangxi has become the principal cassava producing province, both in terms of planting area and root production. The cassava area in Guangxi is now about 260,000 ha producing 3,700,000 tonnes of fresh roots (**Table 5**), or approximately 62% of the national area and production (**Table 3**). The average yield in 1998 was 14.2 t/ha, a marked improvement over the yield of 8.9 t/ha in 1991 (**Table 4**).

Guangxi is located in a mountainous area, and the natural conditions are very poor compared with those of other southern provinces. Soils are very unfertile and acid, while many areas are quite dry. Cassava is a very suitable crop. Everyone agrees that Guangxi is the place most suitable for growing cassava, even though the yields are rather low. In many places of Guangxi, cassava is a very important traditional crop, previously eaten as a staple food; but now cassava is considered an income resource of farmers who sell to factories, either in the form of fresh roots or dry chips. In many areas, they also use it for animal feeding. Both in the past and now, most farmers plant cassava with poor management; they apply fertilizers but not in the correct way. Actually, they don't care about the yield, and for many farmers who have small areas of cassava (less than 0.2 ha), cassava is only a secondary crop, the more important one being the intercrop, such as peanut, watermelon, mungbean, etc.

Table 3 shows that every year about 50% of the 3,700,000 tonnes of cassava roots produced in Guangxi is used for processing into starch, modified starch, alcohol and other kinds of chemical products; 20% is made into chips which are sold to factories, including for export to other provinces; 20% is used for on-farm animal feeding and another 10% for other uses (Guangxi Starch Association, 2000).

Table 4. Cassava area, yield and production in China, 1954-1998.

	Area ('000ha)				Yield (t/ha)				Production ('000t)			
Year	Guangdong	Guangxi	Hainan[1]	Total	Guangdong	Guangxi[2]	Hainan[1]	Total	Guangdong	Guangxi[2]	Hainan[1]	Total
1954	40.45	67.45	-	107.90	7.43	1.89	-	3.97	300.5	127.6	-	428.1
1955	27.53	62.65	-	90.18	4.27	1.69	-	2.48	117.7	106.1	-	223.8
1956	60.07	93.01	-	153.08	2.19	1.88	-	2.00	131.8	174.8	-	306.6
1957	89.01	104.32	-	193.33	3.55	2.62	-	3.05	316.3	273.0	-	589.3
1958	109.07	132.57	-	241.64	7.52	3.74	-	5.45	820.8	495.6	-	1,316.4
1959	131.70	118.84	-	250.54	6.22	3.54	-	4.95	819.7	421.0	-	1,240.7
1960	86.27	127.91	-	214.18	2.77	2.07	-	2.35	238.8	264.1	-	502.9
1961	117.27	104.35	-	221.62	2.82	3.33	-	3.00	331.1	347.6	-	678.7
1962	-	183.55	-	-	-	3.09	-	-	-	567.8	-	-
1963	-	153.43	-	-	-	2.98	-	-	-	457.0	-	-
1964	110.07	154.31	-	264.38	3.12	3.11	-	3.12	343.5	480.7	-	824.2
1965	98.38	158.52	-	256.90	3.57	3.18	-	3.33	351.8	503.5	-	855.3
1966	106.86	102.22	-	209.08	3.35	2.48	-	2.92	358.2	253.3	-	611.5
1967	-	70.30	-	-	-	7.41	-	-	-	521.1	-	-
1968	-	73.67	-	-	-	6.60	-	-	-	486.4	-	-
1969	126.47	124.73	-	251.20	4.72	5.21	-	4.96	597.1	650.2	-	1,247.3
1970	164.49	145.60	-	310.09	5.09	4.86	-	4.98	837.2	708.0	-	1,545.2
1971	-	129.61	-	-	-	4.89	-	-	-	633.9	-	-
1972	167.54	124.48	-	292.02	3.79	6.32	-	4.87	635.0	786.8	-	1,421.8
1973	152.47	107.90	-	260.37	3.89	5.74	-	4.66	593.9	619.6	-	1,213.5
1974	134.00	100.85	-	234.85	3.98	5.08	-	4.45	533.7	512.3	-	1,046.0
1975	135.15	131.90	-	267.05	3.79	5.92	-	4.84	512.3	781.3	-	1,293.6
1976	102.23	110.47	-	212.70	3.82	5.08	-	4.47	390.3	561.2	-	951.5
1977	90.75	74.57	-	165.32	4.57	5.70	-	5.09	415.2	425.6	-	840.8
1978	175.16	131.02	-	306.18	5.08	5.91	-	5.44	890.4	774.8	-	1,665.2
1979	185.90	155.99	-	341.89	5.51	6.01	-	5.74	1,025.2	937.9	-	1,963.1
1980	177.58	207.76	-	385.34	6.15	6.95	-	6.58	1,092.6	1,443.6	-	2,536.2
1981	173.17	190.39	-	363.56	7.06	7.63	-	7.36	1,223.6	1,452.8	-	2,676.1
1982	167.27	175.17	-	342.44	8.07	8.02	-	8.04	1,349.3	1,404.8	-	2,754.1
1983	131.27	120.64	-	251.91	8.03	8.12	-	8.07	1,054.1	980.0	-	2,034.1
1984	127.07	94.00	-	221.07	10.81	7.70	-	9.49	1,373.7	723.5	-	2,097.2
1985	125.07	100.75	-	225.82	9.71	7.78	-	8.55	1,146.5	783.6	-	1,930.1
1986	148.79	134.15	15.33	298.27	10.20	9.06	10.66	9.71	1,518.2	1,215.0	163.4	2,896.6
1987	181.09	198.97	27.44	407.50	12.19	10.00	12.98	11.18	2,208.6	1,990.7	356.2	4,555.5
1988	187.53	211.21	28.93	427.67	11.71	8.36	13.61	10.19	2,195.9	1,766.5	393.7	4,356.1
1989	173.09	210.67	26.23	409.99	12.23	8.22	13.55	10.26	2,117.3	1,732.0	355.4	4,204.7
1990	174.40	219.37	24.17	417.94	12.27	8.83	12.79	10.50	2,140.6	1,937.6	309.2	4,387.4
1991	173.36	221.53	18.59	413.48	12.72	8.98	11.54	10.81	2,205.6	1,991.0	275.9	4,471.5
1992	-	213.32	19.17	-	-	9.92	12.55	-	-	2,120.7	305.9	-
1993	-	207.60	24.90	-	-	11.50	13.05	-	-	2,381.9	324.9	-
1994	-	234.80	-	-	-	12.30	-	-	-	2,889.4	-	-
1995	-	272.90	-	-	-	13.70	-	-	-	3,738.4	-	-
1996	-	288.90	-	-	-	13.70	-	-	-	3,873.7	-	-
1997	-	273.30	-	-	-	14.20	-	-	-	3,885.9	-	-
1998	-	260.50	-	-	-	14.20	-	-	-	3,701.6	-	-

[1] Hainan was part of Guangdong province before 1990.

[2] In Guangxi, production and yield calculated by multiplying data on dry slices by three.

Source: *B. Stone, 1987; Guangdong Statistics Bureau, 1971-1980; Guangxi Agric. Bureau, 1990-1994.*

2. Guangdong Province

Guangdong is the most developed province in China. Because of the low economic value of cassava, the crop has been gradually replaced by other crops, starting in the mid 1990s. Especially in the eastern coastal area there is now very little cassava grown. The cassava area and production in Guangdong province is gradually decreasing and is now mainly concentrated in the western part of the mountainous area, as well as in the coastal area in the south (Henry and Howeler, 1996).

Table 5. Cassava area, production and yield in districts and cities of Guangxi province of China from 1991 to 1998.

	Area ('000 ha)							
	1991	1992	1993	1994	1995	1996	1997	1998
Guangxi	**221.5**	**213.3**	**207.6**	**234.8**	**272.9**	**288.9**	**273.3**	**260.5**
Nanning city	13.3	12.4	14.1	16.3	22.7	23.4	22.7	20.6
Liuzhou city	6.0	4.9	4.6	4.6	4.5	4.7	3.7	2.8
Guilin city	3.2	3.1	2.8	3.0	3.1	3.3	3.7	3.4
Wuzhou city	3.9	3.8	3.5	3.5	4.0	4.0	30.2	28.9
Beihai city	6.7	7.7	8.5	9.1	10.8	11.7	9.7	9.4
Guigang city[1)]	-	-	-	-	-	17.4	16.2	16.0
Nanning district	34.2	31.9	34.9	36.2	41.1	40.9	37.9	32.6
Liuzhou district	28.3	26.7	25.0	23.6	25.3	27.9	24.2	22.2
Guilin district	8.2	7.6	7.7	9.1	10.2	11.1	11.4	11.6
Wuzhou district	34.2	34.5	34.5	35.1	38.7	41.4	-	-
Yulin district	38.8	37.1	37.7	45.4	43.0	26.1	26.1	25.8
Bose district	11.1	11.2	11.9	12.5	24.8	31.5	29.2	27.3
Hechi district	18.3	17.0	8.9	19.3	23.1	22.9	23.4	23.1
Qinzhou district	15.3	15.5	13.8	15.5	19.3	20.2	18.5	19.4
Hezhou district[2)]	-	-	-	-	-	-	14.7	14.6

	Production ('000 tonnes)							
	1991	1992	1993	1994	1995	1996	1997	1998
Guangxi	**1991.0**	**2120.7**	**2381.9**	**2889.4**	**3738.4**	**3873.7**	**3885.9**	**3701.6**
Nanning city	158.8	167.4	216.4	288.5	438.1	445.8	450.4	414.9
Liuzhou city	37.0	36.9	39.6	39.3	46.4	64.4	40.8	32.7
Guilin city	25.5	25.5	29.2	33.8	40.6	43.0	42.5	38.9
Wuzhou city	26.8	24.8	27.2	30.8	40.0	40.4	466.7	459.5
Beihai city	139.7	209.5	230.0	236.0	299.2	261.5	253.6	246.3
Guigang city[1)]	-	-	-	-	-	200.6	316.3	222.3
Nanning district	240.3	242.2	296.4	470.6	546.8	473.6	452.4	393.5
Liuzhou district	169.4	146.8	157.7	165.2	201.7	225.5	201.9	195.1
Guilin district	47.2	58.5	78.0	101.2	129.5	140.5	150.1	136.9
Wuzhou district	355.7	389.1	460.3	519.3	551.3	612.5	-	-
Yulin district	419.1	445.0	490.1	508.7	547.0	441.0	422.0	438.6
Bose district	94.5	100.7	125.0	135.0	333.5	381.3	370.4	366.0
Hechi district	123.0	107.0	70.3	154.4	233.1	229.6	239.2	247.6
Qinzhou district	154.0	167.4	161.7	201.3	301.0	257.2	257.2	285.1
Hezhou district[2)]	-	-	-	-	-	-	195.5	193.0

Table 5. (continued)

	Yield (t/ha)							
	1991	1992	1993	1994	1995	1996	1997	1998
Guangxi	**8.9**	**9.9**	**11.5**	**12.3**	**13.7**	**13.7**	**14.2**	**14.2**
Nanning city	11.9	13.5	15.3	17.7	19.3	19.1	19.8	20.2
Liuzhou city	6.1	7.5	8.6	8.6	10.3	13.8	10.9	11.5
Guilin city	7.9	8.2	10.5	11.3	13.1	10.0	12.8	11.5
Wuzhou city	6.8	6.5	7.8	8.8	10.0	10.0	15.5	15.3
Beihai city	20.7	27.2	27.1	25.9	27.7	22.3	26.0	26.2
Guigang city[1)]	-	-	-	-	-	11.5	19.6	13.9
Nanning district	7.1	7.6	8.5	13.0	13.3	11.6	11.9	12.1
Liuzhou district	6.0	5.5	6.5	7.0	8.7	8.1	8.3	8.8
Guilin district	5.9	7.7	10.1	11.1	12.8	12.6	13.2	11.8
Wuzhou district	10.4	11.3	13.3	14.8	14.3	14.8	-	-
Yulin district	10.8	12.0	13.0	11.2	12.7	16.9	16.2	17.0
Bose district	8.5	9.0	10.5	10.8	13.4	12.1	12.7	13.4
Hechi district	6.7	6.3	7.9	8.0	10.1	10.0	10.2	10.7
Qinzhou district	10.1	11.7	11.7	13.0	15.6	13.9	13.9	14.7
Hezhou district[2)]	-	-	-	-	-	-	13.3	13.2

[1)]Guigang city is a new city previously part of Yulin district
[2)]Hezhou district is a new district, previously part of Wuzhou district
Source: *Guangxi Statistics Bureau, 1994-2000.*

Cassava processing in Guangdong is the most developed in China, mainly because the equipment and the technologies they developed are more advanced, and their management is more modern than in other provinces. But because of the shortage of raw material, total production is now smaller than in Guangxi. Also, the development of cassava-based chemical products in Guangdong has fallen behind that of Guangxi province (**Table 3**). In 1997, production of cassava starch in Guangdong province was about 100,000 tonnes, that of modified starch 40,000 tonnes, and sweeteners 10,000 tonnes (**Table 6**).

Table 6. Annual production of cassava starch and starch-derived products (tonnes) in China in 1997.

	Total	MSG	Modified starch	Sweeteners	Alcohol	Sorbitol	Organic acids
Guangxi	385,000	25,400	30,000	2,000	50,000	25,000	20,450
Guangdong	100,000	NA	40,000	10,000	NA	NA	NA
Hainan	>30,000				10,000		
Yunnan	10,000				NA		

Source: *Guangxi Starch Association, 2000.*

3. Hainan Province

Hainan is the southern most province of China and is completely surrounded by sea. The natural conditions are very good for agricultural production, having a relatively high temperature and rainfall; soils are also more fertile as compared to other cassava producing provinces; so, it is the best area for cassava production in China. But, because Hainan is a much smaller province compared with Guangxi and Guangdong, the cassava area of 30,000 ha and production of about 450,000 tonnes of fresh roots are relatively small, even though the yield is high. Hainan province accounts for about 7.5% of cassava area and production in China.

Before the 1990s, Hainan was very undeveloped and was part of Guangdong province. Most of the cassava was used for farmers' food and for animal feeding. In the early 1990s, Hainan became a separate province and a special economic zone, resulting in a very rapid development of the economy as well as agricutural production. The living standard of farmers increased a lot and the yield and total production of cassava also increased. In the late 1990s, many starch factories were established and the total production capacity is now about 30,000 tonnes of starch.

4. Yunnan and Other Provinces.

Yunnan is a new cassava producing province, which means that only in the past five years cassava roots have been used commercially on a large scale. In the past, farmers, in the mountainous areas also grew cassava, but very scattered in many small areas, using the fresh roots mainly for food. Since 1995, they have imported a thousand tonnes of cassava planting material from Guangxi and have greatly expanded the cassava area, which is presently concentrated mainly in the middle and southern parts of the province, in Shimao and Honghe districts. Since then, several starch factories as well as alcohol factories have been established in these districts. Now, the annual cassava planting area and production are estimated to be about 25,000 ha and 400,000 tonnes, respectively (Yunnan Animal Husbandry Bureau, personal communication). The provincial government is now disseminating to farmers a new technology of using cassava leaves and roots for making silage to be used for animal feeding (Liu Jianpin and Zhuang Zhongtong, 2001). With this technology, some farmers living in the mountains prefer to plant cassava.

Beside these four provinces, some cassava is also grown in Guizhou, Shichuan, Jiangxi and Hunan provinces. The roots are mainly used for on-farm animal feeding. In some areas farmers like to plant sweet varieties, as the roots are used mainly for production of snack food.

CONSTRAINTS IN CASSAVA PRODUCTION AND PROCESSING IN CHINA

1. Production Aspects

a. Lack of an effective organization and management system for developing cassava production

Cassava is an important upland crop in southern China, and plays an important role in many rural areas. Even though the price and income are not very high, farmers still like to grow cassava, maybe because the soil is too poor to grow any other crops. Looking back at the history of cassava planting, we can see that even when the price was very low, farmers still keep a certain area of land for cassava. But, surprisingly, the government never paid any attention to cassava growing and processing; they did not show any interest in developing the cassava industry. Most considered that there was no need to use any inputs in cassava production as the crop is easy to grow and the economic value is low. They did not believe that the crop has a good potential, but requires some attention in order to develop. So, until now we have not yet developed a very successful working system, and the development of cassava is rather haphazard.

b. Lack of good varieties, poor management, low yield

Presently there are only 2-3 varieties farmers use in their fields, i.e. SC201, SC205 and SC124; these 2-3 varieties occupy about 99% of the total cassava area. Several new promising varieties developed by CATAS and GSCRI have not yet been extended over a large area. Also, some advanced cultural practices have not yet been adopted by farmers. Farmers are still not very concerned about obtaining high yields. Generally, the income of farmers from cassava is not high; therefore, farmers normally do not invest much in cassava production and don't care about the yield. In fact, for most farmers, cassava is not their main crop; they grow cassava only for feeding animals, but when the price is reasonably good, they sell to factories or to traders; otherwise, they use it themselves.

c. Serious soil erosion and decline in soil fertility

In China, cassava is mainly planted on hillsides while flat and fertile land is used for other kinds of economic crops, like fruit trees. Cassava grown on sloping land without proper cultural practices can cause very serious erosion problems. In China, farmers normally plant cassava from Feb to April. Soon after planting, the rainy season starts. As of May, rain water may wash out the top soil when the canopy of cassava has not yet covered the ground, so the soil's fertility decreases fast. At this moment, farmers don't realize this is a problem, and they do not take any measures to protect their soil from erosion. Experimental data indicate that soil losses due to erosion caused by cassava planting on a 15% slope without any erosion control practices may be ten times higher than those obtained with good management practices.

2. Processing Aspects

a. Confusing organization

There are about 200 cassava processing factories in China, and about 75% of these are in Guangxi province. Of all these cassava processing factories, more than 90% are small (with production capacity of less than 5000 tonnes/year). Some factories are owned by the central government, some by local governments and some by townships. Some factories are owned by the private sector, but they tend to be very small and very old; they work very independently.

b. Shortage of scientific and management talent

Up till now, scientists and skilled workers in the starch industry comprise less than 2% of the total staff, so the general level of competence of the staff is quite low. This is a main limitation for developing cassava processing.

c. Short processing period, high consumption of energy

In China, most factories process fresh cassava roots from the end of Oct to the end of Jan, only three months; from Jan to March they may use dry cassava chips, which results in lower efficiency and lower starch quality. Some factories operate even less then three months per year, use outdated equipment and have poor management. Hence, the production cost is very high and the products are not very competitive.

d. Shortage of funds and poor economic base

In many cases, the investment in fixed assets was too high, resulting in a high and long-term economic burden; this has affected the processing activity and profits. And, because profits are low, banks do not like to provide loans to so many small starch factories.

e. Serious pollution

As mentioned above, about 90% of the starch factories are small, they use poor equipment and have poor management. Their profits are very low and it is difficult for them to set aside money for resolving pollution problems. Several big processing factories have adopted some measures to reduce pollution, but the results do not seem as good as expected. The majority of factories are still causing heavy pollution when they process cassava roots.

FUTURE OPPORTUNITIES IN THE CHINESE CASSAVA MARKET

In 2000, total starch production in China is about 4,000,000 tonnes, 82% of which is maize starch, and about 12%, or 470,000 tonnes, is cassava starch (Guangxi Starch Assoc., 2000; Zhao Jixiang, 2000) (**Table 1**); this just meets the demand of several industries (**Table 7**). Actually, China imports a lot, more than 100,000 tonnes of cassava starch from Thailand, and dry chips from Vietnam for making starch.

Some of this starch is used for the production of modified starch, or other chemical products (**Tables 8** and **9**); the rest is used for other purposes, for example, for making noodles, enzyme products, etc. In the future, this demand will further increase in line with economic development and improvements in the people's living standards (**Table 10**).

Table 7. Annual production ('000 tonnes) of various starch-based products and their starch requirements in China in 2000.

	MSG	Sweeteners	Modified starch	Pharma-ceuticals	Noodles	Paper	Total
Production	520	400	200				
Starch requirement	1,400	400	200	800	800	400	4,000

Source: *Guangxi Starch Association, 2000.*

Table 8. Annual consumption of modified starch (tonnes) in China in 1997 and expected consumption in the year 2000.

	1997	%	2000*	%
Paper	80,000	38	400,000	58
Textile	55,000	26	80,000	11.5
Feed	50,000	24	100,000	14.5
Food	18,000	8.6	100,000	14.5
Others	5,000	3.4	10,000	1.5
Total	**208,000**	**100**	**690,000**	**100**

* includes imported starch.

Source: *Guangxi Starch Association, 2000.*

Table 9. Various cassava-derived products produced in Guangxi in 1997.

	Production (t)	% of national production	Remarks
Starch	385,000	72	of cassava starch
Alcohol	50,000	70	of cassava alcohol
Modified starch	30,000	15	includes maize modified starch
Sorbitol	25,000	24	includes maize modified starch
Sorbitol acid	450	60	
Citric acid	10,000	5.5	
MSG	25,400	4.5	
Acetic acid	10,000	2.0	

Source: *Guangxi Starch Association, 2000.*

Table 10. Potential future markets for starch in some industries in China.

	Production (tonnes/year)	Starch consumption (tonnes/year)
Citric acid	300,000	400,000
Modified starch	500,000	500,000
Candy	800,000	16,000
Feed	4,000,000	200,000
Bakery products	600,000	30,000-60,000
Pastry	1,000,000	50,000-100,000
Meat products	2,000,000	200,000
Plastic products	1,400,000	70,000
Enzyme products	140,000	
Total		**> 1,500,000**

Source: *Guangxi Starch Association, 2000.*

FUTURE PLAN OF CASSAVA PRODUCTION DEVELOPMENT IN GUANGXI

After a long disscusion and evaluation regarding the present situation and future potential of cassava, the Guangxi government has recognized that Guangxi has a comparative advantage for the development of cassava production, and that cassava-based industries have a bright future. But, how important this industry is in comparison to other industries is still not clear.

In 1997, the Guangxi government organized a working group of specialists to work out a future cassava development plan, to discuss, evaluate and compare the cassava situation both inside and outside the country. After almost three years, the plan is about finished (**Table 11**); it is the only such provincal development plan for cassava in China, as other cassava producing provinces have not yet made any similar plans.

This plan has gained the government's interest, and they have taken the first steps to implement the plan by making some initial investments in the dissemination of new cassava varieties, as well as in improving the processing equipment and technologies. To meet the various targets, there are many things that have to be done. For the government, shortage of money (funds) is the major problem. Hence, their strategy is to find any channels to raise money; they especially recommend that private enterprises invest in the industry. In other words, any measures and methods that will benefit the development are encouraged and supported.

In order to meet these targets, the following should be done first:

a. Adopt advanced technologies and equipment to improve the cassava processing efficiency and product quality

Compared with the past, the level of cassava processing in Guangxi province has improved a lot, but there is still a way to go compared with other countries. So, both better technologies and advanced equipment should be developed and adopted in order to improve the quality of the products and to reduce energy and water consumption; this will reduce the costs, increase the profit of the various products and improve their competitiveness.

b. Develop various products

There are many people with a lot of experience who have obtained good results in developing many types of cassava processing products in Guangxi. The advanced level of technologies developed in other parts of China can also be taken advantage of and utilized in further developing the industry.

c. Cassava processing factories need to be modernized and developed to a larger capacity

Presently, there are only 5-7 starch factories with a capacity of more than 10,000 t starch/year in Guangxi, while the remaining small ones have not been able to modernize and develop any further. The government has already initiated a policy to limit the setting up of small factories, and at the same time has encouraged the further development of the big ones; this is going to be the future trend.

d. Comprehensive utilization of resources, reduction of pollution and protection of the environment

In Guangxi, the annual production of cassava-based products is 350,000 tonnes; this is producing at least 10,500,000 tonnes of waste water. The appropriate disposal or

Table 11. Cassava production and processing parameter estimates in Guangxi province during the next 20 years.

	1997	2000	2005	2010	2020
1.Cassava planting area(‘000ha)	273	300	350	400	500
% of new high-yielding varieties	5	10	25	50	80
Yield (t/ha)	14.2	15	20	25	30
Total production (‘000t)	388	450	700	1000	1500
2.Starch					
production (’000t)	385	400	600	800	1200
water consumption (m^3/t starch)	40	35	30	25	20
coal consumption (t/t starch)	0.12	0.1	0.1	0.1	0.1
electricity consumption (KWH/t starch)	200	180	170	160	150
3.Alcohol					
production (‘000t)	50	100	300	600	1200
processing days (days/year)	75	100	200	250	300
4.Modified starch					
production (‘000t)	30	70	150	300	600
-for paper making		32	66	130	250
-for textile making		16	24	40	70
-for feed		10	20	40	60
-for food		10	30	70	150
-for other purposes		2	10	20	70
5.Sweeteners					
production (‘000t)	2	20	30	100	200
-fructose			15	50	100
-glucose-syrup			12	35	70
-others			3	15	30
6.Fermented products					
production (‘000t)			100	180	360
-MSG	25.4	26	40	50	80
-citric acid	10	12	20	50	100
-lactic acid		5	20	50	100
-others			20	30	80
7.Various chemical products					
production (’000t)		27	57	140	250
-sorbitol	25	25	30	55	100
-sorbic acid	0.45	2	10	20	40
-feed additive (lysine)			5	20	30
-hygroscopic agent			2	5	10
-others			10	40	70
8.Other chemical products					
production (‘000t)			320	640	960
-acetaldehyde			50	100	150
-ethylane oxide			50	100	150
-acetic acid			50	100	150
-ethyl acetate			50	100	150
-acetic acid			50	100	150
-butyl alcohol			50	100	150
-others			70	140	210

Source: *Guangxi Starch Assoc., 2000* utilization of this is a serious problem for the industry and could become a strong limitation for its future development. So ,we must spare no effort to try to reduce the pollution and protect the environment by a more comprehensive utilization of all resources and by-products.

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STATUS AND POTENTIALS OF THE PHILIPPINES CASSAVA INDUSTRY

Jose L. Bacusmo[1]

ABSTRACT

Cassava is planted each year in about 120,000 hectares of agricultural land in the Philippines, producing about 1.8 million tonnes of cassava roots. Principal products of the processing industry are food, dried chips and starch. As a traded commodity, however, cassava contributes only about 2% to gross value-adding in agriculture.

The following factors favor the expansion of the industry: a) trends in associated commodities, b) dwindling prime agricultural land, c) expanding demand for cassava products, and d) availability of improved technologies.

As a food crop, demand for cassava is increasing and this trend is expected to continue with the increase in population and improvements in techniques for transforming cassava roots into more stable, convenient and attractive products.

Cassava has gained gradual acceptance as a high-energy component in commercial feed formulations. This is fueled by chronic shortages and the resulting high price of domestically produced maize. In specific locations, farmers now recognize that intercropping cassava with maize and given optimum care, this cropping system is economically comparable to two maize monocrops, and provides a more reliable income.

The outlook for the cassava starch industry in the Philippines is rather bleak. Trade liberalization and the absence of real government assistance in improving productivity and efficiency are threatening the survival of this sector. The agricultural modernization program, which is supposed to cushion the impact of trade liberalization, virtually has had no funding during the first two years from its passage, and until now has not produced anything of practical significance.

With the negative outlook for the Philippine sugar industry, cassava emerged as the most viable alternative source of raw material for production of alcohol for liquor. San Miguel Corporation has been investing heavily on plant construction and supply base development since 1995. The greatest challenge in the future will be to put in place a system that results in an adequate and stable year-round supply of cassava for the distillery.

Strengthening the cassava industry in the Philippines requires strengthening the linkage between production and markets accompanied by improved access to credit, supportive government policies and appropriate technical support.

INTRODUCTION

The cassava industry in the Philippines is relatively small compared to that of Thailand, Indonesia and Vietnam. The industry is composed of three sectors representing the main uses of cassava in the Philippines, namely, food, dried chips for feed, and starch. Though most of the cassava in the Philippines is used for food, its use for starch processing appears to be the most important in the industry, as much of the commercial production and trading are associated with this sector. Dried cassava chips for the feed sector is new, small and more localized compared to the other sectors.

The insignificance of the cassava industry in the Philippines is not surprising, as the crop itself is accorded only minimal development support by the government. Agricultural programs in the Philippines have for decades been focused primarily on rice and maize. The development of the cassava industry has primarily been private sector-led. Even

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though the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) has continually, for more than two decades, supported research on root crops, the support for technology transfer has been very limited. Many of the developed technologies have not yet reached their intended beneficiaries.

In spite of the lack of development support, cassava is among the top ten crops in terms of producing carbohydrate per unit area per unit time. Broad adaptability of the crop makes it an important component in cropping systems in newly opened forest areas and in farms with highly degraded soils.

The crop has a strong economic relationship with resource-constrained farmers situated in forest margins and marginal lands. Hence, any development in cassava will have an implication on food security, poverty alleviation, and on the protection and utilization of marginal lands in the Philippines that at present contribute very little to agriculture.

Some developments appear to favor the expansion of the cassava industry of the Philippines. These include:

1. Trends in associated commodities
   - Maize production has always lagged behind the growth of the livestock industry.
   - Maize production will be short of demand by at least 1 million tonnes each year.
   - The outlook of the domestic sugar industry is unstable.
   - Areas devoted to rice are decreasing and there is slow improvement in irrigation facilities.
2. Dwindling access to prime agricultural areas
   - Annually around 8,000 ha of agricultural land are converted to other uses.
   - Agriculture will increasingly be pushed to less favorable areas.
   - Crops tolerant to adverse agro-climatic conditions will become more important.
3. Expanding markets
   - Resistance to use of cassava as a replacement of maize has weakened.
   - Prospects for investments in other uses of cassava have improved.
4. Improved technologies
   - A pool of technologies and information for pushing cassava productivity higher is available.

PRESENT STATUS

Production

Cassava is the most widely grown of the root crops in the Philippines. The area planted to cassava expanded rapidly during the 1970s, but has remained fairly constant during the 1980s and 90s (**Figure 1)**. Production and yield reached a peak in 1978, after which both declined in the early 80s and stabilized in the 1990s. Presently, about 210,000 to 225,000 ha are planted to cassava annually (**Table 1**). The average volume of production during the past ten years is close to 2.0 million tonnes. Of this volume, it is estimated that 75% is utilized for food, 20% for starch processing and 5% for feed (estimates based on data about starch production and trade of dried chips).

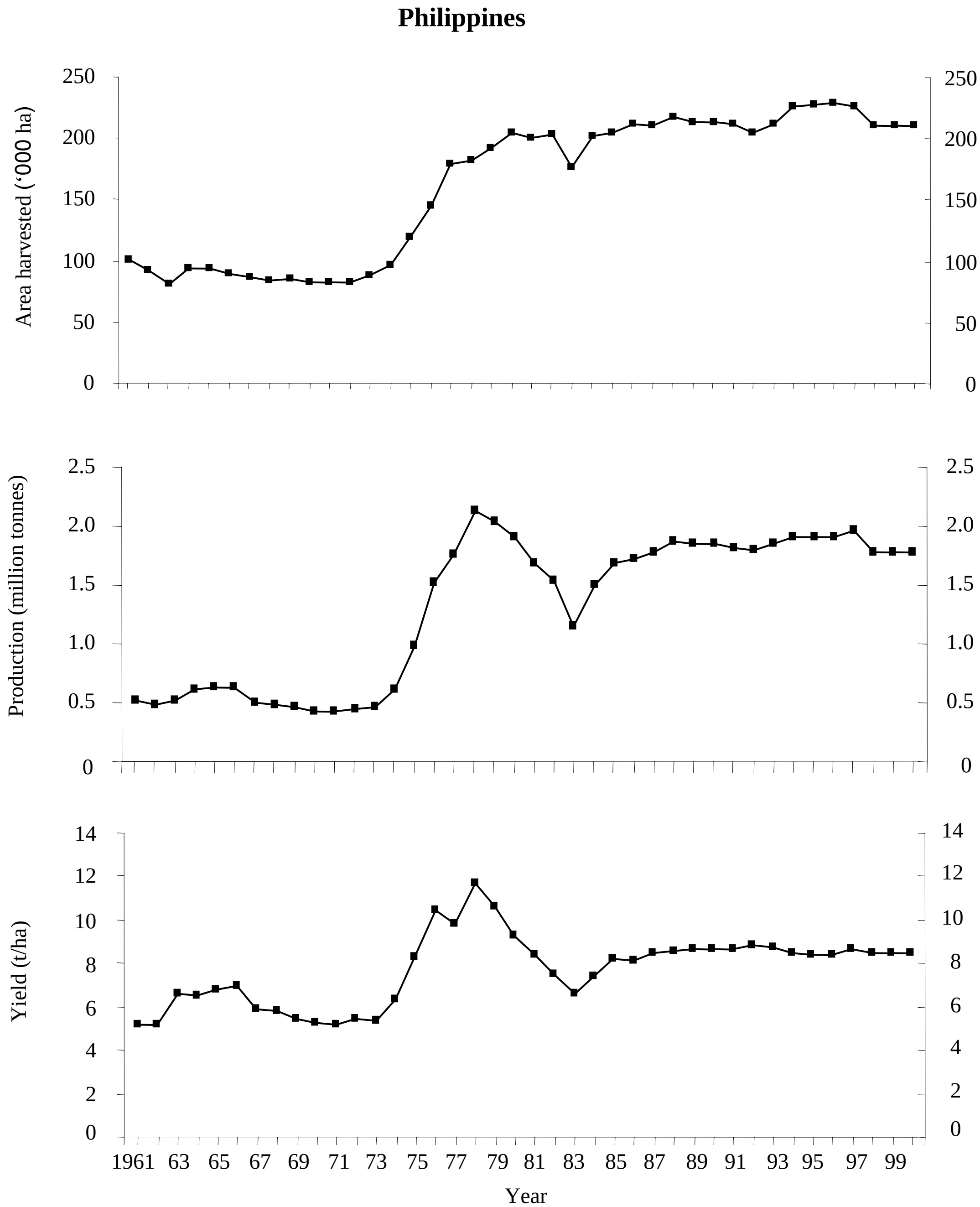

Figure 1. Trend in cassava harvested area, production and yield in the Philippines from 1961 to 2000.
Source: *FAOSTAT, 2001*

Table 1. Area and production of cassava in the Philippines (1990-1999).

Year	Area planted (ha)	Production ('000 t)	Yield (t/ha)
1990	213,653	1,853	8.67
1991	210,908	1,815	8.61
1992	204,175	1,784	8.74
1993	211,263	1,843	8.37
1994	212,877	1,890	8.88
1995	225,751	1,906	8.44
1996	228,343	1,911	8.37
1997	230,522	1,958	8.49
1998	215,263	1,734	8.05
1999	221,618	1,794	8.09

Source: *Bureau of Agric. Statistics (BAS), 2000.*

Although cassava is grown extensively in the Philippines, it is mostly grown in small patches for subsistence. There are, however, areas in the country where cassava is grown as a cash crop and on a commercial scale. These areas include Bukidnon, Lanao del Sur and Negros Occidental. **Table 2** shows that the principal cassava growing areas are located in Mindanao, which accounts for 59% of the area and 71% of production in the Philippines; of this, the Autonomous Region of Muslim Mindanao (ARMM), which comprises Lanao del Sur, Maguidanao, Sulu and Tawi-Tawi provinces, is by far the most important region. **Table 2** also shows that during the past ten years cassava production has shifted from Bicol and the Visayas towards the Mindanao region, especially to Western Mindanao and ARMM.

Cassava is generally grown with minimal inputs and care, and this is reflected in the low national average yield of about 8.0 t/ha – one of the lowest yields in southeast Asia. However, in areas where cassava is grown for starch and dried chips, the average yield is about 20 t/ha. The improvement in yield is mainly due to adoption of high-yielding varieties and slightly better cultural practices.

Cassava for Food

As in most Asian countries, rice is the principal and preferred food in the Philippines. In some islands in the Visayas and Mindanao, where narrow coastal plains provide little opportunity to grow cereals, people largely subsist on root crops including cassava. Cassava figures largely in the diet of the Muslim population in Lanao del Sur, Lanao del Norte and Cotabato. Highest per capita consumption of cassava in the Philippines is in the islands situated in the Sulu Archipelago (south of Mindanao) where cassava is the staple food.

Table 2. Cassava area, production and yield in the various regions of the Philippines in 1990 and 1999.

Region	Area (ha) 1990	Area (ha) 1999	Production ('000 t) 1990	Production ('000 t) 1999	Yield (t/ha) 1990	Yield (t/ha) 1999
Philippines	**213,653**	**221,618**	**1,853.38**	**1,793.59**	**8.67**	**8.09**
1. CAR	276	134	2.36	1.92	8.56	14.33
2. Ilocos Region	1,806	1,944	10.73	13.95	5.94	7.18
3. Cagayan Valley	436	2,268	1.42	17.90	3.26	7.89
4. Central Luzon	1,247	1,027	7.99	7.65	6.41	7.45
5. Southern Tagolog	10,241	11,031	63.04	66.64	6.16	6.04
6. Bicol	32,113	30,548	263.03	189.73	8.19	6.21
7. Western Visayas	9,895	6,048	50.77	50.82	5.13	8.40
8. Central Visayas	20,405	16,322	167.46	115.14	8.21	7.05
9. Eastern Visayas	26,839	22,146	97.88	59.46	3.65	2.68
10. Western Mindanao	22,308	24,339	218.80	235.98	9.81	9.69
11. Northern Mindanao	9,499	8,053	92.20	81.68	9.71	10.14
12. Southern Mindanao	3,874	2,292	33.17	15.71	8.56	6.85
13. Central Mindanao	1,856	1,115	13.19	7.86	7.11	7.05
14. Caraga	9,855	5,545	38.18	38.66	3.87	6.97
15 ARMM	63,003	88,806	793.18	890.47	12.59	10.03

Source: *Bureau of Agric. Statistics (BAS), 2000.*

In many rural communities, root crops are eaten or sold as boiled roots and processed products such as fried chips, cakes and sweet porridge. Shoots of cassava are also a favorite vegetable among Filipino Muslims.

Some new products from cassava, such as choco-roll, piloted by the Philippine Root Crops Research and Training Center (PhilRootcrops), are successfully getting into the markets. Increased demand and consumption of root crops in transformed forms have been demonstrated in these pilot projects. However, much has still to be learnt in pushing these products to the market. Noticeable increases in the use of cassava in both urban and rural areas have been processing into cassava cakes and *cutsinta*. Both are local preparations that have gained wide acceptance and a good market, and commercialization of these two products is evident in both rural and urban areas.

Cassava for Animal Feed

The dried cassava chips sector of the industry is relatively young and small. The sector is centered in the northern corridor of Mindanao. This includes the provinces of Misamis Occidental, part of Zamboanga del Norte, Misamis Oriental and Bukidnon.

The developments of cassava and maize in these areas are highly interrelated. Farmers' decision to grow maize or cassava is influenced by the relative prices of maize grain and cassava chips. When the buying price of maize is high, it is easier to sell cassava chips/meal to the feed miller, but it will be difficult to convince farmers to grow cassava instead of maize. Conversely, when the price of maize is low, it is difficult to trade cassava chips/meal, but more farmers will shift from planting maize to planting cassava. Clearly, any discussion on the status and potential of cassava for feeds will invariably include a presentation on the status of maize in the Philippines.

1. Status of maize in the Philippines

Total maize utilization in the Philippines has been increasing from 1980 to 1996. Contributing mainly to the trend is the continuous increase in the volume of maize used for animal feeds, resulting from increased demand from the livestock sectors (**Figures 2** and **3**). The pig sector grew by about 2.5% and the broiler sector expanded by about 6% per year from 1990 to 1997. Such growth has not been matched by the domestic maize sector through area expansion and/or yield improvement. Ironically, the maize area in the Philippines has declined since 1991 by about 2.7 million hectares. Overall productivity of maize in the Philippines has improved and is still improving. Total maize production generally increased from 1980 to 1990 but declined slightly from 1991 to 1996. This decline is attributed mainly to the shifting of areas under maize to other crops.

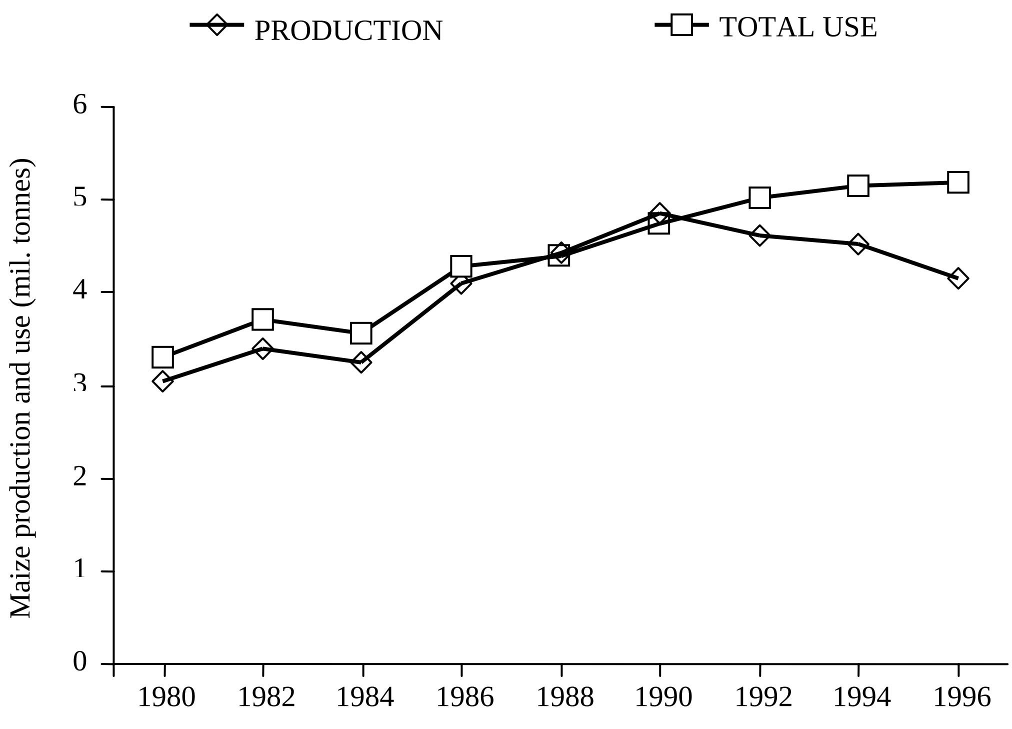

Figure 2. Maize: production and use estimates in the Philippines, 1980-1996.
Source: *Bureau of Agric. Statistics (BAS), 1997.*

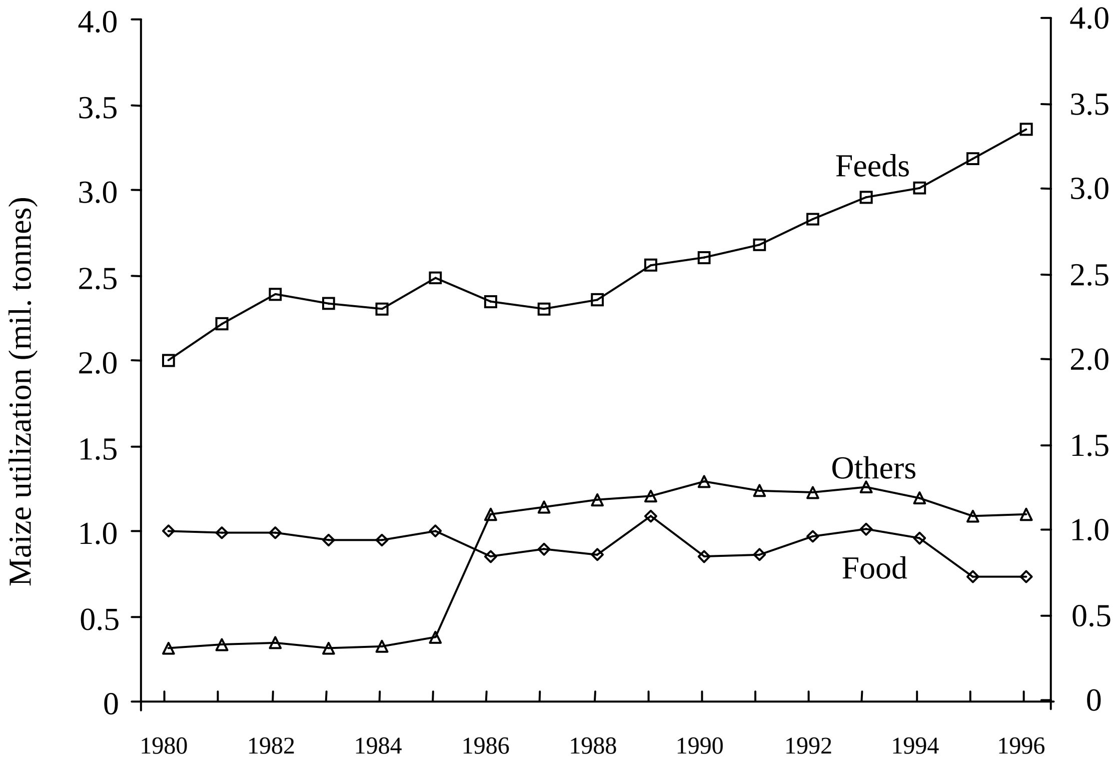

Figure 3. Use estimates of maize in the Philippines, 1980-1996.
Source: *Bureau of Agric. Statistics (BAS), 1997.*

The volume of maize used for various feeds accounts for about 61% of total production, food for 30% and other uses 9% (**Figure 4**). The maize deficit has widened in 1996 to 1.03 million tonnes, and since then has not dropped below one million tonnes per year. This supply shortfall is further aggravated by climatic factors. In 1998, the production of maize decreased from 4.33 to 3.70 million tonnes, resulting in a shortfall of 1.70 million tonnes. These supply shortfalls for years have been solved largely through importation of maize, and to some extent through the use of other more available feed ingredients including dried cassava chips.

2. Cassava dried chips production and trading

Trading of dried cassava chips in the Philippines was non-existent in the 1980s even when dried cassava chips had become a major export commodity for Thailand and Indonesia. After a long drought at the end of the 1980s, and a favorable export price, together with an unfilled common quota of GATT member countries, three companies (Capicor, Guani Marketing and San Miguel Corporation) started campaigning for the massive planting of cassava in northern Mindanao, by buying and exporting dried cassava

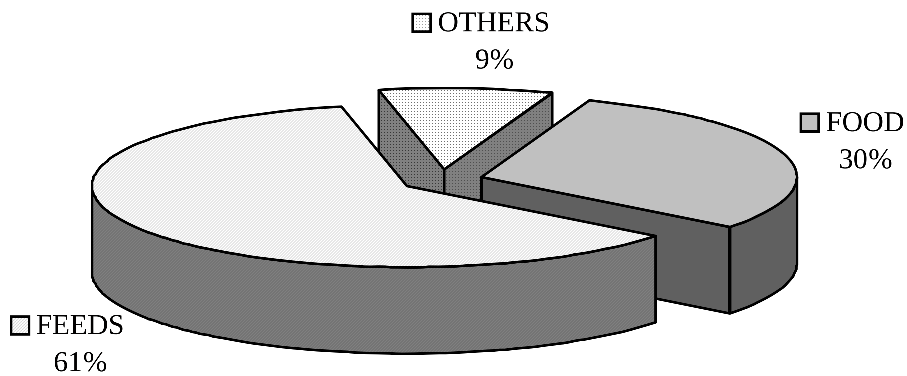

Figure 4. Average relative shares of maize utilization in the Philippines, 1980-1996.
***Source:** Bureau of Agric. Statistics (BAS), 1997.*

chips. A subsequent drop in export price caused widespread losses to growers, and the virtual death of a budding trade. Widespread cassava planting in the area was restored only recently in connection with a supply base development by San Miguel Corporation (SMC) and its subsidiary for feeds and alcohol.

In the 1980s, PhilRootcrops campaigned for the use of cassava meal in feed formulations, especially for pigs, as data from PhilRootcrops have indicated comparable weight gains of animals even with a complete shift from maize to cassava as the energy source. The effort gained lukewarm response. Problems in quality of chips and reliability of supply were raised by feed millers and were overemphasized. In the past three years, however, resistance to the use of cassava in feeds has gradually declined, and some major commercial feed brands in the country are now using cassava meal though at a lower proportion to maize than recommended. **Table 3** shows an increase in the volume of cassava dried chips traded in the Mindanao northern corridor area since 1990. The sharp increase in the volume of dried chips in 1992 and 1993 was due to a long drought in 1989 and 1990 as well as a favorable export market. The 1997-1999 surge in dried chips volume has more significant implication as these chips were utilized locally for feeds. This gradual acceptance of cassava in feed formulation can be explained by the widening deficit in yellow maize since 1991, as is shown in **Figure 2**. It is estimated that on the average 40,000 tonnes of dried cassava chips are traded annually for domestic feed formulations. This does not take into account cassava roots used as feed for on-farm livestock feeding. Although small compared to the traded volumes in the main cassava-producing countries in

Asia, the trend already represents a significant improvement over the situation in the 1980s in the Philippines.

Table 3. Estimated area of cassava harvested for dried cassava chips in the northern Mindanao corridor in the Philippines, and the volume of cassava chips traded from 1990 to 1999.

Year	Area harvested ('000 ha)	Traded volume ('000 tonnes)
1990	0.50	8.5
1991	0.80	17.5
1992	3.00	30.5
1993	8.00	60.8
1994	0.50	4.4
1995	0.40	3.0
1996	0.50	3.8
1997	3.00	16.0
1998	2.00	14.0
1999	3.00	25.0

Source: *J.L. Bacusmo (unpublished data).*

The use of cassava in feeds has been a clearly growing sector of the cassava industry in the Philippines. In the absence of policies that overly favor the development of cereals, cassava has shown that it is competitive with domestic maize in terms of returns and reliability of harvest. One problem with cassava is its long cropping duration. Cash-strapped growers have difficulties in sustaining their families between planting and harvest of cassava. Maize and some other crops have the advantage of being short duration crops; hence, cash flow is better. One cropping system that addresses this and is now widely practiced in Bukidnon and Misamis Oriental is the intercropping of maize with cassava. Briefly, the system involves planting maize first and then planting cassava 20 to 30 days later between the rows of maize or between every other maize row. Maize is harvested four months later, while cassava is harvested 10-12 months after planting. This practice not only offers better cash flow and returns (over cassava monocrop) to farmer (**Table 4**), it also cuts down significantly the risk of failure in cropping maize (due to pests and diseases) in the second cropping season.

Table 4. Comparative expenses and income per hectare of maize, cassava and maize-cassava intercropping.

	Cassava	Maize	Maize-cassava intercropping
Production costs (Philpesos/ha)			
Land preparation	3,225	3,225	3,225
Planting materials	1,000	1,400	2,600
Fertilizer/Chemicals	2,150	4,000	5,100
Labor			
-Planting	750	400	900
-Fert./chem. application	200	700	700
-Weeding	1,500	1,500	3,000
-Cultivation	650	800	800
-Harvesting	3,000	1,800	4,500
-Chipping	2,500	-	2,225
-Shelling and drying	-	4,000	3,600
-Drying (chips)	2,000	-	1,780
-Handling	2,000	1,200	2,880
-Sacks	800	800	800
Total	19,775	19,825	32,110
Production (tonnes)			
Maize grains	-	4.5	4.0
Cassava chips	10.0	-	8.0
Selling price (per tonne)	2,500	6,000	6,000/2,500
Gross income (P/ha)	25,000	27,000	44,000
Net Income (P/ha)	5,225	7,175 x 2 =14,350	11,890

Source: *Bacusmo, 1999.*

3. Problems

3.1 Lack of efficient mechanical dryers for cassava chips

This is the most important constraint in the expansion and quality improvement of dried cassava chips in the Philippines. Drying is critical as this has implications on quality and stability of the product. Fresh cassava roots contain roughly 65% water. Removing this will require a high amount of energy and time as drying at high temperatures causes gelatinization and subsequent "locking" of moisture in the chips. The problem therefore goes beyond simple drying, but encompasses drying the chips at an acceptable cost. The San Miguel Corporation has commissioned a number of dryer fabricators and engineers to provide mechanical dryers that can dry cassava at a drying cost of US $ 8/tonne of fresh chips. The average cost attained from various dryer designs was US $ 3/tonne of fresh chips. The lowest drying cost attained from various drying designs was US $ 20/tonne – roughly twice the acceptable drying cost.

3.2 Maize importation

The propensity to import maize as the immediate solution, instead of encouraging use of other domestic feed ingredients, contributes to difficulties in promoting a locally produced alternative to maize as a feed ingredient. Ironically, from 1996 to 1998, the Philippines imported not only maize but also 20,000 to 30,000 tonnes of cassava chips. Minimum Access Volume for maize (import volume slapped with a lower tariff) is determined without considering other locally available feed ingredients such as cassava chips. This does not bode well in developing domestic self-sufficiency in feed ingredients for the growing livestock industry.

3.3 Limited access to credit and rampant "pole-vaulting"

Many growers complain that they cannot grow cassava profitably because they do not have cash reserves (that can be tied up for 8-10 months) for the purchase of necessary inputs for the adoption of recommended agronomic practices for cassava. This makes the constraint to higher productivity a socio-economic rather than a technical problem. Credit or production support for cassava would enable farmers to improve their management practices in growing cassava and hence increase production per unit area. However, cassava is not usually included in the list of crops that banks are willing to support. Among the reasons for this is a track record of irresponsible application of production loans and the rampant practice of "pole-vaulting" by cassava growers. "Pole-vaulting" refers to the practice of evading payment of production loans by selling the cassava produce to buyers other than the one agreed upon by both growers and the bank. The buyer appointed by the bank is supposed to collect payments for production loans from the proceeds of sales of the delivered produce.

Cassava for Starch

Cassava is the primary raw material for the manufacture of starch in the Philippines. Due to its higher availability, most food manufacturers favor the use of maize starch; hence, about 70% of starch consumption in the Philippines is that of maize starch.

In 1997, there were ten cassava starch mills operating in the country (**Figure 5**) with a combined annual capacity of 200,000 tonnes of starch. Except for two mills in the Visayas, cassava starch mills are concentrated in Mindanao. Demand for starch tends to follow the trend of the country's economy. The economic upturn in the middle of the 1990s increased the use of starch for food, plywood, packaging products and textiles. Use of root crops in the manufacture of starch is projected to remain fairly high with improvement in the economy.

CASSAVA STARCH MILLS IN THE PHILIPPINES

1. Universal Starch Industrial Corporation, Kabankalan, Negros Occidental
2. Philippine Starch Industrial Corporation, Carmen, Bohol
3. Phil-Agro Industrial Corporation, Baungon, Bukidnon
4. Aznar Agro Industrial Corporation, Baungon, Bukidnon
5. Matling Industrial and Commercial Corporation, Malabang, Lanao del Sur
6. Lobregat Family Milling Corporation, Balabagan, Lanao del Sur
7. Purakan Plantation, Inc., Malabang, Lanao del Sur
8. ITIL Plantation Inc., Balabagan, Lanao del Sur
9. Philippine Trade Center, Cotabato City
10. Pacific Starch Corporation, Midsayap, North Cotabato

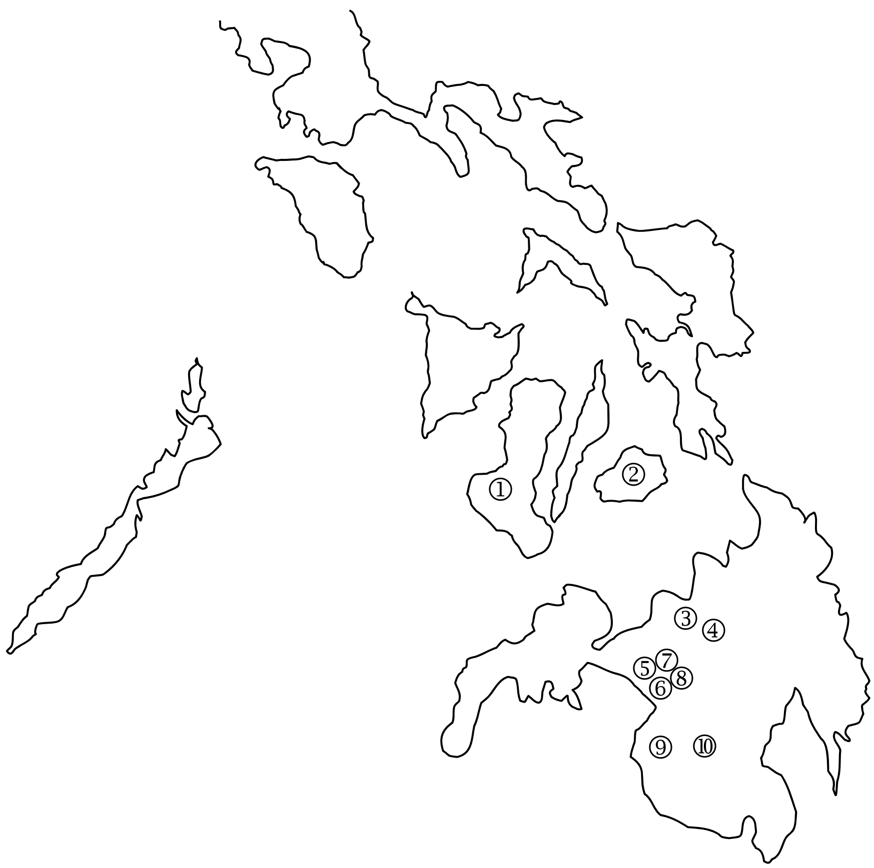

Figure 5. Distribution of cassava starch factories in the Philippines in 1997.

1. Problems

Starch manufacturing in the country is beset with structural, infrastructure and socio-economic problems that include:

1.1 Trade Liberalization and Philippine cassava starch milling

The biggest problem faced now by cassava starch mills in the Philippines is the accelerated reduction of import duties for cassava starch. Philippines being a member of the ASEAN and committed to AFTA is reducing tariffs for cassava products at an average rate of 5% per year. This situation has caused a deluge of imported cassava starch in recent years, and has led to the closure of two starch mills. **Table 5** shows the tariff rate, domestic production and import volume of cassava since 1993. Clearly, the volume of cassava imports increased significantly when the tariff went below the 30% level. Most of these imports come from Thailand, Indonesia and Vietnam, and are declared under Tariff Heading No. 3809.91.00; hence, they fall under the classification of Industrial Starch with only 3% duty.

Table 5. Tariff rates, import volume and production of cassava starch in the Philippines (1993-2000).

Year	Rate of duty (%)	Import volume (in 50-kg bags)	Domestic production (in 50-kg bags)
1993	40	2,470	978,802
1994	35	370	916,445
1995	30	15,102	606,950
1996	25	16,834	574,292
1997	20	not available	437,500
1998	20	not available	409,868
1999	15	520,000	1,232,500
2000	10	not available	not available

Source: *Cassava Growers and Millers Association, 1999. (personal communication)*

1.2 Old and inefficient machinery

Most of the mills have not kept up with technological change. A few plants are hardly fit for operation, having pre-war components resulting in low processing capacity and high production costs.

1.3 Security problem

Most of the mills are situated in the Lanao del Sur area where insecurity is a serious problem. To ensure continuity of operation, mills in this area commit high expenses to security.

THE FUTURE

Cassava for Food, Feed and Starch

Cassava will play a more important role in the diet of more Filipinos in the future in the light of an increasing population and the dwindling availability of agricultural land. Although a large proportion of the daily caloric requirement of the Filipinos still comes from rice, it is doubtful whether the existing rice fields in the Philippines can provide the necessary production. In spite of this clear gap between demand and production, it is unlikely that there will be a significant shift in the choice of the food staple. Rice will still be the preferred staple and future deficits will be addressed through inter-regional trade. In terms of proportion to total production, the use of cassava for food by Filipinos may decline with increased access to a variety of foods in more convenient forms – easy to prepare and to preserve. Increased attention should therefore be given towards transforming cassava into more elaborate and convenient forms, and to extend the shelf life of fresh roots in order for cassava to remain a major food source in a growing economy characterized by rapid urbanization.

Starch use will continue to increase. Innovations on properties and uses of starch should increase future demand. Potential use of starch for the production of high fructose sugar and other sweeteners is not too far-fetched, considering the unstable outlook of the sugar industry in the Philippines. This, however, is by no means a guarantee to the survival of the domestic cassava starch sector. Most of the starch requirements in the country can be filled by use of other starches. Zero tariffs coupled with high transport cost from the south to Manila, not to mention other problems that beset the cassava starch sector, is enough to confer better competitiveness of imported starch over that of locally produced cassava starch. Will this domestic starch-manufacturing sector be able to attain competitiveness before it totally collapses?

Use of dried cassava chips is expected to continue growing. Maize production is not expected to improve significantly in the next five years. The irrigation program of the government is at a virtual standstill, and farmers are abandoning the growing of maize. Crop failure due to pests and diseases coupled with large losses due to inadequate postharvest facilities are simply too much for the maize growers. Moreover, after long periods of drought, many farmers shift to growing cassava as money intended for growing maize may have been spent to tide the family over the long drought. Drought followed by heavy rains (La Niña) also means higher pest and disease pressure for maize, thus pushing the farmers to grow other crops such as cassava.

Cassava for Alcohol

Fervent expectations for growth in the cassava industry of the Philippines are anchored on the successful development of cassava as an alternative raw material of liquor alcohol production. With the unstable production of sugar in the Philippines, SMC has turned to cassava as an alternative raw material for alcohol. The company decided to install an additional distillation column that can take cassava or molasses as raw materials. The objective is to supply 25% of the total alcohol requirement of its subsidiary La Tondeña Distillers Inc. from cassava. Annual requirements of this plant are 180,000 tonnes of dried cassava chips, which would roughly need 25,000 ha of cassava to produce. This entails big investment for infrastructure and supply base development, but will partly shield and prepare the company from the negative impact that may develop from the unstable sugar industry, hence unstable molasses supply.

1. Status of Philippine Sugar/Molasses

The Philippines used to be one of the biggest sugar-producing countries and the top exporter of sugar in Asia in the 1950s and 1960s. Though still considered among the main Asian sugar producers, the Philippines has become a net importer of sugar (**Table 6**). Recent data indicate that the Philippine production is already below domestic consumption, and the years of high levels of protection, control and encouraging sugarcane growing under unsuitable agro-climatic conditions have made the industry inefficient. The industry is surviving mainly from a "distorted" domestic price and access to the U.S. market as a tariff-free export. Under freer trade, however, it is unlikely that the Philippines will be able to compete with Thailand, India and Australia, nor the low-cost cane sugar industries in Latin America and Africa.

It is most likely that benefits from high domestic price and preferential access to the U.S. for sugar accrue largely to traders while benefits to producers are limited. Many growers in the Philippines suffered losses, and many have given up growing sugarcane in the latter part of the 1990s.

Table 6. Asian sugar economy balances (tonnes raw sugar) in 1999.

	Production	Imports	Exports	Consumption
Net exporters				
India	15.8	0.3	0.5	15.7
Thailand	5.5	0.0	3.7	1.6
Net importers				
China	7.7	1.1	0.6	8.4
Pakistan	3.0	0.3	0.2	3.1
Indonesia	2.1	1.0	0.0	3.1
Japan	0.8	1.6	0.0	2.4
Philippines	***1.8***	***0.4***	***0.2***	***1.9***
Malaysia	0.1	1.2	0.1	1.1
South Korea	0.0	1.4	0.3	0.9

Source: *USDA, May 1999 Sugar Market Report (cited in Young et al., 1999).*

2. Why cassava as an alternative to molasses?

Any sugar or starch-containing crop can be processed into alcohol. Hence, in the case of an inadequate supply of molasses, many crops can be used as alternative raw materials for alcohol. The decision of SMC in the Philippines to develop cassava as the alternative raw material for alcohol production has several considerations. Cassava is cheap and available locally. There are reasons to believe that the productivity of cassava can still be improved significantly. Moreover, the supply of cassava complements well the annual supply trend of molasses in the Philippines.

In terms of alcohol yield, a tonne of dried cassava chips can give 420-460 liters of alcohol. This compares well with local molasses that produce 280-295 liters of alcohol per tonne (**Table 7**), and especially with imported molasses, which have less sugar content due to improved efficiencies in sugar extraction by sugar mills in other countries. Cassava, however, requires additional steps in processing, and has to be converted into a stable form (dried chips) to attain flexibility in scheduling of use.

Table 7. Parity price of molasses and dried cassava chips at various levels of alcohol cost.

Price of molasses (in pesos/tonne)	Equivalent alcohol cost (in pesos/liter)	Dried cassava chip buying price (in pesos/tonne)
1,475	5.00	1,365
1,549	5.25	1,470
1,622	5.50	1,575
1,696	5.75	1,680
1,770	6.00	1,785
1,844	6.25	1,890
1,918	6.50	1,995
1,991	6.75	2,100
2,065	7.00	2,205
2,139	7.25	2,310
2,212	7.50	2,415
2,286	7.75	2,520
2,360	8.00	2,625

Assumptions:

Alcohol yield from molasses	295 l/t
Alcohol yield from dried cassava chips	420 l/t
Additional processing costs using chips	1.75 pesos/l

Source: *J.L. Bacusmo (based on SMC estimates).*

3. Development of a supply base

Developing cassava for alcohol production requires the development of a supply base. It was determined that the most flexible format of using cassava as a raw material is in the form of dried chips. The distillery is understandably strategically located near sugarcane farms and mills, but far from the cassava production base. Drying cassava chips will stabilize the produce and allow warehousing, thus gaining flexibility in schedule of use.

In 1996, supply base development for this purpose was initiated in Mindanao. About 5,000 ha of new cassava plantings were developed through a contract growing scheme. By 1997, however, the construction of the new distillation column that can take cassava chips as raw material was not completed. Production from these plantings went to produce animal feeds in 1997 and 1998. Subsequently, the price went down to as low as 1.50 pesos/kg (US $ 0.04/kg).

A number of problems and restrictions surfaced from the experience. Variety choice for example was limited to varieties with low HCN content. Technically, it does not matter since HCN can be removed during processing, but in the beverage business market perception is important and must be protected. On the production side, inadequate supply and the slow multiplication rate of planting materials hindered area expansion, while, on the primary processing side, drying remains the main problem.

4. System development: the main challenge

Developing a functional system of providing the distillery with cassava at a competitive price of an acceptable quality and reliably at the time when needed is the component that should firmly establish cassava as a viable alternative to molasses in the Philippines. Product format (dried chips) and the constraint in drying make cassava supply highly seasonal, hence, threatening reliability and requiring high warehousing and inventory costs. Supply-base sites and product format are being reconsidered to attain the basic features the system must have. Among the considerations is the culture of prospective growers. Sugarcane growers, for example, are not burdened with the processing of sugarcane. They simply deliver their sugarcane to the mill and the rest is a well-established system of sugar extraction, warehousing, trading and payment without the growers' participation. If the objective is to convince these growers (sugarcane growers in less favorable farms) to shift from sugarcane to cassava, decentralized chipping may be a bad approach.

Cassava Research Challenges

To exploit the full potential of cassava, the development framework should include moving cassava to more favorable environments. However, pressure for land will eventually push cassava and other crops into the more fragile ecosystems. In the Philippines, the area covered with natural grasslands (usually highly acidic uplands) is now estimated to be around 10.0 million ha, or equivalent to a third of the agricultural land in the country. This is the most likely area where cassava will be growing in the future. The challenge of research in the next decade is to develop cassava varieties that are adapted/tolerant to highly acidic and infertile uplands, and to develop a package of recommended practices for cassava in this fragile ecosystem that results in high productivity while maintaining soil productivity.

Another important challenge is the development of efficient mechanical dryers for cassava. Research towards developing new products from starch is also important as this will open up new markets.

CONCLUSIONS

1. Improving the cassava industry of the Philippines requires expansion of market opportunities, efficiency in production and processing, adequate support services and favorable government policies.
2. The cassava industry of the Philippines is at a crucial point. The starch sector of the industry is adversely affected by trade liberalization and could totally collapse in the absence of supportive government policies and programs directed towards enhancing efficiency and solving social and structural problems that beset the sector.
3. Increased use of cassava for feeds is expected to continue. Strong advocacy specifically on tariff rates and importation procedures for maize and other feedstuffs is necessary to sustain and enhance the increased acceptance and use of cassava for feeds.
4. The Philippine cassava industry can grow significantly if the attempt by SMC to use cassava as an alternative raw material for liquor alcohol production proves viable. This hinges on putting in place a system that will sufficiently meet the requirements of price, quality and reliability of supply of the raw material.
5. Pressure on land will increasingly push cassava into more fragile ecosystems. Attaining high productivity from cassava under such an environment is difficult considering that resources to support yield increases are limited. The most important challenge for cassava research in the Philippines, therefore, are the development of cassava varieties adapted to the grasslands/acidic and infertile areas, as well as the development of recommended cultural practices for cassava in these areas that addresses productivity and soil conservation.

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PRESENT SITUATION AND FUTURE POTENTIAL OF CASSAVA IN MALAYSIA

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ABSTRACT

In Malaysia, the processing of sago starch predates that of cassava, having been established before 1416. With its introduction, cassava, which is a much shorter term crop, quickly replaced sago palm as the preferred raw material among starch processors. Hence, except for a small amount serving the fresh food market, cassava is planted in Malaysia mainly for starch processing. The cassava area in Peninsular Malaysia has declined steadily to 1,631 ha in 1997 after peaking in 1976 at 20,913 ha. This decline is due to the curbing of illegal cultivation; land alienation policy with a bias against cassava; switching from cassava to more lucrative crops; rising costs of production; low prevailing price for cassava roots; and competition for land for agricultural and non-agricultural activities during the economic boom prior to July 1997. Of the eight starch factories reported in Perak in 1984, only two are still in operation. Recently, in Sabah, a starch factory opened to process roots supplied through contract farming from an area of more than 3,000 ha. In trade, cassava starch takes the form of flour, flakes, pearls and starch powder. There is a growing demand for starch with imports amounting to 88,210 tonnes in 1997. Most of this starch is used in food industries, particularly for making monosodium glutamate (using about 3,000 tonnes of starch per month). Other significant users are manufacturers of glucose, bakery and biscuit products, textiles and paper. There is also increasing interest in growing edible varieties of cassava for processing into snacks.

The future potential in terms of domestic demand for cassava starch is very good. Since the onset of the economic downturn faced by Southeast Asia, the Malaysian government has actively encouraged agriculture (to offset the country's huge food import bill amounting to almost US$ 2.9 billion a year) by providing easier access to farmland. There is recent renewed enthusiasm for planting cassava for production of starch, dried chips for livestock feed and sweeteners (high fructose glucose syrup or HFGS). For large-scale mechanized cassava production, certain prerequisites of soil type, terrain, climate and farm size matching the factory's capacity, must be satisfied. While land is hard to come by in Peninsular Malaysia, more than 80,000 ha of land are still available in Sabah.

Starch is the most likely product to be feasible and profitable in the immediate future compared to dried chips and HFGS production, because of a high demand in the local market, and a well-established technology for starch processing. Stable, high-yielding varieties with intermediate to high starch content to ensure higher starch recovery are required; better still if they can be harvested early.

The potential of using cassava as a carbohydrate-rich animal feedstuff is promising, but being low in protein compared to maize, additional protein is required from another source, entailing extra costs. Also, it is costly to dry cassava by artificial means. Although it is technically possible to produce HFGS from cassava, it involves converting starch by enzymatic processes – a complicated and expensive procedure. This does not seem economically feasible in the immediate future, given the current low world price for sugar. Instead, modified starches and their products have very good future potential as profitable agro-based industries. Modification of starches not

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only expands their scope of utilization by altering their physico-chemical characteristics, but also increases their value as compared to native starch.

An alternative use of cassava, which has some prospects, is the production of snack foods. Although oil-fried crisps and crackers are traditional snacks produced by cottage industries, only recently have attempts been made by larger food processors to improve their quality and packaging, and to target the more up-market urban consumer and overseas market. Preliminary work at MARDI has shown that cassava makes a very good raw material for extruded snacks.

INTRODUCTION

One of the earliest records of cassava in Asia was in 1786, when it was introduced into Ceylon (present-day Sri Lanka) from Mauritius. Two routes of introduction into Asia have been postulated: (1) by the Portuguese to India *via* Africa from Brazil; and (2) by the Spanish to the Philippines, directly from Mexico (Burkill, 1935). Burkill also mentioned that cassava was brought to Penang from Batavia (Jakarta in present-day Indonesia), while the first recorded commercial planting of cassava in Malaysia was in Malacca state around 1851.

The sago palm processing industry predates cassava starch processing, having been carried out earlier than 1416. However, with the introduction of this far shorter term crop, cassava was quickly able to replace sago palm as the preferred raw material among starch processors. The resultant product was of a high enough quality to be able – to quote Burkill – "to hold its own against the tapioca (cassava starch) of Brazil" in European markets.

CURRENT SITUATION

Current Situation in Cassava Production

Except for a small amount destined for the fresh food market, cassava has been planted in Malaysia mainly for starch extraction. The production area of cassava in Peninsular Malaysia (no accurate figures for Sabah and Sarawak are available) shows a steady decline since peaking in 1976 (**Figure 1**). From an all-time high of 20,913 ha, the area has shrunk to 1,631 ha in 1997 (latest published figure). This decline may be attributed to several reasons:

1. Curbing by relevant authorities of illegal cultivation (rampant in the 1960s and 1970s) on state and private land
2. Land alienation policy for agriculture with a bias against cassava, based on a negative impression of its soil-exhaustive properties
3. A switch by small farmers from cassava cultivation to more lucrative crops, especially oil palm and fruits
4. Rising costs of production (mainly due to farm labor shortages)
5. A very low prevailing price for cassava roots at RM 0.13 per kg, equivalent to US$ 0.034 (based on US$ 1.00=RM 3.80);
6. Competition for land for agricultural and non-agricultural activities (e.g. housing development, industries) during the economic boom prior to July 1997.

Figure 1. Area cultivated with cassava in Peninsular Malaysia (1970-1997).
Source: *Anon. 1971-1997, 1998.*

By contrast, currently sago covers 34,000 ha under smallholdings and 10,700 ha under estates in Sarawak, producing more than 60,000 tonnes of starch per year.

Cassava Processing and Marketing

As mentioned above, cassava is grown in Malaysia for the decades-old starch extraction industry. At least three family businesses had been operating starch factories for more than 40 years. These factories were facing increasingly a lack of sufficient root supply to keep them running at full capacity due to the decrease in production area. Since early 1999, most starch factories in Perak state (where the majority of them were located) have stopped processing cassava roots, leaving two still in business – a significant drop from the eight factories mentioned in 1984 (Tan and Welsch, 1986).

Starch sells currently for RM 700 per tonne (equivalent to US$ 184 per tonne). At this price, some of the formerly larger starch companies have found it more profitable to switch from processing to importing starch from Thailand for repacking and sale to those small local industries using starch as a raw material.

In trade, cassava starch takes the forms of flour, flakes, pearls and starch powder. A growing net demand for starch can be seen in **Figure 2**, which traces the total imports and exports of cassava starch over the period 1971-1997. The net imports of starch in 1997 amounted to 88,210 tonnes (this tallies closely with the figure provided by Rojanaridpiched and Sriroth, 1998), valued at RM 52.9 million (currently, equivalent to US$ 13.9 million). A major proportion of this starch is used in the food processing industries, not the least of which is the manufacture of monosodium glutamate. An estimated 3,000 tonnes of starch is used per month (36,000 tonnes per year) for this purpose. Other significant users of starch are manufacturers of glucose, bakery and biscuit products, textiles and paper.

As a matter of interest, cassava starch imports amount to 58% in value of the total amount of starches imported into Malaysia. These other starch sources include maize, wheat, sago and potato (**Table 1**).

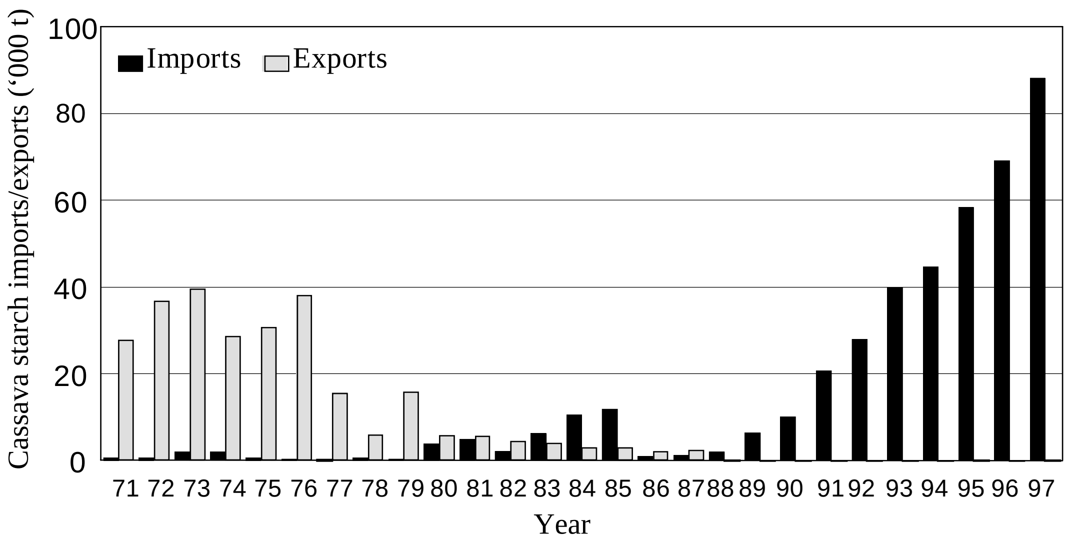

Figure 2. Imports and exports of cassava starch in Malaysia (1971-1997).
Source: *Anon. 1972-1998.*

FUTURE POTENTIAL

Renewed Interest

As may be seen from **Table 1**, imports of cassava starch have an annual growth rate of 36%. Thus, the future potential in terms of domestic demand for cassava starch is very high. As will be discussed later, the potential demand for cassava in other processed forms is also significant.

Since the onset of the economic downturn currently faced by Southeast Asia, the Malaysian government has actively encouraged greater agricultural output, particularly to offset the country's huge food import bill amounting to RM 10-11 billion (US$ 2.63-2.9 billion) a year. One way is to provide easier access for interested parties to farmland for growing crops.

This move has generated recent renewed enthusiasm for planting cassava for several purposes:

1. Starch (to reduce growing imports)
2. Dried chips for livestock feeding (to counter the large amount of maize imported annually, totaling 2.0 million tonnes and valued at US$ 0.28 billion in 1996)
3. Sweeteners - mainly high fructose glucose syrup or HFGS (to offset high annual sugar imports, amounting to US$ 216.4 million in 1996).

Table 1. Imports and exports of various starches in Malaysia (1997).

	Cassava		Sago		Others[1]	
	Quantity (tonnes)	Value (US$'000)	Quantity (tonnes)	Value (US$'000)	Quantity (tonnes)	Value (US$'000)
Imports	88,210	20,565	750	121	32,581	14,615
AGR[2], 1989-97	36%		60%		3%	
Exports	14,292	2,713	9,568	3,335	1,161	958
AGR[2], 1989-97	63%		2%		16%	

[1]Starches from wheat, maize, potato and others.
[2]AGR = annual growth rate

Sources: *FAOSTAT and Department of Statistics, Malaysia.*

Prerequisites for Large-scale Production

It is unlikely that cassava production will remain the domain of the small farmer for long, except for cases where the crop is produced on a small or backyard scale to serve the small fresh food market. Field production technology for cassava is well-established in Malaysia.

Several companies have shown interest in investing in large-scale cassava production, but before this can become a reality the following prerequisites must be satisfied:

1. Production must be at least partially mechanized (planting and harvesting) to overcome the farm labor shortage
2. The terrain must not be hilly (i.e. not exceeding 6º slope) to allow for safe tractor maneuverability and to curb soil erosion
3. The soil must not be drained peat (not mechanizable with current technologies) nor heavy clay (which hampers machine operation when wet, and cakes up into hard clods when dry)
4. The soils should be well drained and not prone to seasonal flooding (which causes root rot)
5. Rainfall pattern should provide sufficient rainless days in a month to allow for high number of machine workdays per month throughout the year

6. The land should be a single contiguous piece for ease of mechanization and to match factory capacity (it has been estimated that for a factory with a daily capacity to produce 25 tonnes of starch 1,500-2,000 ha of land will be required to keep it fully running using one shift per day).

Production Constraints and Research Solutions

Starch

Assuming the land and climate prerequisites for large-scale production are satisfied, growing cassava for starch is the most likely to be feasible and profitable in the immediate future. This is because:

1. There is a ready and growing market for starch within the country
2. Starch production is more profitable than dried chip and HFGS production (see explanations which follow)
3. The technology for starch processing is well-established and readily available for new-comers.

The only area where research is likely to make an impact is the development of stable, high-yielding varieties with intermediate to high starch content to ensure higher starch recovery at the factory. Another bonus would be the characteristic of early harvestability in new varieties, i.e. producing a reasonably high yield after six months' growth, in contrast to the growth period of 12 months shown by the current commercial variety, Black Twig. Early harvestability also allows for greater flexibility in scheduling planting and harvesting in a mechanized production system.

Animal feedstuff

The potential of using cassava as a carbohydrate-rich animal feedstuff is promising, considering the large volume of maize imported annually for the production of poultry and pig feeds. Up to 30% maize can be replaced by dried cassava chips without detriment to the two categories of livestock. However, being poorer in protein content (<2%) compared to maize (about 7%), it is necessary to add more protein from another source (like fish meal) when cassava is used in feeds. This of course entails additional costs.

Maize is currently very cheap in the world market. Despite the currently unfavorable exchange rates facing Malaysia, the price is around 13 US cents per kg (FLFAM, 1998). Fresh cassava roots (at about 65% moisture content) is currently sold to starch factories at 3.4 US cents per kg. The dried chips have a moisture content of around 15%; this means its equivalent price works out to 8.3 US cents per kg. Such a price level may not be considered favorable compared to the price of imported maize because it does not yet account for chipping and drying costs nor the addition of protein. Of course, there is currently a problem of availability as well, since cassava roots are in short supply even for starch extraction, let alone trying to process them into dried chips.

There is in fact a lack of a cost-efficient mechanical drying system for producing dried chips. In Malaysia, unlike Thailand, it is not possible to depend on sun-drying because the climate is much wetter throughout the year, and rainfall is largely unpredictable. For cassava production to take off as an animal feedstuff, replacing at least 30% of the imported maize, research has to address itself to developing an efficient and relatively cheap system for drying cassava. Perhaps, solar energy can be harnessed for the initial stages of drying before mechanical dehydration involving fuels take over to finish the job.

Sweetener

Malaysia has limited areas which have the correct agro-climatic conditions for growing sugarcane. Thus, the importation of raw sugar is likely to continue. The good news is that the price of raw sugar in the world market is currently very low at 12.3 US cents per kg (futures market in October 1999) (CSCE, 1999).

High fructose-glucose sweetener (HFGS) has almost the same degree of sweetness as sucrose sugar. It is especially useful in replacing sugar in the manufacture of canned, bottled or packaged beverages as well as tinned foods. However, its direct use as a substitute of sugar by the ordinary man in the street is less suitable by virtue of its liquid nature.

Although it is technically possible to produce HFGS from cassava, the process requires starch first to be extracted then converted by enzymatic processes into the sweetener – a complicated and expensive procedure. This is certainly not economically feasible in the immediate future, given the current price of sugar.

Other uses

Modified starches and their products (e.g. beverages, sauces, extruded snacks, coatings, emulsifiers, bulking agents, encapsulators, paper, textiles, adhesives, water absorbers, fat replacers, biodegradable plastics, industrial acids and alcohols) have very good future potential as profitable agro-based industries. Modification of starches not only expands their scope of utilization by altering their physico-chemical characteristics, but also increases their value in comparison with native starch.

An alternative use of cassava which has some prospects, is as a raw material in the production of snack foods. A local survey showed that many of the snacks (not including confectionery) available in the market are manufactured from wheat flour, maize and potato – all of which are imported (Lee *et al*., 1997). Although oil-fried crisps (*kerepek*) and crackers (*keropok*) are traditional snacks produced by cottage industries, only recently have attempts been made by larger food processors to improve their quality and packaging and target the more up-market urban consumer.

Demand for *kerepek* especially is good in the nearby Singapore market. Preliminary work at MARDI has shown that cassava makes a good raw material for extruded snacks: it has expandable/puffing qualities, producing a crispy product; and it has a bland taste which is favorable for addition of various flavorings to give a range of different tastes (Lee, 1999).

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CASSAVA IN ASIA: DESIGNING CROP RESEARCH FOR COMPETITIVE MARKETS[1]

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ABSTRACT

This paper reviews cassava in Asia from a broad perspective, culminating in a definition of the research areas that will contribute effectively to development goals in the region. The first section outlines regional trends in production, trade and utilization, drawing comparisons to global trends. A basic tenet of the paper is that the competitive marketplace – at local, regional and international levels – is rapidly changing cassava's roles in development. Hence, in the second section the discussion is placed in the context of the external social, economic and political environments that impact the cassava sector. The third section then indicates specific constraints and opportunities in the cassava system. Finally, we outline the role of key research areas for the cassava systems of Asia.

INTRODUCTION

Successful agriculture underlies the progress of most societies. Even many of today's more economically advanced countries continue to rely heavily on the productivity of the land as one of the key driving forces for economic growth and human development. The benefits come from diverse and adequate diets; employment and income generation throughout the entire system of production, processing and trade; and export earnings for balancing trade. When agriculture is economically viable, farmers are more likely to invest in practices that protect the environment (Kawano, 2001).

Curiously, after many years of international concern about food shortages, there is an evolving sense that food *overproduction* is becoming a serious economic menace to many producers, even for farmers of the third world. In fact, most farmers are keenly aware of this, as most have moved away from subsistence, toward dependence on the marketplace for income and livelihood. Market prices for basic commodities that are barely above production costs, and sometimes below costs, are common. This either drives producers out of business (and often precipitates migration to cities) or toward greater efficiencies and higher production, thereby putting even greater pressure on markets. As markets are opened to free trade, international competition exacerbates this trend. Conversely, open trade can also bring new market opportunities, and the possibility to have increased production without depressed markets.

The challenges of producing enough food for all are certainly not behind us, but much progress has been made. Among many agricultural scientists and policy-makers, emphasis is shifting toward assuring an appropriate balance between production, market development, and distribution systems, such that efficient producers are assured a fair income, while consumers have access to food and other agricultural products at affordable prices. There is also increasing awareness of the need to employ methods that preserve the environment for long term productivity.

[1] Based on Hershey *et al*., 2000

[2] Farmer and cassava consultant, 2019 Locust Grove Road, Manheim, P.A. 17545, USA.
[3] CIAT Cassava Office for Asia, Dept. Agriculture, Chatuchak, Bangkok, 10900, Thailand.

Cassava fills a number of basic roles around the world. In subsistence and poorly-developed market economies, it is usually a starchy staple. This role is declining in importance in Asia, but remains a key in some areas, especially parts of Africa. With urbanization and rising incomes, per capita demand for staples stops rising. Cassava's high versatility allows it to be processed into a very wide array of higher value products, such as convenience and snack foods. With higher income, people also tend to consume more animal products, and drive the demand for production of the ingredients of balanced rations. There is already a long history of research and practical experience in the use of cassava in animal feed. The rapidly growing global market for starch will absorb increasing quantities of cassava. These markets may compete directly with grain sources, or may be specialized markets where cassava's specific starch traits are required.

The vast majority of cassava growers in Asia produce the crop because they view it as their best alternative for generating income. This is not, however, the result of a high per-unit value. On the contrary, it is generally a low-value crop, often one of few alternatives in areas where it is grown. Rice continues a long tradition as the principal and preferred staple food in much of Asia, but where soils are marginal in fertility, and rainfall is uncertain, cassava may have a strong adaptive advantage.

The links between cassava and environmental protection revolve mainly around implications of the large proportion of this crop grown in fragile or otherwise marginal ecosystems. Cassava's historical reputation as a crop that causes soil degradation grew out of the plant's ability to produce on poor soils, where most other crops would fail. Managing erosion is a critical need when cassava is grown on slopes and in light soils, especially during the first months before the canopy closes. Disposal of waste products from processing is another environmental concern especially when processing plants become larger. The solutions lie in research on environmentally and economically sound waste management, by-product development, and reasonable regulation (Howeler *et al*., 2000).

A. TRENDS IN PRODUCTION, TRADE AND UTILIZATION[4]

Cassava in Asia has succeeded in diverse physical, socio-economic, and political environments. The species is a relatively recent introduction to the agriculture of Asia, in comparison to the several-thousand-year-old rice culture. Best evidence indicates it was first introduced to the Philippines during the Spanish occupation. By the beginning of the 19th century, explorers and traders had effectively distributed the crop throughout tropical Asia. Colonial administrators promoted cassava culture by developing a starch processing and export industry in Malaya in the 1850s, and later in Java. The Dutch in Java and the British in southern India also promoted cassava as a famine reserve crop. In this heavily rice-dependent region, cassava found a niche in environments where rice was risky or difficult to grow. Production was concentrated on Java and in Malaysia for much of the period up to World War II. The disruptions of the war and the rising prominence of maize as a source of starch brought a decline to the cassava starch export industry. Markets for internal consumption remained strong in Indonesia, and this country led production in Asia up to the late 1970s.

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[4] This section draws heavily on Lynam, 1987, for the period up to the mid-1980s.

Two powerful influences dominated the cassava sector in the post-World War II era, through the 1970s. First, the *green revolution* in rice brought a measure of food security in the region, diminishing the importance of cassava as a famine reserve crop. Secondly, rapid growth in the animal feed industry in developed countries, and a twist on Europe's import policies, brought opportunities for dried cassava exports. From the beginning, Thailand dominated the export market for animal feeds.

From the 1980s to the present, the main influences on cassava production and commerce were: (1) rapid growth in many Asian economies, with accompanying changes in food consumption patterns; (2) increased demand from industry for starch; and (3) increasing implementation of trade policies that reduced cassava's preferential treatment in European markets. Except for a few products such as *krupuk* in Indonesia, cassava generally enters markets where other calorie or industrial starch sources may readily be substituted. Future growth, therefore, is largely linked to cost competitiveness. Alternatively, there is growth potential for new products that require specific characteristics that only cassava provides.

This section concentrates on seven countries which together account for 99% of current production: Thailand, Indonesia, India, China, the Philippines, Vietnam, and Malaysia (**Figure 1**). Thailand and Indonesia alone produced 70% of the region's cassava in 2000. Sri Lanka was a significant producer in the 1970s, with over 150,000 ha, but this has declined to about 30,000 ha. Cambodia, Laos and Myanmar each produce cassava on about five to eight thousand hectares.

1. Production Trends

FAO monitors cassava area and production in thirteen countries of South and Southeast Asia (**Table 1**). Together, these represent 32% of global production. To a large degree, Thailand has defined the variations in total annual output for Asia over the past 30 years. Other countries have made relatively modest contributions to the fluctuations in aggregate production (**Figures 2** and **3**).

Production trends for Asia divide roughly into three periods:

(1) *pre-1960s*. Internal consumption and early international trade in starch absorbed most of the production. There were overall modest increases in area planted over time.

(2) *1960s and 1970s*. This era was defined by growth in the export market for dried cassava for animal feed, mainly to Europe. Other countries, especially India and Indonesia, were also responding to deficits in rice production and increased the planting of cassava as a food security crop. In post-war Vietnam, production surged in the late 70s as the country began to rebuild its economy, and then gradually decreased during the 1980s.

(3) *1980s and 1990s*. Area planted and production leveled off overall. Indonesia steadily decreased area planted, but realized steady slow growth in production due to greater use of fertilizer, to satisfy growing internal demand in the starch markets. Production in Thailand fluctuated strongly from year to year in response to pressures to reduce exports to Europe and the search for new external and internal markets. Area planted peaked in 1989 at 1.6 million hectares, with a steady decline thereafter and reaching levels of a decade earlier (1.2 million hectares) by 1996.

Supply growth in the decade 1976-1985 was almost equally divided between area expansion and yield increase. In the period 1986-1995, aggregate annual decline in area planted (0.9%) was slightly less than the annual average yield increase (1.2%), giving a

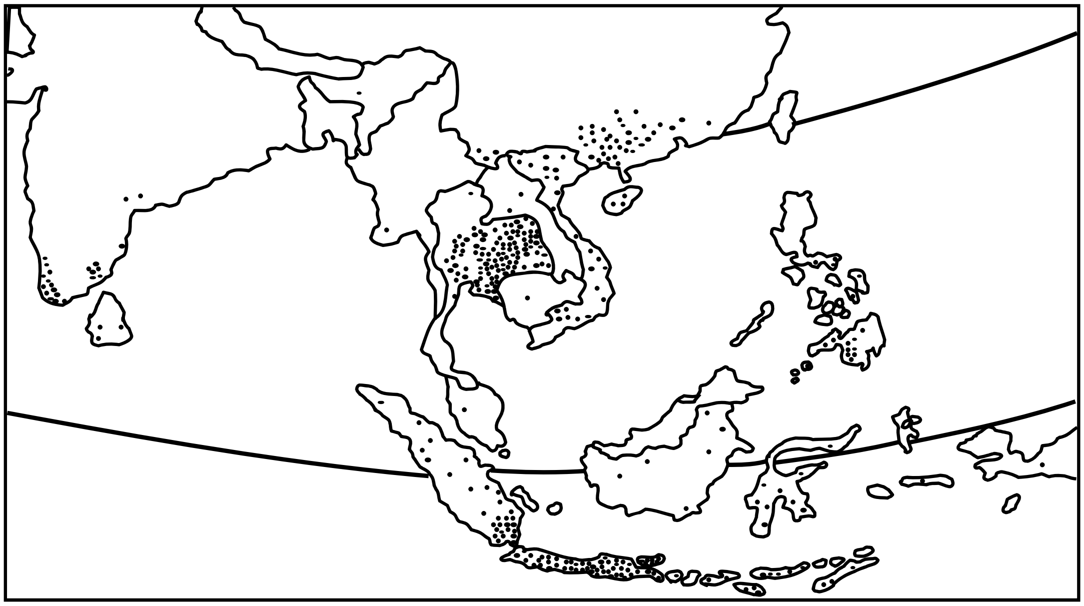

Figure 1. Cassava production zones in Asia in 1999. Each dot represents 10,000 ha of cassava.

nearly stable production over the period (**Table 2**). In some countries, especially Thailand, reduction in area is not being offset fully by yield increases, as the crop was pushed toward more marginal land. It appears that this trend may have been reversed over the past few years in Thailand, with widespread adoption of new varieties and improved production practices.

2. Production Systems

Most crops occupy the micro-environments where they are best adapted within a region. Cassava, though, rarely does. Paddy rice predominates in most lowland farming systems in tropical Asia. It is the highly preferred calorie source in the diet, and cassava does not normally compete on land suited to its cultivation. In rainfall-limited areas such as eastern Java, northeast Thailand, or non-irrigated southern India, few crops can match the stability of production of cassava. Cassava normally occupies the hillsides and drought-prone areas, and acid soil regions where other crops can be successfully grown only with high input levels.

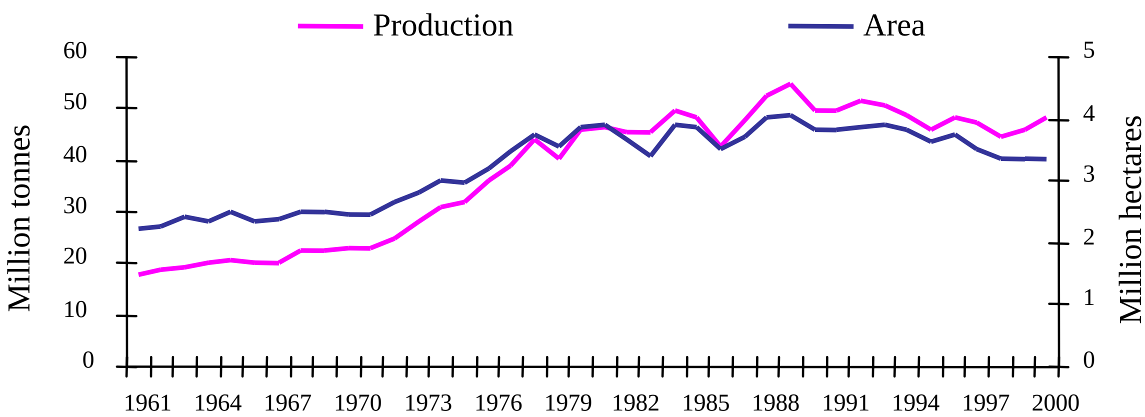

Figure 2. Aggregate area and production of cassava in Asia, 1961-2000
Source: *FAOSTAT, 2001.*

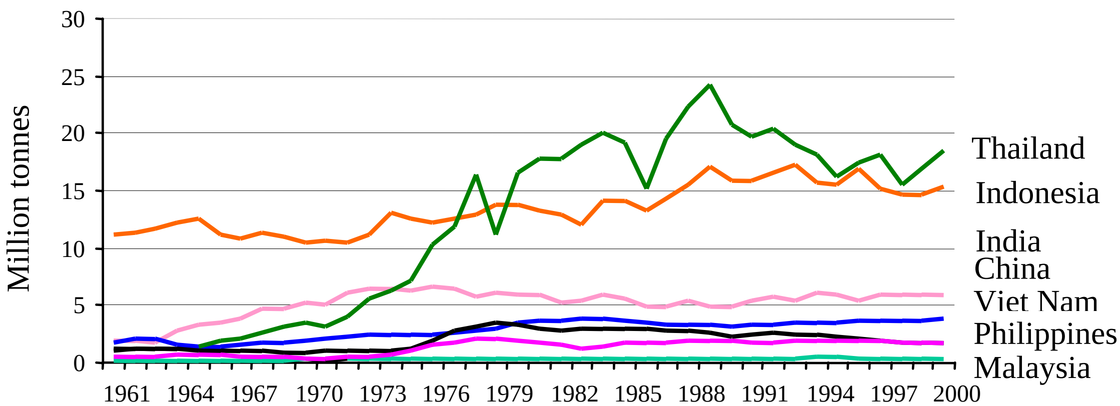

Figure 3. Cassava production trends in Asia's principal producing countries.
Source: *FAOSTAT, 2001.*

Table 1. Area, yield and production of cassava in Asia, 2000.

Country	Area (ha)	Yield (t/ha)	Production (tonnes)
ASIA	**3,351,119**	**14.4**	**48,163,007**
Brunei	135	11.9	1,600
Cambodia	7,000	9.6	67,500
China	235,045	16.0	3,750,658
India	250,000	24.0	6,000,000
Indonesia	1,205,330	12.8	15,421,885
Laos	5,200	13.7	71,000
Malaysia[a]	39,000	10.3	400,000
Maldives	9	4.7	42
Myanmar	7,736	11.4	88,144
Philippines	210,000	8.5	1,786,710
Sri Lanka	29,470	8.8	260,000
Thailand	1,135,394	16.3	18,508,568
Vietnam	226,800	8.0	1,806,900

[a]According to Dr Tan Swee Lian, MARDI, FAO data for Malaysia are highly inaccurate. National figures show that current area is on the order of 7000 ha, with average yields of about 20 t/ha.

Source: *FAOSTAT, 2001.*

Table 2. Annual growth rates (%) in cassava production, area and yield, by continent, 1976-1995.

	Production		Area		Yield	
	‘76-85	‘86-95	‘76-85	‘86-95	‘76-85	‘86-95
Africa	2.6	4.1	1.3	2.2	1.3	1.9
Asia	**3.0**	**0.3**	**1.4**	**-0.9**	**1.7**	**1.2**
Latin America	-1.2	0.0	-1.1	-0.3	-0.1	0.2

Source: *Henry and Gottret, 1996.*

Table 3 compares the area planted in broadly-defined agro-ecological zones. Compared to either Latin America or Africa, a higher proportion of cassava in Asia is planted in dry climates (sub-humid or semi-arid). By these estimates, about 67% of cassava is seasonally drought-stressed in Asia, compared to about 40% in Latin America and 46% in Africa. Area planted in the subtropics is midway between that of Latin America and Africa, at about 15%. Almost none is grown in highlands (over 1500 masl), which may be due in part to scarcity of adapted germplasm. Early introductions from the Americas probably did not include highland-adapted materials, and this never developed as a priority in Asia.

Table 3. Global cassava area (%) by continent and climatic zone.

	Latin America	**Asia**	Africa	World
Lowland humid tropics	15	**18**	34	27
Lowland sub-humid tropics	33	**41**	38	38
Lowland semi-arid tropics	8	**26**	8	13
Highland tropics	15	**0**	10	8
Sub-tropics	29	**15**	10	14
Total area ('000 ha, 1993)	2781	**3921**	8921	15623

Source: *Henry and Gottret, 1996.*

Production practices vary widely across the region (**Table 4**). The vast majority of farms in Asia are small, usually in the range of 0.5-5 ha. In the more land-rich areas, cassava competes principally with tree crops: coconuts in the Philippines; coconuts and rubber in Kerala, India; oil palm and rubber in Malaysia and the outer islands of Indonesia; cashew in southern Vietnam and rubber in eastern Thailand.

Cassava is mainly monocropped, but intercropping is common on parts of Java where there are not severe soil and water constraints. Main intercrops here are upland rice, maize and various grain legumes. In Tamil Nadu of India, intercropping with vegetables has become relatively common. In China and Vietnam, maize, peanuts, black beans and various minor species, such as watermelon or pumpkin, may be intercropped, usually at a low density. Cassava is commonly used as an intercrop during the establishment of young tree crops like rubber and cashew, especially in China and South Vietnam.

In contrast to both Latin America and Africa, genetic diversity is extremely limited in commercial plantings in Asia, with the exception of Indonesia. In most countries only a few varieties account for most of the production. The narrow genetic base has apparently not led to any major production disasters. It did, however, limit the possibilities to extend the range of adaptation, or to make adequate improvement in some characters. By good fortune, few of the pests and diseases of the New World found their way to Asia, so a broad genetic base was less critical for supplying resistance genes, as compared with Africa or Latin America.

Table 4. Characteristics of cassava production and utilization in Asian countries.

	China	India	Indonesia	Malaysia	Philippines	Thailand	Vietnam
Cassava production('000 t) 1997	3,501	5,979	16,102	22	1,900	18.084	1,983
Cassava harvested area ('000 ha)	230	244	1,300	2.1	215	1,230	239
Cassava yield (t/ha)	15.2	24.5	12.4	10.3	8.8	14.7	8.3
Utilization -main	Starch -domestic	Human consumption	Human consumption	Starch -domestic	Human consumption	Animal feed (50%) -exp. (90)/dom. (10)	On-farm pig feed
-secondary	On-farm pig feed	Starch -domestic	Starch -dom./export		Starch -domestic	Starch (50%) -exp. (60)/dom. (40)	Starch -export/dom.
Farm size (ha/farm)	0.5-1.0	0.4-0.6	0.4-1.0	2-3	3-4	4-5	0.6-0.8
Cassava area (ha/farm)	0.2-0.4	0.3-0.4	0.3-0.5	-4	-	2-3	0.25-0.30
Crop. system (%) -monocrop	40	70	40	99	60	95	65
-intercrop	60	30	60	1	40	5	35
Time of planting	March	Apr/Sept	Oct/Nov	year round	May-Aug	Apr-May Oct-Nov	Feb-May
Land preparation	manual/oxen	manual/oxen	oxen/manual	tractor	oxen	tractor	oxen/manual
Planting position	horizontal	vertical	vertical	horizontal	horizontal	vertical	horizontal
Weed control	manual/ herbicides	manual/gorru	manual/ herbicides	herbicides/ manual	manual/ oxen	manual/mech./ herbicides	manual
Fertilization -organic	some	some	some	none	some	some	some
-chemical	low	rel. high[1)]	rel. low (N only)	high	low	Low-medium	low
Labor cost (US$/day)	1-2	2-3	1-2	4-5	2-3	3-4	1-2
Production costs (US$/ha)	300-500	500-1,000	300-500	390-520	300-700	300-400	200-700

[1)]in irrigated areas

Source: *Adapted from Howeler, 2000.*

Production practices may be fully manual, or with mechanized/animal-powered land preparation. The broadly rising incomes and labor costs in Asia are motivating increased mechanization, especially in Thailand and Malaysia, and in the plantation systems of other countries. Most other operations are manual. The largest production cost for cassava in Asia is consistently labor, especially for land preparation, weed control, and harvest. For example, Ratanawaraha *et al*. (2000) indicate that labor requirements are 96 mandays/ha in Thailand, comprising 65% of production costs. But many of the labor inputs for cassava are technically difficult to substitute with mechanization on small holdings with irregular terrain.

Production costs vary significantly across the region (Howeler, 2001b). In general, Asian countries are comparatively efficient producers, by use of some inputs, good management, and low pest and disease pressures. **Table 5** illustrates production costs for Thailand, Brazil and Colombia, and the competitive advantage that Thailand has had in world markets in part because of lower costs, both in production and processing.

Table 5. Cassava production costs, farmgate prices, and product prices in three major producing countries (average for 1990-1994, US$/tonne).

	Cassava production costs	Farmgate price of cassava		Domestic chip price	Cassava starch price
		For industrial use	For fresh consumption		
Thailand	$20.34	$28.67	-	$85.70	$233.34
Brazil	$27.80	$31.63	$128.18	-	$357.17
Colombia	$34.85	$42.20	$85.30	$177.77	$522.95

Source: *Henry and Gottret, 1996.*

3. Products and Markets

Diversity is the defining characteristic of cassava products and markets in Asia, both within and across countries. About 40% of cassava in the region is destined for human consumption (in Indonesia, the level is about two-thirds) (FAOSTAT, 1997). Most of the remainder is processed for industrial purposes, principally pellets for animal feed, and starch. Fresh roots are not traded on any significant scale. The initial processing defines to some degree the market sector to which roots can be destined. This is unlike the grains such as maize which are traded as whole, unprocessed grain, to be converted into any number of products in the importing country.

a. Fresh for human consumption

Outside of Kerala, India and some poorer districts of China and Vietnam, nearly all cassava for food is first processed; direct consumption of baked or boiled fresh roots is minor. This form of consumption is largely a rural practice, and often by households having cassava in their own backyard garden. Fresh consumption has limited growth potential, and in fact will probably decline with increasing urbanization and changes in dietary preferences.

b. Chips and pellets for animal feed

The commercial cassava pellet industry has its origin in Thailand, which has a long history of an agricultural economy driven by exports. With a surplus land base, rice exports became the foundation of Thai trade up to World War II. Development of the upland sector in the North and Northeast brought diversification to agriculture, adding maize, cassava, pineapple and sugarcane.

Exports of dried cassava products climbed steadily up to 1990, but declined afterwards as Europe began to withdraw its favorable import conditions. Thailand has aggressively sought alternative markets, with some success, but not nearly at levels absorbed by Europe in the 1980s (**Figure 4**, **Table 6**). While the potential for development of internal markets remains promising, the generally low commodity prices of the past several years have made this difficult.

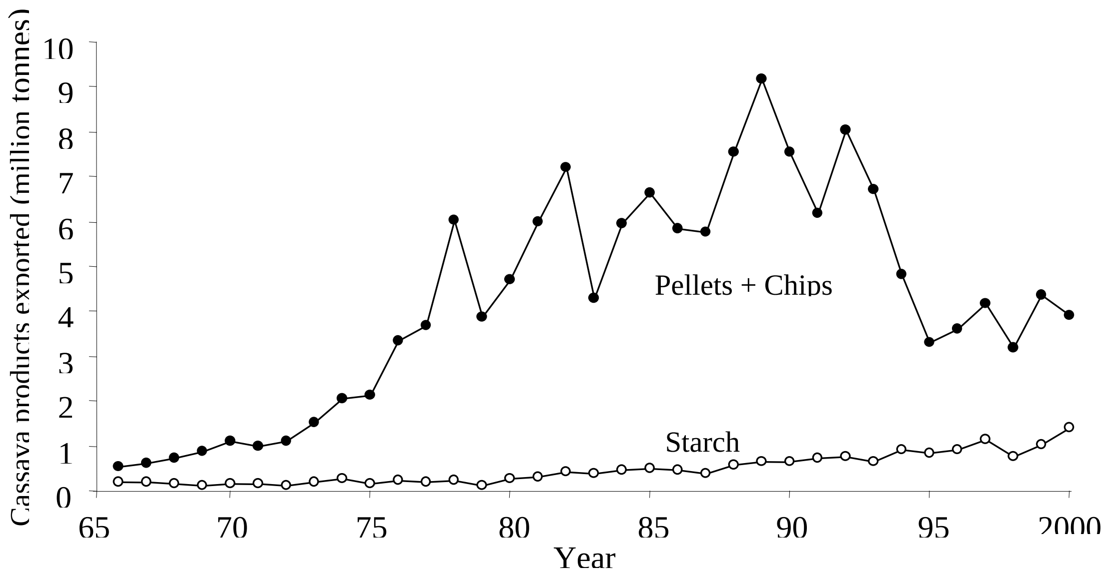

Figure 4. Quantities of cassava products exported from Thailand from 1966 to 2000.
Source: *Adapted from TTTA, 2000.*

Table 6. World trade of cassava products (chips, pellets and starch: million tonnes).

	1994-1995 avg.	1996-1997 avg.	1998-1999 avg.
World exports	**6.30**	**6.39**	**5.47**
Thailand	5.00	5.16	4.62
Indonesia	0.60	0.43	0.23
China & Taiwan	0.40	0.39	0.20
Others	0.25	0.42	0.43
World imports	**6.30**	**6.39**	**5.47**
European Union	4.20	3.72	3.58
China & Taiwan	0.65	0.61	0.62
Japan	0.35	0.38	0.32
Korea, Rep.	0.35	0.46	0.35
Others	0.70	1.23	0.61

Source: *FAO Commodity Market Review 1999-00.*

c. Starch for food and industry

Starch for industry is classified as *native* or *modified*. The technology for modifying starches with physical, chemical and biological processes is highly advanced and evolving rapidly. These modified starches are absorbing an increasing market share. At the same time, there is pressure in some industries, especially foods, to move away from modification based on chemicals.

Starch-derived products include sweeteners (high fructose syrup, glucose syrup), dextrins, monosodium glutamate, pharmaceuticals and various chemicals. Starch is used in large quantities in the manufacture of paper, plywood, textiles, and as a filler/stabilizer in processed foods. New products from starch are continually entering the marketplace. Bio-degradable plastics appear to be especially promising. Throughout the region, the industry is moving toward larger, more technologically advanced plants, and small, less efficient factories are closing.

Thailand is leading the Asian *starch boom*, surpassing Indonesia in recent years (**Figure 5**). Both export sales and domestic use have increased significantly. Although the starch export industry of Thailand has been active since the 1940s, it was rejuvenated in the 1980s when Europe began to set limits on imports of cassava chips and pellets (**Figure 4**). This was also a time of rapid economic growth in Thailand, and the starch industry attracted the attention of entrepreneurs. The focus for exports has been on modified starches, to get around some of the import barriers imposed against native starch. Nonetheless, the increase in starch exports has not nearly kept pace with the decline in pellet exports. Private and public sectors are cooperating to identify and exploit internal growth markets for starch as a complementary strategy to export-orientation.

Internal markets absorb most of Indonesia's starch. Nearly two-thirds goes into *krupuk*. Because of the specific starch characteristic required for this product, maize starch is not a competitor. This gives some insulation from the fluctuations of world starch prices. Both China and Vietnam have significantly expanded and modernized their starch industries. Monosodium glutamate and glucose (starch derivatives) are rapidly growing markets in both countries. In Thailand, Indonesia and Vietnam, cassava is virtually the only raw material for starch production. Any growth in starch demand should benefit the cassava sector. In China, India and the Philippines, there are other starch sources (especially sweetpotato and maize in China), but these are often used in industries such as noodle-making where cassava starch does not compete. Hence, even in these countries the market potential for cassava starch is strong.

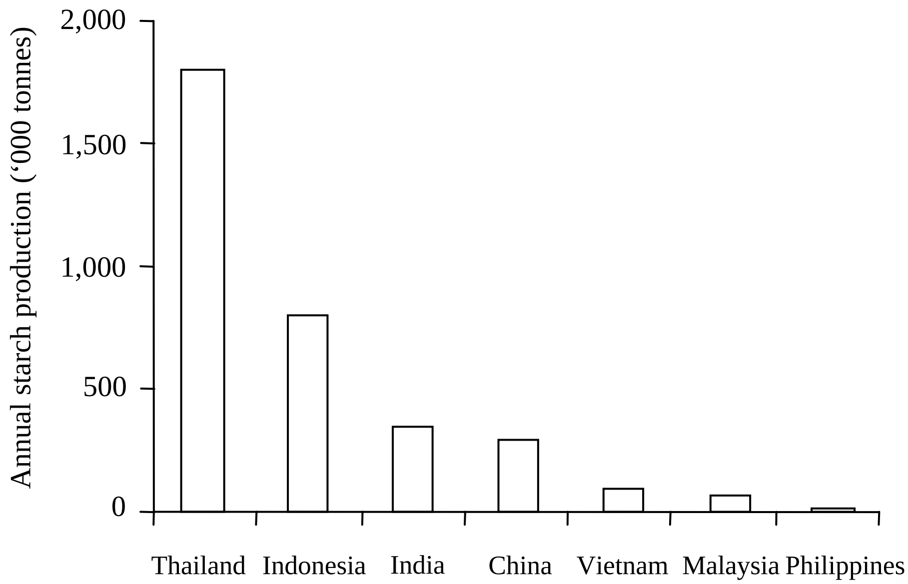

Figure 5. Cassava starch production in various countries in Asia (in 1992).
Source: *Ostertag, 1996.*

d. Flour

Cassava flours come in many forms. The most common is *gaplek* in Indonesia. Roots are peeled, chipped or sliced, and dried. The dried chunks are ground or milled to a meal, which is then used in a wide array of food preparations. It is consumed especially in times of rice scarcity, and partially substitutes for rice in rural daily diets. Cassava flour may also partially substitute for wheat flour in bakery and other products. This is still minor in Asia, but is reported unofficially from several countries (Henry and Gottret, 1996).

4. Projections

Thailand's continuing efforts to reduce its dependency on the European animal feed market will dominate directions of the Asian cassava sector for the next decade. This will take several forms: introducing production technology to keep prices competitive with alternative energy sources; aggressively seeking new markets outside Europe; development of internal feed markets; and further diversification into starch and flour, with strong support for research on new processes and products. Other countries of the region, once with aspirations to penetrate export markets for pellets, are now recognizing that opportunities will depend very much on increasing production and processing efficiencies (**Table 7**).

Prospects for starch vary widely depending on the specific market. There are two extremes: purely commodity starches with generic application, and highly specialized starches reliant on functionality. The latter are often derived from modified starches. However, in the middle, there are starches that are comparatively specialized, though sharing functionality with other starches. In this group, functionality is the initial criteria of suitability, followed by price and supply. For generic starch, the different sources (maize, cassava, sweetpotato, white potato) compete with one another on the basis of price. The markets for specialized starch are rather uncertain. On the one hand there is increasing demand, but on the other, there is a continually evolving technology for modifying starches to meet specific product properties. While technology for modification is moving rapidly, at the same time there is a strong trend away from modified starches in some products and in some key markets like the US and EU. For example, baby foods use virtually no modified starches, and the amounts used in soups is much reduced compared to just five years ago. Ostertag (1996) suggests that most developing countries will use their resources most effectively to first concentrate on developing internal starch markets, to reduce the risks inherent in the export sector.

In a recent study of the major tropical root crops, Scott *et al*. (2000a) project cassava production and utilization in the year 2020, based on a model that takes into account virtually all the world's food production and consumption (International Model for Policy Analysis of Commodities and Trade (IMPACT)). Moderate demand growth for cassava products in Asia through 2020 will sustain viable cassava-based development. The growth sectors vary within the region. In China, growth in feed demand will be among the strongest anywhere, at 2.1% per year, accompanied by a continuing trend for lower direct use as food. Southeast Asia should see healthy growth in all sectors: 1.4% in food, 0.13% for feed, and a total of 1.25% (including industrial use) (**Table 8**). The import demand in the non-cassava producing countries of East Asia will rise at 1.0% per year, providing some additional market possibilities.

B. THE EXTERNAL ENVIRONMENT: INFLUENCES ON THE FUTURE OF THE CASSAVA SECTOR

Agricultural research has a key role in development. But for maximum impact it must be attuned to the broader social and economic environments of the target area. Progress towards improvement of production, processing and market development systems that will broadly benefit society is intimately related to broader trends and influences.

Table 7. Present constraints in cassava production, processing and marketing, and potential future cassava products.

Country	Constraints	Future potential
China	Crop competition Small farms Soil erosion Low soil fertility	Starch MSG Modified starch Animal feed
India	Crop competition Mosaic disease Small farms Markets	Starch Modified starch Converted starch Sweeteners Snack foods
Indonesia	Small farms Price fluctuations Soil erosion Low soil fertility	Starch Modified starch Animal feed Flour MSG
Malaysia	Crop competition High labor cost	Starch Modified starch Animal feed Snack foods
Philippines	Financial resources Markets Low soil fertility	Starch Animal feed Alcohol
Thailand	Price fluctuations Labor shortages Low soil fertility Soil erosion	Modified starch Domestic animal feed MSG Lysine
Vietnam: North	Small farms Financial resources Low soil fertility	Animal feed
Vietnam: South	Small farms Financial resources Low soil fertility Crop competition	Starch MSG Animal feed

***Source**: Compiled by R. Howeler from interviews, personal observations and national program data.*

Table 8. Projected production and utilization of cassava in 2020.

	Growth rate for utilization 1993-2020 (percent per year)			Utilization in 2020 (million tonnes)	Production in 2020 (million tonnes)
	Food	Feed	Total		
China	-1.27	2.08	1.19	3.9	4.2
India	1.00	0.00	1.00	7.6	7.8
Other East Asia	-0.95	1.09	0.63	3.5	0.0
Other South Asia	1.00	0.00	0.83	0.6	0.6
Southeast Asia	1.4	0.13	1.25	27.0	51.1
Latin America	0.26	1.26	0.78	39.3	40.5
Sub-Saharan Africa	2.51	0.29	2.47	166.0	166.0
Developing	2.01	1.18	1.88	248.8	271.1
Developed	0.03	0.01	0.02	22.7	0.4
World	2.01	0.59	1.68	271.6	271.6

Source: *Adapted from Rosegrant and Gerpacio, 1997; and Scott et al., 2000.*

1. Trade and Economic Policy

The policy arena, possibly more than any other influence, sets the stage for cassava's role in a given country. Agricultural policy, as well as broader economic and trade policies, impact the cassava sector in several ways. Liberalized trade became the economic mantra of the 1990s. The watershed Uruguay round of multilateral trade negotiations, under the General Agreement on Tariffs and Trade (GATT), was a fundamental influence on the direction of the global economy. While more recent attempts at broad trade agreements under the World Trade Organization, successor to GATT, have been less successful, there is little likelihood of reversing the broad trend toward freer trade. Trade liberalization will bring complex and sometimes unpredictable adjustments to agriculture. The implementation of regional trade agreements is well-advanced in Asia. The Asia Pacific Economic Co-operation forum (APEC) has 18 members, which in total comprise half the world economy. Most of the major cassava-producing countries of the region (excepting India) are members. APEC aims to achieve free and open trade and investment by 2010 for its industrialized members and by 2020 for the others. The Economist© magazine called APEC "*potentially the most far-reaching economic agreement in history*" (27 Sept. 1997).

Previously-protected sectors of the economy are in flux as they are subjected to the open market. Countries that expect to export their products are under strong pressure to open their markets to imports as well. Agriculture has been one of the sectors most broadly affected by this trend, since it is of nearly universal relevance to countries' economies, and touches fundamentally on the lives of nearly all people. On the whole, liberalized trade agreements should drive broad-based growth through specialization, efficiency gains, and increased trade in agricultural products. In a free trade environment, commodity prices typically fluctuate more (based on supply and demand) than in a regulated environment.

Producers are more likely to switch in and out of crops to take best advantage of these fluctuations. The dilemma that cassava-producers often face, however, is the fact that they have little flexibility in choice of crops. First, on the more marginal soils, cassava may be the only choice without resorting to costly inputs. Secondly, the nature of cassava's propagation does not allow quickly gearing up for production if a supply of planting material has not been assured by the previous year's crop. Stabilizing demand in an environment of freer trade will depend on the ability of the industry to respond quickly to shifts in product demand.

Projections on the evolution of trade of agricultural products generally assume a continuation of the trend, first for regional trade agreements, followed by more broadly open global trading systems. There is, however, bound to be a certain cyclic nature to this long-term movement toward freer trade. When free trade has a negative impact on local economic sectors affecting people with political power, there will be temporary retreats to some type of trade restrictions. This will create regional shifts in market opportunities for various products. The more broadly a particular commodity or product is integrated into the global economy, the more of a buffer it will have against imposition of restrictions in a given country or trading block. Diversity and flexibility of processes and products will be another important way of weathering the cyclic effects of policy shifts.

A second trend important to trade is the tendency to add value at the site of origin, and to trade in processed products. By 2020, there will be far less trade of the traditional raw agricultural products (e.g., grains); most will be products with value added either by processing or through genetically engineered specialty traits incorporated for specific end-uses. Often, trade policies affecting processed products are different from those imposed on raw products.

2. Demographics, Income and Food Demand

Population increase remains a major driving force that will shape development progress, at least for a few more decades to come. Poorer countries absorb most of the impact. While on a global level it seems that food production can keep pace with population increase, poverty and hunger persist in many countries, especially in the tropical belt. The consequences of these dual scourges of poverty and hunger then reverberate throughout all areas of human and environmental well-being.

The United Nations projects that global population will continue to rise to about the year 2040, when it will have doubled from today's level, to 8-11 billion. Growth rate should decline from about 1.4% to 1.0% by 2020. This mean rate hides the highly disproportionate differences between developed and developing countries – a 3.4% population increase in the former, compared to 35.8% in the latter, in the period from 1998 to 2020. By far the greatest burden of this continued population growth will be felt in urban areas. Latin America is already at a level of almost three-quarters of its population living in cities. Like much of the rest of the world, Asia has been moving toward greater urbanization for at least several decades (**Figure 6**). Both Africa and Asia appear set to continue a nearly linear trend toward greater urbanization, with about equal numbers of rural and urban residents in both regions by 2020 (FAOSTAT). This is largely the dynamic that drives commercial agriculture -- urban dwellers need to purchase nearly all their food.

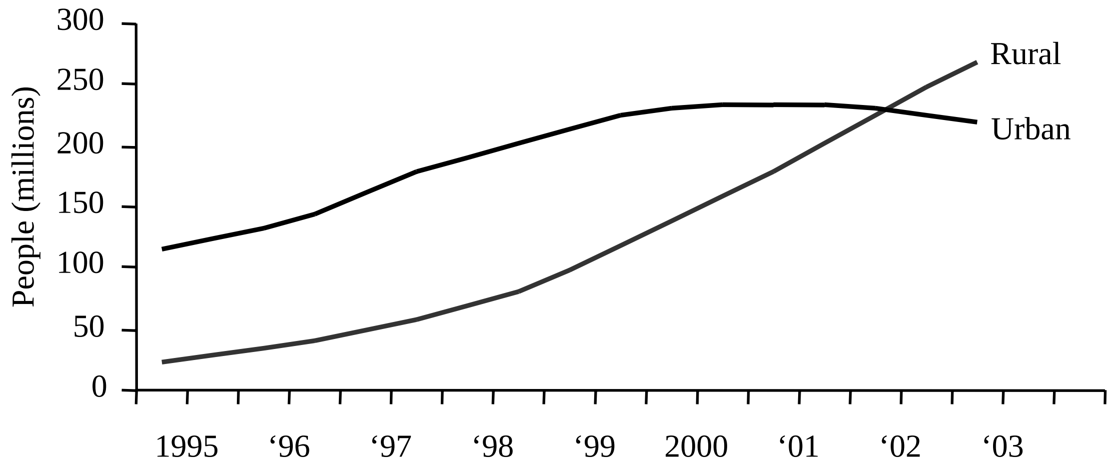

Figure 6. Historical and projected population growth in Asia.
***Source:** FAOSTAT, 2001.*

Population dynamics affect cassava production and marketing in various ways. In the simplest of cases, population increase imposes a proportional increase on food demand. With most of the productive land already cultivated, this places pressure on marginal environments where cassava has strong adaptive advantages. On the other side, urbanization typically reduces demand for cassava and its products for direct food use. Huang and Bouis (1996) note several reasons for shifts in food demand that follow urbanization:

- A wider choice of foods is available in urban markets
- People are exposed to new dietary patterns from different regional traditions
- Urban lifestyles place a premium on foods that require less time to prepare
- Transaction costs are lower
- Urban occupations generally require fewer calories than more physically demanding rural ones

Except in Indonesia and southern India, cassava has never been broadly popular as a dietary staple in Asia. In several countries there remains a considerable stigma against cassava as a food -- a reflection of past difficult economic times. Rising incomes will further erode cassava's direct role in Asian diets. The overwhelming preference for rice as the starchy staple, and the increasing demand for meat (**Figure 7**), will keep per capita consumption levels low throughout Asia. The growth in meat consumption, however, is the basis for projecting strong potential to use cassava for on-farm feeding, or in balanced rations, especially for pigs and chickens.

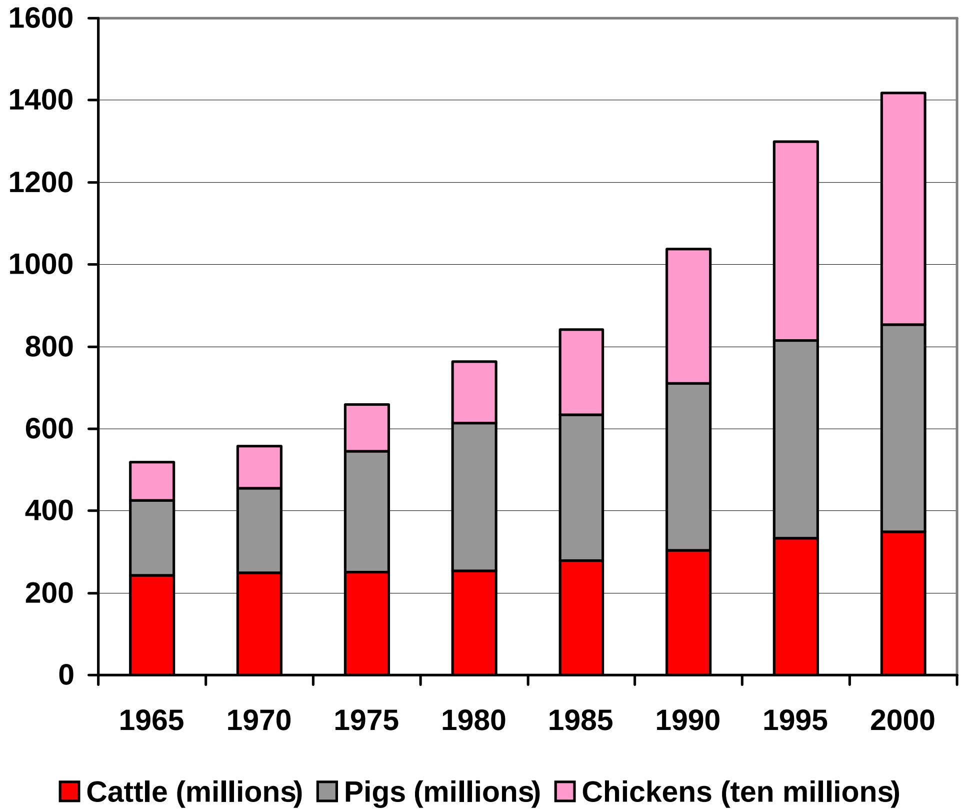

Figure 7. Animal stocks in seven major cassava producing countries of Asia.

While not all countries have benefited equally, Asian economies on the whole have seen healthy growth in the past two decades (**Table 9**). Industrial development, the service sector, and labor demand, have all had an impact that affects all sectors of society. Rising household incomes open the way for purchase of consumer goods, education and health care. Improved tax bases contribute to public infrastructure in the form of roads, schools and public services. In this scenario, cassava tends to move toward industrial uses, such as animal feed and starch-based products.

3. Trends in Competing Commodities

Cassava's competitive position in national and international markets is closely linked to internal and world supplies and market prices of alternative commodities or products. Because of cassava's versatility, it may compete with a range of products in different markets. In the market for balanced feed rations, cassava in dried chip or pellet form competes mainly with sorghum or maize, and sometimes barley. On a global level, maize is the principal source of starch.

Table 9. Growth in gross domestic product and rural population in principal cassava -producing Asian countries.

	Gross domestic product growth (%)		Share of agriculture in GDP (%) in 1999	Rural population (%) in 1999
	1980-1990 avg.	1990-1999		
China	10.1	10.7	18	68
India	5.8	6.0	28	72
Indonesia	6.1	4.7	19	60
Malaysia	5.3	9.9	11	43
Philippines	1.0	3.2	18	42
Thailand	7.6	4.7	10	79
Vietnam	4.6	8.1	25	80

Source: World Bank, 2001 (http://www.worldbank.org/data/).

In the cassava-producing countries of Asia, rice, maize and cassava production all increased three to five-fold in the past twenty-five years (**Figure 8**). Even this dramatic success, however, was not adequate for supplying growing and somewhat more affluent populations. Grain imports, dominated by wheat, maize, rice and soybeans, rose from just over ten million tons in 1960 to 47 million tonnes in 1995, with some decline again in the latter part of the decade during the Asian economic slowdown (**Figure 9**).

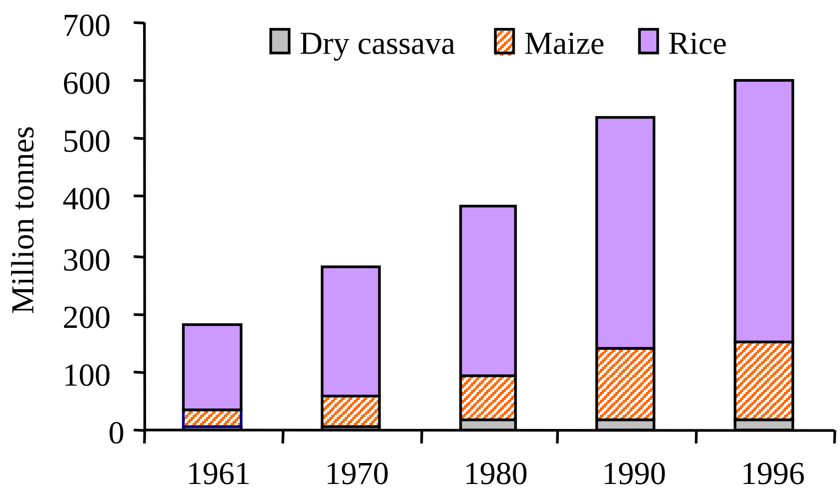

Figure 8. Crop production trends in seven major cassava-producing countries of Asia.
***Source:** FAOSTAT.*

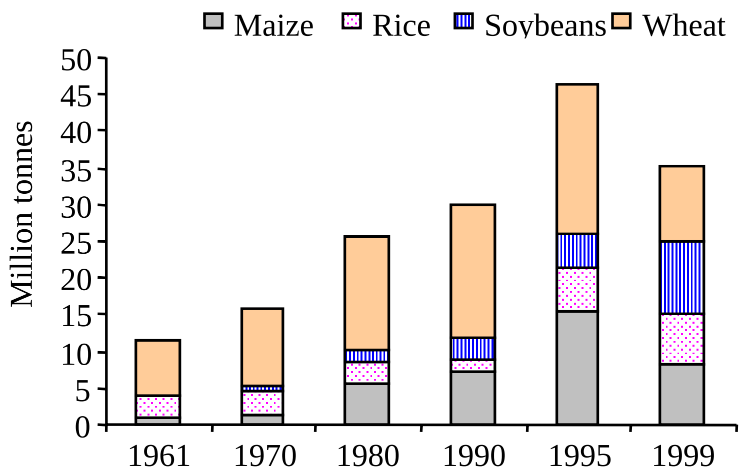

Figure 9. Grain imports to seven major cassava-producing countries.
***Source:** FAOSTAT.*

However, on a global basis, grain supplies have increased steadily and prices have been declining in inflation-corrected terms. Decline during the last five years has been particularly steep. Prices in 1999 were virtually identical to those in 1985 (uncorrected for inflation) (**Figure 10**). Projections by IFPRI and FAO indicate that if governments pursue appropriate economic policy and invest in agricultural research, cereal prices will continue their downward trend (Pinstrup-Anderson and Garrett, 1996). The cassava market will, for the most part, parallel these declining commodity prices. Rosegrant and Gerpacio (1997) project a price decline for cassava on world markets of 3.4% by the year 2020. While this is a lesser decline than projected for other roots and tubers, it represents a substantial challenge to growers.

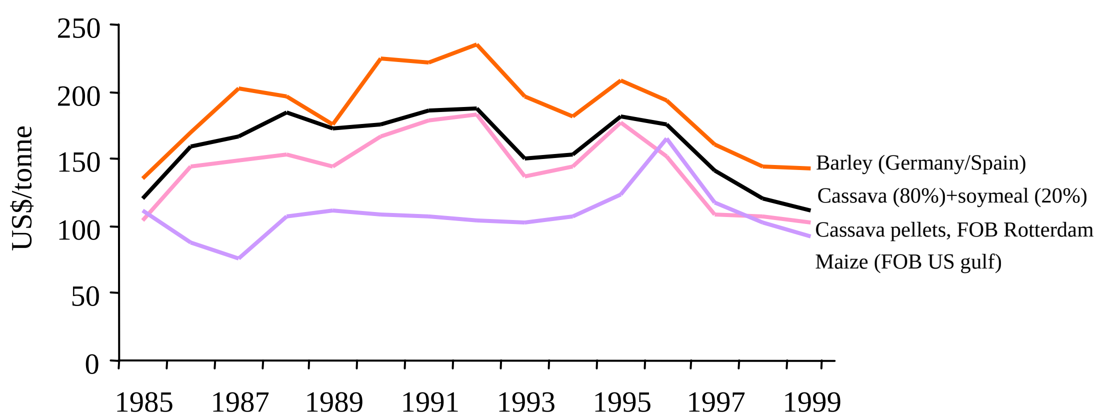

Figure 10.World prices of cassava and competing grains (unadjusted for inflation).
***Source:** FAOSTAT.*

4. The Environment

While a certain level of environmental consciousness has swept much of the world over the past twenty-five years, the actual progress toward ameliorating serious threats remains mixed. The industrialization of previously agrarian societies presents clear environmental threats, but seems to be far less serious than the heavy use of non-renewable energy by developed countries. Population increases in fragile environments often offsets progress in other areas.

The fact of global warming is broadly accepted, but the likely effects, and appropriate remedial measures, are highly controversial. Within the next decade there will be greater consensus as the sensitivity and reliability of monitoring devices improve, and more widely accepted models are developed.

5. Evolution of Farming Systems

Food for mass markets will increasingly be produced by managing larger units of production to take advantage of economies of scale. It is a normal outgrowth of competition within commercial agriculture. In Latin America, this will generally mean larger individual farms or land-holdings. In most of Africa and Asia, there will be greater need for associations among small-holders, and coordinated production by contract to vertically integrated production, processing and marketing firms.

The trend toward less biologically complex (e.g., monocropping) systems will spread throughout the tropics as crop risk is managed by inputs rather than diversity. However, irrigation will increase only modestly because of cost and supply constraints.

6. Science and Agricultural Research

Scientific advances underpin development. Four elemental shifts underway will define the agricultural landscape in the next few decades in developing countries: (1) the privatization of knowledge and technology; (2) the biotechnology and information revolutions; (3) the increasing policy focus on low-cost food supplies for urban centers as compared to income-generation and food security concerns for producers; and (4) increasing sector specialization in world markets; the trend toward specialized value-added traits for most commodities.

These shifts have fundamental implications for the gap between science in developing and developed countries. Without sweeping agreements on equitable interchange of information, genetic resources and technology between North and South, there will be a continual further eroding of competitiveness in developing countries. The recognition that, in the long term, this gap is detrimental to everyone, should drive new interest in mechanisms to improve investment in research in developing countries. During the next decade the large multi-national agricultural research firms will begin to see the developing countries as a major growth market for biotechnology-derived, IPR-protected technology. However, a turn-around in narrowing the science and technology gap that exists between developed and developing country capacity in science is not yet on the horizon.

7. Economic and Political Empowerment

The next decades will bring a widening gap between income levels within developing countries. This gap is already historically wide in Latin America, and continues in spite of a rising middle class. The inequities will be widely and intimately perceived through the pervasive reach of communications technology to even the poorest people. The natural reaction to this widening gap will be some form of search for justice. In the future, governments will be under relentless pressure to address these inequities, which will then be recognized as a global threat to social stability.

People will continue to strive for greater freedom of economic and political choices, and make those choices more wisely. This will be driven in part by education and the communications revolution, but also by the recognized failure of many systems that restrict these freedoms.

Empowerment is importantly a gender issue. It is expected that the next generation will be more conscious of the value and the right of gender equity.

8. Infrastructure

Subsistence farming requires virtually no infrastructure -- no need for purchased inputs, and no need for highways for reaching markets. Commercial agriculture, on the other hand, depends heavily on infrastructure. Rapid economic expansion and urbanization have outstripped the capacity of existing infrastructure, and created serious impediments to further investments and growth. Insufficient electricity generation capacity, outdated and inadequate telecommunications facilities, poor roads and inefficient ports are the most crucial infrastructure problems.

Purchased inputs for agriculture are for the most part available, but may not be used on cassava because of other constraints. There is little likelihood of major investment in infrastructure aimed solely at supporting cassava development, but the general development of the region will bring collateral benefits to growers, processors and consumers.

9. Institutional Resources

Cassava research in Asia is generally supported by departments of agriculture and/or universities, along with CIAT through its office in Bangkok. India and Thailand have major root crop centers with full interdisciplinary research teams. As in much of the world, government attempts to control spending growth have cut into agricultural research budgets in many Asian countries. The private sector has filled this gap in a few cases, but for the most part there remain serious deficiencies in support to the cassava sector.

Table 10 compares national research and development capacity across different disciplinary areas and sectors. Overall, the highest research capacity is in varietal development. Thailand has a clear predominance in broad-based R&D strength, with 22 researchers working on cassava (Ratanawaraha *et al*., 2000)

There are three cassava-specific networks active or semi-active in Asia. These networks have a considerable potential to facilitate and coordinate research, in order to make efficient use of scarce resources. Funding is a continual challenge, and none of the existing networks has been able to reach the potential that its members represent.

Cassava breeders in Asia formed an informal network in 1984 during a regional meeting. The group later incorporated agronomy, and became the *Cassava Breeding and Agronomy Network*, and later, simply, the *Asian Cassava Research Network*. It has held triennial scientific meetings and published widely-read proceedings. The network serves to inform members of research activities, provides guidelines and resources for germplasm exchange and testing, and coordinates specific regional projects with high regional priority. A coordinated series of soil fertility maintenance and erosion control trials were an important project of this network.

Table 10. Relative strengths of national cassava research and development systems in Asia.

	Varietal development	Pest/crop interactions	Crop/soil interactions	Processing/ marketing	Basic extension services
Thailand	✶✶✶✶	✶	✶✶✶	✶✶✶	✶✶✶
Indonesia	✶✶	✶	✶✶	✶	✶✶
India	✶✶✶✶	✶✶✶	✶✶✶	✶✶	✶✶
China	✶✶	✶	✶✶	✶✶	✶✶
Vietnam	✶✶	✶	✶✶	✶	✶✶
Philippines	✶✶	✶	✶✶	✶✶	✶
Malaysia	✶✶	✶	✶		

The *Cassava Biotechnology Network* (CBN) has acted as a stimulus to interest a number of research institutes and private companies in advanced cassava research since the late 1980s. The network has seen considerable fluctuation in support and coordination, but appears newly energized in the early 21^{st} century. Projects include work in propagation, transformation and regeneration, cyanogenesis and starch modification. The network is evolving toward a regional structure, in order to bring a better focus to addressing specific regional problems and opportunities.

The *Manihot Genetic Resources Network* (MGRN) is the newest of the networks, formed in 1992. It does not have specifically funded coordination or activities, and operates on an informal basis. Its principal activity in Asia has been to plan the transfer of the CIAT cassava core collection to Thailand to improve security of conservation, and to broaden the genetic base of Asian cassava. This transfer is presently underway.

C. OPPORTUNITIES AND CONSTRAINTS FOR SYSTEM IMPROVEMENT

1. The Resource Base and Production Technology

There are several fundamental issues surrounding development strategies that exploit marginal lands, both from the economic and environmental vantage points. Although less-favored areas make up only about 24% of the total land area in developing countries, they contain more than 36% of all the rural poor. The largest share of these people, 263 million, live in Asia. In the past, governments and donors adopted a strategy of investment in high-potential areas, since by definition, these generate more agricultural output and higher economic growth at lower cost. Even with these strategies, however, population growth and pressure on the environment have continued to worsen in less favored areas. A consensus is now evolving that critical investment in these areas is socially necessary, economically viable, and imperative for reversing serious land degradation.

Cassava can be a key component within this strategy. The comparative advantage that the crop has here is quite strong, but there are trends that could change this. First, other crops may begin to offer broader alternatives to cassava farmers. Breeders of several species, especially maize and sorghum, have paid more attention to stress tolerance in the past twenty years. There are certainly practical limits to which breeders can take a given species in adapting it to new environments, but there is also apparently considerable margin for improvement for most crops in stressed environments. This progress could displace cassava from some areas, and perhaps continue to push the crop toward the very poorest soils. The need for effective and economical soil fertility maintenance and erosion control will increase with this trend.

Secondly, farmers' increased purchasing power, and technology for soil stabilization, will allow improvement in some areas, from marginal to moderately productive conditions. This would also tend to displace cassava with higher value, more demanding crops. In either scenario, cassava will probably be pushed further toward the very poorest soils, exacerbating the risk of environmental degradation. Clearly, if there are crops that provide better income to growers than cassava, and/or are less of a threat to the environment, these should be encouraged.

Most national cassava programs have given research priority to resolving production constraints, especially through varietal improvement, and crop and soil management. This approach evolved from the era of explosive growth in cassava markets, and the need to meet market demand with increased production. As the challenges of marketing cassava products become more acute, and environmental concerns more apparent, programs are shifting the balance of research investment to include both demand and supply factors.

In an exercise to quantify constraints on global production, processing and marketing, CIAT surveyed a broad range of scientists and others knowledgeable about the cassava system, for their experience and perspectives (Henry and Gottret, 1996). A follow-up study (Van Norel, 1997) obtained further information from national programs, intending especially to upgrade information on post-harvest constraints. **Table 11** summarizes key information for Asia, with comparison to global estimates. In spite of the rather hypothetical nature of some of these estimates, the relative values across categories of constraints, and across continents, give a tangible basis for prioritizing research. The following sections review the constraints that could be targeted to achieve the greatest economic impact.

a. Yield potential

Intrinsic yield potential of varieties may be the single most important factor limiting yields in Asia (**Table 11**). The definition of yield potential for cassava needs to be considered within the context of the crop's predominant role in Asia as an upland crop, in poor soils and with irregular rainfall. The CIAT survey specified a moderate level of management inputs, within the reach of most farmers of the region. This would be a *moving target*, presumably increasing as agriculture develops.

Table 11. Cassava constraints analysis for Asia, with comparison to global.

Constraints	Yield gain from alleviating constraint (%)	Yield gain from alleviating constraint ('000 tonnes)	Asia's contribution to global yield gain (%)[a]
Production			
Soil management	35	17,067	36
Crop management	21	10,291	22
Intrinsic yield potential	24	11,384	31
Climate	11	5,153	25
Diseases	2	929	3
Pests	3	1,478	7
Total	**96**	**46,301**	**2396**
Post-harvest			
Quality	13	6,390	31
Processing	4	1,806	30
Product marketing	4	1,727	47
Total	**21**	**9923**	**32**
Total Cassava Sector	**116**	**56,224**	**24**

[a]Yield gain in Asia as percent of expected global yield gain from alleviating a given constraint.

Source: *Adapted from Henry and Gottret, 1996.*

For the medium-term future (10-15 years), this would rarely include irrigation, with the exception of existing irrigated areas. The definition specifies nutrient use at low to moderate levels, but with most other agronomic practices at optimum levels -- land preparation, planting systems (time of planting, stake position, spacing), and weed control. Within these parameters, the analysis suggested a possible 26% yield gain across 89% of the Asian cassava-growing area, or a 24% potential increase over all Asia.

A number of pathways are possible for increasing that potential. These can be broadly divided into approaches that, (1) increase harvest index (direct a greater proportion of photosynthate to the roots as compared to top growth); and/or (2) increase total biological yield. Much of the research in recent years has aimed at improving distribution of photosynthates, but both approaches have been successful. Probably the greater difficulty and greater potential lie in improving total biological yield, since many individual mechanisms may be involved -- increased efficiencies in photosynthesis, nutrient uptake or utilization, and starch synthesis, for example. Breeders are already combining higher biological yield and higher harvest index as an effective multi-pronged strategy to improve yield potential (Kawano *et al., 1990).*

Biologically, cassava is relatively straightforward as a target for genetic improvement. Two particular constraints confront the breeder: a low reproductive rate, either by vegetative or sexual means; and a long breeding cycle. On the other hand, vegetative propagation allows additional options in design of breeding schemes.

Until 15-20 years ago, the germplasm base in Asia was very narrow, with most countries relying on only a handful of varieties. This was undoubtedly one of the principal constraints to improving yield potential. Thailand was the extreme case, where all but a small percentage of area was planted to Rayong 1. Indonesia has reasonably broad diversity, but still narrow in comparison to Latin America. With the establishment of the CIAT Regional Office in Bangkok in 1983, one of the main thrusts has been to increase genetic diversity in the region. Typically, breeders introduce ten to thirty thousand seeds, each genetically distinct, every year from nurseries in Colombia. Even though only a small fraction of this diversity ever reaches farmers' fields, there is little doubt that far more genetic diversity was introduced into Asia in the past twenty-five years than in the previous two hundred.

b. Soil management

Significant constraints from low soil fertility and erosion affect much of Asia's cassava. Nitrogen is frequently the limiting nutrient, in contrast to Latin America, where potassium and phosphorus tend to be more limiting (Howeler, 1995; 2001). Fertilizer recommendations have been established on the basis of extensive soil analyses and fertilizer trials. Fertility constraints are as much a function of education and credit availability as the lack of scientific information. In India, China, Vietnam and Thailand, about half the farmers use small amounts of fertilizer, usually not at economically optimum levels. In Indonesia, associated crops tend to be fertilized, with some residual benefit to cassava. Elsewhere, fertilizer use is very limited except for special situations, such as large commercial plantations. It is estimated that economically optimum use of practices to improve soil fertility could add 22% to current yields across the region, or over ten million tonnes.

Limiting soil erosion is a challenge in virtually any system involving annual crops on sloping fields. Cassava has two features that increase this challenge somewhat: it is easy to plant on steep slopes, with minimal land preparation; and it has a relatively slow rate of canopy formation. On the positive side, the long growing season means that the soil is covered by vegetation and is undisturbed over a long period of time once the canopy is established (Howeler *et al*., 2000). The survey estimated potential yield increases of 0-10% by adoption of erosion control practices. More importantly, erosion control is indispensable for sustaining longer term productivity. Soil fertility maintenance and erosion control are closely inter-related. An obvious relationship is the loss of nutrients that accompanies erosion. A more subtle association follows from the effect of better fertility on more rapid canopy development. In trials throughout Asia, as well as Latin America, appropriate fertilization is consistently one of the most cost-effective ways to reduce erosion. It may not be enough on its own to reduce erosion to acceptable levels, but it is often a good starting point (Howeler *et al.,* 2001).

c. Crop management

On a regional basis, Asia has higher average yields than either Latin America or Africa. Farmers tend to manage their crops intensively, because of high population density and the need to optimize productivity of land. Hence, only modest yield increases can be expected from improving crop management (excluding *soil management*) in the Asian situation. According to the CIAT survey, quality planting material (*stakes*) and better weed control could contribute 7-8% each to yield, while optimum land preparation and spacing would provide modest yield improvements of only 3-4% each.

Farmers are often unaware of the multitude of influences on stake quality. Many constraints do not conspicuously affect stake appearance, and are not recognized as yield-reducing constraints. Given the generally low incidence of pest and disease problems in Asia, it is likely that sub-optimum quality of planting material derives primarily from a complex of physical rather than biological constraints. These may include: nutrient status, as an outcome of soil conditions or length of storage; poor stake selection (too young, too old, etc.); poor storage conditions; or poor post-storage management.

Weed control consumes the second highest level of labor input among crop management operations in Asia, from a low of 13 mandays/year in Malaysia and the Philippines, to a high of 97 in Tamil Nadu, India. In general weed control is good; survey results indicate inadequate control in about 37% of area planted, for an overall potential yield increase of about 7%. Most weed control is manual, but herbicide use is increasing in all countries, and is most wide-spread in Thailand. As demand for herbicides grows, agro-industries will find it profitable to develop herbicides targeted more specifically to the cassava plant and cropping systems. Currently herbicides are adapted from other crop systems to cassava, and often have not been adequately researched to optimize their use.

A herbicide-resistant cassava could prove highly beneficial to growers. Herbicide resistance, especially to glyphosate, is already incorporated into several crops and is widely used in the United States and Argentina, especially in soybeans and maize. The last few years have seen some increase in consumer concern about food safety and environmental impact for these genetically engineered crops. So it is somewhat uncertain how quickly the technology will spread to other crops, even where there is high potential grower demand.

d. Climate constraints

Drought imposes severe constraints on cassava growth and yield in parts of Asia, particularly northeast Thailand, eastern Java, and southern India (especially Tamil Nadu). Survey results indicate a potential yield increase of 9%, through a combination of practical management, and breeding for varietal adaptation. Management can include improving the soil's water-retaining capacity through incorporating organic matter, surface mulching to reduce evaporation, or ridging to capture maximum rainfall. No increase is projected through expansion of area under irrigation.

e. Pests and diseases

Perhaps the single most striking contrast between production in Asia and elsewhere is the severity of pest and disease constraints. With a few important exceptions, these constraints are very limited in Asia. The Indian cassava mosaic disease, with etiology and symptoms similar to the African strain, occurs exclusively in India. Control is mainly through resistant varieties. The survey estimated a potential medium-term yield increase of

6% within the affected area. This low figure reflects the fact that moderately resistant varieties are already widely used by farmers. Root rots and bacterial blight are endemic in the more humid environments, especially in the Philippines, and the sub-tropics. Root rots can be controlled mainly through management (rotation, land preparation) and bacterial blight through resistance breeding.

Among the arthropod pests, only the red spider mite is of broad importance. Its control through host plant resistance or biological control could contribute about 2% to overall yields in Asia. The pest and disease situation will require constant monitoring, since introduction of new pests or pathogens, or changes in cultural practices could set the stage for new yield-reducing outbreaks.

2. Production Potential

The sum of individual components defines a potential yield increase of 96% by moderate alleviation of constraints. Given the existence of technology components to address nearly all these constraints to some degree, it should be possible to test the reality of these figures. The Asia Cassava Research Network has carried out well-managed trials in Asia for almost two decades. While breeding trials are aimed mainly at identifying potential new varieties, the trials also include good soil preparation, optimum plant spacing and weed control, and moderate fertilizer use. Yields of the hybrids, under good management in representative cassava areas, have been two to five times greater than the national average. Most of this increase appears to be from management, since hybrids yielded about 30% more than local varieties, similar to the potential increase projected by the constraints analysis.

3. Post-harvest

In the context of the survey, post-harvest constraints do not quite fit into the same analytical scheme as production factors, for projecting yield gains from constraint alleviation. In order to be consistent with units for yield gain, the post-harvest elements are divided into three parts: quality improvements are based on expected price premiums; gains in processing on reduced costs per unit; and gains in marketing on reduction in marketing margins (mainly reducing consumer prices). These estimates have some highly subjective components, and are biased toward the very conservative side.

Improved root quality will have the highest overall positive impact on post-harvest constraints (**Table 11**). Two traits are especially relevant: starch and post-harvest deterioration. Starch content is key to nearly every use of cassava in Asia, and especially the industrial sectors of starch extraction and pellets for animal feed. Raising starch content by breeding is clearly feasible, and has been a major objective of genetic improvement in most programs. Much of the recent success of new varieties in Thailand derives from a higher starch content as compared to the landrace variety, Rayong 1 (CIAT, 1996).

Cassava roots normally begin to deteriorate within a few days after harvest. The processing industry has had to develop elaborate systems for coordinating supply of raw material with processing capacity. This has often worked best when roots are converted at the farm or village level to a more stable product, such as dried chips. When fresh roots are delivered to a central factory, many small producers must coordinate their harvests. Even under the best circumstances factories processing fresh roots cannot operate at full capacity throughout the year. Extending the shelf-life of fresh cassava roots could add valuable flexibility to cassava management systems.

Currently-known management techniques include refrigeration, paraffin-coating of roots, and treatment with microbial inhibitors, followed by storage in plastic bags. None of these are practical for managing large volumes of roots destined for processing. A genetic approach seems most appropriate, given the ease and low cost of implementation. Longer term, there is reason to believe biotechnology approaches could offer innovative solutions (Wenham, 1995).

D. CASSAVA AS A CATALYST FOR DEVELOPMENT: ROLES AND STRATEGIES FOR RESEARCH

Cassava thrives in Asia because of the ability of growers, entrepreneurs, R&D institutions, and policy-makers to adapt to evolving physical, biological, economic and social environments. Optimizing the role of cassava as a catalyst for development in the coming years will build on these attributes and resources. Strategies revolve around the constraints and opportunities described in preceding sections.

There are three broad priority areas for intervention by R&D institutions: (1) stimulating higher demand through market development; (2) adding post-harvest value through process and product development; and (3) improved production systems through technology for increasing production efficiency and profitability. In addition, institutional support, including education of policy-makers, is an *umbrella* activity covering all these areas. Interventions in production, processing and marketing cannot be undertaken independently -- there is continual interaction and feedback among these system components.

1. Market Development: Stimulating Higher Demand for Cassava Products

Sometimes market demand drives product development, and sometimes new products create market opportunities. For either to succeed, products and markets need to develop in coordination.

Cassava markets are of two broad types: markets where cassava competes directly with other carbohydrate sources; and markets that make use of the specific traits of cassava. The non-specific markets include animal feed and most of the uses for starch. It is by far the largest current type of market for cassava in Asia. These markets will be driven by macro-economic forces such as growing demand for meat in developing countries, and the ever-widening range of uses for starch. The cassava sector, mainly processors, will need to drive product development for replacement of existing ingredients, including convincing the user that the alternative product is as good, if not better, than that already used.

There is a clear need to promote research on markets that exploit cassava's unique starch characteristics. In markets where starch-consuming industries are beginning to use functional ingredients, tremendous market opportunity presents itself. Success depends on the ability of the starch industry to assist the processors in technical issues relevant to application development. This is a strategy with considerable risk, as noted by Ostertag (1996). The technology for starch conversion is well-advanced and evolving rapidly. New technologies will allow native starch from almost any source to be converted to specific market needs, and thus the differential between raw materials tends to disappear. There is, nonetheless, considerable concern about the engineering of microorganisms (for converting starch) that could have unknown consequences in the environment, or the health and environmental effects of chemical modification. With that caveat, there certainly is still some opportunity for developing markets that favor cassava starch, or expanding existing ones. Success will come mainly from partnerships between public R&D institutions and the private sector.

2. Process and Product Development: Adding Post-harvest Value

A subsistence crop has a very short pathway from production to utilization -- it is usually destined either for direct consumption by the producer, or fed to animals to obtain meat, eggs or milk. The global trend in commodity markets is to continually add value to products as consumers increase their economic position. Low-value raw products at the farm level pass a series of transformations, each of which produces income or other value to a particular consumer. In developed countries, even basic food products may be valued at hundreds of times the price received by the farmer for the raw product. A box of white rice in a U.S. grocery store costs the equivalent of about $3000 per tonne. A box of rice-based breakfast cereal may sell for the equivalent of $8,000 per tonne. That cereal will have passed through ten or fifteen value-adding steps before reaching the consumer. As consumers become more affluent, the more they are willing to pay for the convenience, quality, status, aesthetics, etc., that these value-added steps represent.

Cassava in Asia has moved well beyond the subsistence stage; there is almost always a series of steps between producer and consumer. Each of these steps adds value to the product, and someone receives income from that added value. Often, public-supported R&D institutions have an interest in making the rural poor the beneficiaries of the highest possible proportion of this added value. This is not easy. Adding value usually takes place after cassava leaves the farm, and the grower may receive little benefit. *A thriving cassava sector is not necessarily indicative of success in meeting targeted development goals*. On the other hand, a cassava-based development strategy has little chance of success unless it taps into markets with potential for overall demand growth, even if a large share of benefits do not come back to the growers. This is the perennial conundrum of rural development, probably even more formidable for a cassava-based strategy: how to target a reasonable proportion of development benefits to cassava growers when the driving force of development is the commercial sector?

Without a tradition of consuming fresh cassava, Asia has been a leader in processing innovations to meet demands of new and changing markets. All of these began at the household and cottage-industry level. At the level of household processing, Indonesia is the leading example of diversity and innovation. Also at the household level, Thailand has fine-tuned chipping and drying to a highly efficient and cost-effective system that gets a high quality product to the market in a timely manner. In Vietnam and China, farmers feed cassava to pigs to obtain a value-added and more marketable product.

Animal feed and starch are the principal growth markets for the medium-range future. Both have a very broad range of levels of sophistication -- from rudimentary on-farm exploitation to high-tech industries. Across this range, there are interventions that have high potential to benefit the rural poor. The principal need for processing innovations lies in the early stages of product conversion. These are the stages closest to the producer, and more likely to bring benefit to the rural poor. They are the stages where a product is converted to something that is more likely to be used by an already-developed industry. For example, the animal feed industry can very readily use hard cassava pellets in balanced rations. No new technology is required. However, converting fresh roots to hard pellets came from a series of innovations specific to cassava's characteristics. Likewise, the efficient extraction of high quality starch from cassava requires technology specific for cassava, but the use of that starch in any number of industries is often the same as for any other starch. A major focus of cassava R&D institutions should be on innovations that bring additional value to growers.

The animal feed export sector, which so much defined the dynamics of the Asian cassava industry for more than twenty years, is still a major force for economic development. It is, however, a market that will require every innovation and efficiency just to retain current market share, because of the increasing competitiveness of coarse grains on world markets. No country of Asia is basing its plans for the cassava sector on dramatically expanded possibilities for export of cassava pellets.

Demand for animal feed will continue rapid expansion in developing countries. It is a growth sector for which several cassava-growing countries should be able to create viable *internal* industries. These industries may be successful across a range of scales of operation -- from rudimentary on-farm feeding of pigs to large, intensive poultry operations. There is, however, as in most industries, a continual move toward larger operations that exploit economies of scale. The animal feed market will thrive with or without a cassava component. For cassava to reach its full potential participation will require aggressive R&D input. The animal feed market for cassava is a very mature market. The potential for additional market share lies in cost reductions, and added value by way of conversions that target specific markets. For example, the pelleting industries could develop capacity to mix complete rations, or even begin contracting the growing of chickens or pigs.

Because of the technical level of the starch and starch derivatives industries, there are possibilities for adding value at the farm level for this sector, by improving the level and consistency of root quality. The starch industry will contribute to rural development mainly through a higher demand for raw roots, and premiums for starch content and quality. Research should continue to focus on pre- and post-harvest crop management that meets the increasingly demanding standards of industry.

Markets for flour substitution seem to be more difficult to penetrate on a large scale. Quality and supply are very critical. There has been a tendency for demand to fluctuate too widely to interest major commitment from processors. This market needs continued research because of its high potential if price-competitiveness, high quality, and constant supply can be assured.

3. Improved Production Systems: Increasing Efficiency and Profitability for Farmers

In broad terms, producers have three possible alternatives to increase their net income from growing cassava: (1) *increase yields*, to reduce per-unit production costs; (2) *reduce costs*, while maintaining production levels; or, (3) *increase the value* of the product offered for sale while keeping costs and production levels the same.

Of course these are not mutually exclusive pathways, and each category has a number of possible variations. Successful crop technology in this century has been overwhelmingly based on the first of these -- on use of inputs to increase yields. The g*reen* *revolution* set the tone for crop improvement strategies, with emphasis on *total system output*. Consumers have been the greatest beneficiaries, with more abundant food at lower prices. It is a strategy that is eminently sensible in a world of food shortages, where increased supply has high social priority. The developing world is now a mosaic of food shortages and food surpluses, and a monolithic strategy for increasing agricultural production is clearly not a universal goal. In Asia's comparatively mature market economy, cassava producers can benefit economically from expanded areas of production, lowered production costs, higher productivity per unit of production cost, higher market value, or value-added features. They can benefit nutritionally both from the greater purchasing power of higher income, and from nutritional enhancements to cassava itself. Indirectly, they can benefit nutritionally from an increase in production that permits feeding cassava to animals. Less tangibly, technology provides avenues for lifestyle improvements such as less arduous physical labor inputs, or more time to pursue education or leisure.

a. Environmental resources

Farming practices are inextricably linked to environmental resources. Characteristics of the environment set limits on the types of agriculture that are economically feasible; and in turn agriculture can enhance or degrade the environment where it is practiced. Tradition, education, regulation, and economics all influence a farmer's attitude and relationship with the land. Generally, education and regulation can be applied successfully to environmental stewardship only if the economics are favorable. On the other hand, farm profitability is not in itself necessarily an incentive for adopting practices that improve the environment.

This interlacing of attitude and economics is a complex target for R&D institutions. Often the technology for preserving the environment is not complex, but there are inadequate economic incentives.

b. Crop management

The greatest returns to research investment in crop technology development should be for interventions that lower the very high labor inputs into cassava, increase yield, and increase starch content.

(1) *Agronomic practices***.** Crop management is already more intensive in Asia than elsewhere. Rearrangements of existing practices or resources (i.e., if no *new* external inputs are applied) probably offer limited potential for improved productivity or profitability. For example, changes in stake planting position or plant density normally offer little advantage, unless in conjunction with another major system modification. There are good possibilities for increasing profitability with management in the areas of fertilizer application and efficient weed control. There are, nonetheless, substantial environmental concerns with both these inputs, and these must be addressed as part of any technology development. The fact is, however, that cassava will have great difficulty competing in the marketplace with crops where high efficiencies of production are achieved with intensive inputs, unless some of those same inputs are applied to cassava.

The economic response of cassava to fertilizer application is well-established (Howeler, 2001a). The constraints to increased use are socio-economic rather than technical. Farmers usually do not have cash reserves that can be tied up for a full year, between planting and harvest. Commercial or government-supported credit are not common. Nonetheless, most farmers now have experience with purchase and use of fertilizer on rice, and translating this to use with cassava should not be an insurmountable obstacle when the economic return is favorable.

(3) *Mechanization***.** Cassava is still a very labor-intensive crop for most growers. Labor productivity has not been a major goal for cassava research, often based on the assumption that public institutions should be wary of technology that displaces labor in situations where underemployment is already high.

In any case, mechanization is typically difficult for cassava -- *economically* because of small landholdings, and *physically* because of cultivation on slopes and uneven terrain, or intercropping. While no-til systems have had limited success in cassava, there may be more potential for *zone tillage* systems, where a type of deep-penetrating tool is pulled through the soil only along the row to be planted. This leaves nearly all the residue on the surface for erosion control, while creating a tilled, aerated zone for rainwater penetration and root development.

The nature of the plant itself also mitigates against easy mechanization. Planting pieces are bulky and irregular in form. Harvest may need to be in a two- or three-stage process, first to cut stems for planting material, then to lift roots, and finally to remove individual roots from the root mass. Mechanical harvest is energy-intensive because of the size and shape of roots. Most mechanization developed for cassava is only appropriate for large commercial plantations, on level, well-prepared land. There is a need for smaller scale, flexible mechanization to manage some of the more labor-intensive tasks for cassava. Asia has typically been a leader in small-scale mechanization, and this industry will develop spontaneously as labor costs rise to the level of justifying the investment. There would be considerable benefit to partnerships between universities/research institutes and private industry to develop mechanization for cassava.

c. Varietal development

Cassava has moved through three *mega-phases* of genetic improvement, characterized by a focus on: (1) yield potential; (2) production efficiency under conditions of environmental stress; and (3) incorporating value-added traits with (1) and (2). This latter phase is in the initial stages, and will probably define cassava genetic improvement in Asia for the next several years.

Cassava has a relatively long breeding cycle compared to many crops. And after successful new varieties are developed, distribution is slowed by the low multiplication rate. In Thailand, both government and private industry participate in promoting new varieties. In India, the extension service has developed innovative methods for facilitating distribution. However, in most countries, distribution relies mainly on informal farmer-to-farmer channels. National programs are now recognizing the importance of extension service involvement in variety promotion.

Many Thai farmers have had considerable exposure to new varieties through various promotion channels. Elsewhere, the practice of introducing and evaluating varieties through extensive on-farm trials is less common. The initial tests by farmers that prove the value of a new variety can translate into a continued, long-term interest in variety evaluation, and thereby greatly simplify the job of the extension service. If the momentum for adopting new varieties grows strong enough, there could eventually be motivation to bring the private sector into the picture to develop and sell varieties. This will be difficult, however, given the ability of farmers to save their own seed from one planting to the next.

The bottom line is that public support for cassava breeding will need to remain strong. The ongoing success of new varieties is significant. This will generate widespread interest in accelerating the pace of variety development, and in expanding the options in terms of varietal characteristics offered. Response to these demands will only be possible with continued, and increased, investments in research.

Breeding offers possibilities of adding value to the products that growers move to the marketplace. A prime example is development of the high starch varieties developed jointly between national programs and CIAT. Although higher starch varieties were available early in Thailand's breeding program, the real impetus for their adoption and further development did not come until industry began paying premiums for this trait. The time is now ripe to move into more advanced value-added traits – because the diversification and specialization of industry create a demand, and also because the technology for targeted genetic modification of cassava is on the horizon. Genetic transformation and regeneration will open the door for applying technologies that are already routine in other crops (insect resistance, herbicide resistance), but more importantly for mapping a future for cassava that meets its specific production and market needs and opportunities. Partnerships involving all sectors will be the key to identifying appropriate research goals, as well as funding and executing the research. Some of the areas with highest potential to provide broad benefits through value-added traits are genetic modification of starch characteristics, tailored to specific markets; and increased post-harvest root storability by genetic means.

4. Institutional Support

Viability of the cassava sector in Asia has been very much the result of both private and public interests. Process, product and internal market development has been primarily in the hands of the private sector. Export development, on the other hand, has had very strong governmental support. While there are some notable examples of private sector participation in support to cassava research, the movement in this direction has been very slow. There is no doubt that in Asia cassava will continue as a basic energy source for food, feed and industry. If public support to research were to decline substantially, there may even be private funding to take on some of the research needs. Certainly, though, the private sector will have a very different development agenda, which would likely include lower priority for directing benefits to the rural poor. Social goals such as food security, poverty alleviation, equity and environmental protection, do not normally attract large sums of private sector investment. On the other hand, private enterprise seems to have a far better track record than does government, of successfully establishing efficient and profitable business practices. It is apparent that the potential synergy between public and private sectors is worth developing further.

Given that cassava producers will rely heavily on public research investment for at least a few more decades, the planning for adequate support is crucial. This support is needed for training of scientists, research infrastructure, and operational costs. The Asian countries that are developing rapidly might well take responsibility for full funding of cassava research. Others will be hard-pressed to provide for more than rudimentary programs, and will need outside support.

R&D institutions can have an important role in policy analysis, as an educational resource for policy-makers who need to have access to comprehensive and unbiased information. With few exceptions, cassava producers have little political clout to influence policy that affects their ability to earn a livelihood. Development organizations can take the role of empowering the cassava sector to effectively present its interests before policy-makers. Farmers' organizations can be highly effective policy lobbyists, but these are still not common. Industry and commodity organizations are often well-positioned to speak for the interests of growers, processors and marketers. They usually recognize the need for a healthy total system, for any one sector to benefit. Prominent examples of such groups are the Thai trade associations. Their principal activities are in the realm of industry promotion and trade, but they also promote supply-side benefits such as training of cassava farmers and the distribution of new varieties by the Thai Tapioca Development Institute (TTDI).

Cassava networks have not been active in policy debate, but this is a role for which they have some unique qualifications. The Asia Cassava Research Network, as the only one with a strictly regional focus, is in the best position to take on policy issues. While an international network would have limited direct voice in national policy debates, it is well-positioned to provide individual members with information and technical backup.

E. CONCLUSIONS: ORGANIZING FOR SHARED SUCCESS IN A COMPETITIVE WORLD

Market competition is becoming the defining trend that drives success in agriculture. Competition, brought about in large part by the global trend of more open markets, is almost universally welcomed by consumers, who benefit from more choices and lower prices. But it is a *double-edged sword* for growers. Market alternatives may be greatly expanded, but successfully entering any of them may require substantial adaptation in production, processing and distribution systems. In particular, cost efficiencies become critical, along with quality and timeliness of production. This can be a major challenge for cassava, when it confronts a commodity like maize, with a long history of global commerce and a massive research support system. On the other side of the equation, more demanding markets also open opportunities for specialized products outside the mainstream commodities trade. Cassava has particular possibilities in snack food and specialized starch markets, where it does not compete directly with other energy sources.

Perhaps the most profound lesson of the past is the critical importance of integrated development of production, processing and marketing components of the system. There are now several models where this type of broad integration has shown both some of the potential pitfalls and the benefits of an integrated approach.

The urgency of finding solutions to today's problems in food and agriculture is clear, and the tools to accomplish this are at hand. The greatest scientific advances in recent years have often been the outcome of partnerships -- between public and private concerns, among countries sharing common problems, and among thousands of motivated people sharing complementary skills and information. Communications technology now allows breaking many of the seemingly intractable barriers to developing effective partnerships – across geographic distance, across professions and disciplines, and across belief systems.

In February of 2001, two of science's most respected journals, *Nature* and *Science*, collaborated to publish results of the complete mapping of the human genome. It is a momentous landmark accomplishment in our understanding of life. It is also a powerful lesson in the advantages of broad-based collaboration among private and public sector institutions, and a sobering reminder of the need for long-term vision and commitment of funding. On the surface there may seem to be little connection between this level of highly sophisticated, lab-based research, and the plight of cassava farmers in difficult tropical environments; but unless connections are made between the best of science and a general benefit to all of society, we are investing poorly in our future.

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CASSAVA BREEDING AND VARIETAL DISSEMINATION IN VIETNAM FROM 1975 TO 2000

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ABSTRACT

Cassava breeding and varietal dissemination in Vietnam initiated in 1975 after Vietnam was unified. The cassava program in Vietnam began to cooperate closely with CIAT and became part of the Asian Cassava Research Network in 1988. Thanks to the introduction of new high-yielding varieties from Thailand and the adoption of improved cultural practices, cassava production in Vietnam has made remarkable progress. Before 1985, Gon, H34 and Xanh Vinh Phu were the most popular cassava varieties. Between 1986 and 1993, HL20, HL23 and HL24 were selected from a local germplasm collection by Hung Loc Agricultural Research Center (HARC) and these varieties have been grown extensively in South Vietnam, with areas of about 70,000 to 80,000 ha planted annually to these varieties. More recently, the Vietnam Cassava Research and Extension Network, working in close collaboration with CIAT, Vedan Vietnam Enterprise Corp. Ltd. and other cassava processing factories, obtained further achievements, especially in the area of breeding and varietal dissemination. Six new high-yielding varieties were recommended and disseminated for production during 1993-1999; these are KM94, KM60 and SM937-26 (three high-starch and high-yield varieties for industrial processing), and KM98-1, KM95-3 and KM95 (three multipurpose varieties suitable for food, feed and processing, with early harvestability and an extended harvest time). The growing areas of KM94 and other new improved varieties were about 60,000 ha in the crop year 1999/2000. The high-yield/high-starch varieties have brought to the producers additional benefits of about 787 billion Vietnamese dong (US$ 60.78 million) during the six years from 1994 to 1999 in five provinces: Dong Nai, Binh Phuoc, Binh Duong, Tay Ninh and Ba Ria-Vung Tau. More than one half of the additional benefits went directly to cassava farmers; the rest was shared among cassava processing factories and traders.

At present, Vietnam has a large and promising cassava germplasm collection. In the future, new varieties will be developed in order to satisfy the demand for higher production and additional processing. The present research direction is to develop high-starch and high-yield varieties by introducing new breeding materials, crossing and applying biotechnology in breeding; to multiply planting material of new varieties; and to enhance the adoption of sustainable cassava production practices.

1. INTRODUCTION

Vietnam has become one of the major cassava producing countries in Asia. The total capacity of cassava processing factories is about 1,080 tonnes of dry starch/day (**Figure 1**). With the development of the processed food, feed and pharmaceutical

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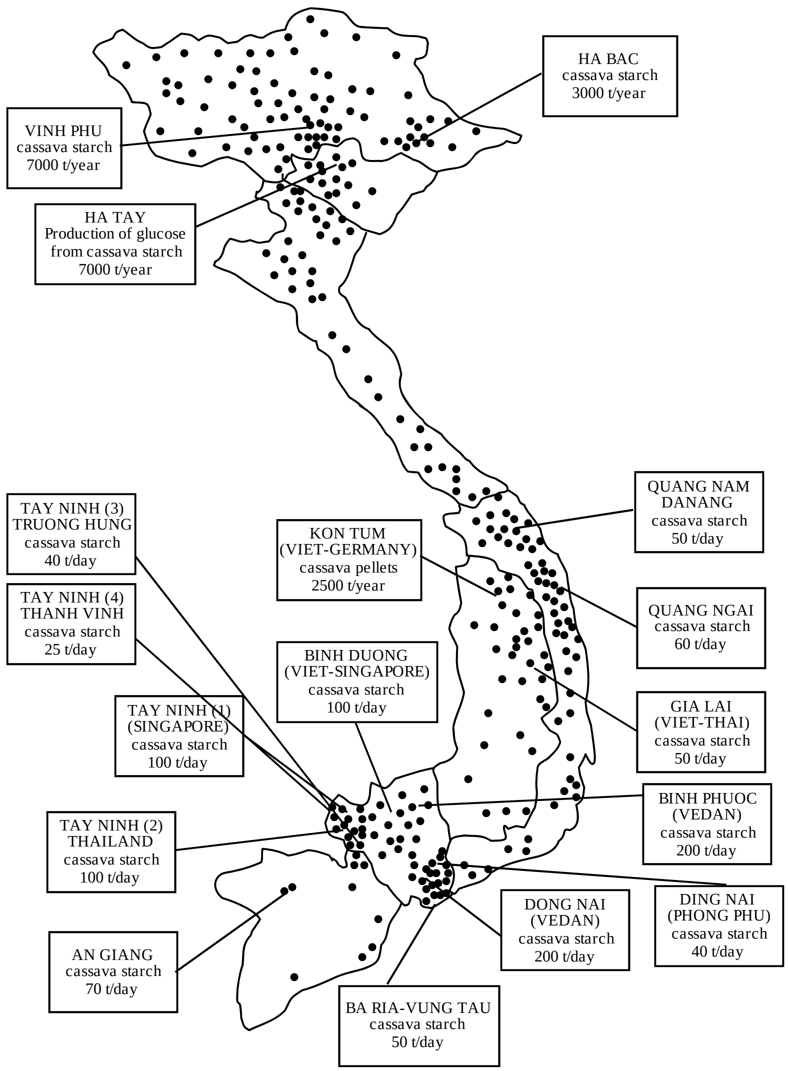


Figure 1. Cassava production and processing areas in Vietnam; each dot represents 1000 ha of cassava in 1997.
Source : *Adapted from General Statistical Office 1998 and Projects under Promotion by the State Committee for Cooperation & Investment (SCCI) 1986-1998.*

industries, cassava is rapidly changing its role from a traditional food crop to an industrial crop.

Recently, the breeding and dissemination of new cassava varieties have contributed to major improvements in cassava yield and production, especially in South Vietnam. Cassava selection began in 1975, soon after the unification of the country, by collecting and evaluating local germplasm. In 1988, Vietnam began cooperation with CIAT and began taking part in the Asian Cassava Research Network. This cooperation gave Vietnam new opportunities of germplasm material introduction for the cassava varietal improvement program. The objectives of cassava breeding in the last decade were:

1. Selection and development of high starch yield varieties for industrial processing, and
2. Selection of sweet cassava varieties with short duration and having an extended harvest time and high starch yield for human consumption.

Toward the 21st century, the Vietnam cassava breeding program will focus on crossing and introducing promising materials as well as applying bio-technology in breeding.

2. MATERIALS AND METHODS

2.1 Materials

Vietnam cassava breeding activities have been conducted mainly at Hung Loc Agricultural Research Center (HARC), belonging to IAS in Ho Chi Minh city; by the Root Crop Research Center (RCRC), belonging to VASI in Hanoi; and by Agro-forestry College of Thai Nguyen Univ. (TNU), Thai Nguyen city. About 128 accessions of cassava germplasm are maintained at VASI (Nguyen Thuc Nhan *et al*., 1996) and about 72 accessions at HARC (Hoang Kim *et al*., 2000). A total of 74,718 F_1 hybrid seeds were introduced, 48,895 seeds from CIAT/Colombia and 23,180 seeds from the Thai-CIAT program. The Vietnam Cassava Program also produced 2,643 seeds (**Table 1**).

At present, KM94 (the Thai variety Kasetsart 50) is the most popular new variety. Two other varieties that can be used for industrial processing are SM937-26 and KM60 (Rayong 60). Three varieties for multipurpose use are KM95, KM95-3 and KM98-1. Besides the good varieties that have been selected and released, other promising breeding materials are continuously being introduced in the form of sexual seed from CIAT/Colombia and the Thai-CIAT program, in order to strengthen the Vietnam National Cassava Breeding Program.

2.2 Methods

Establishment of the National Cassava Research and Extension Network

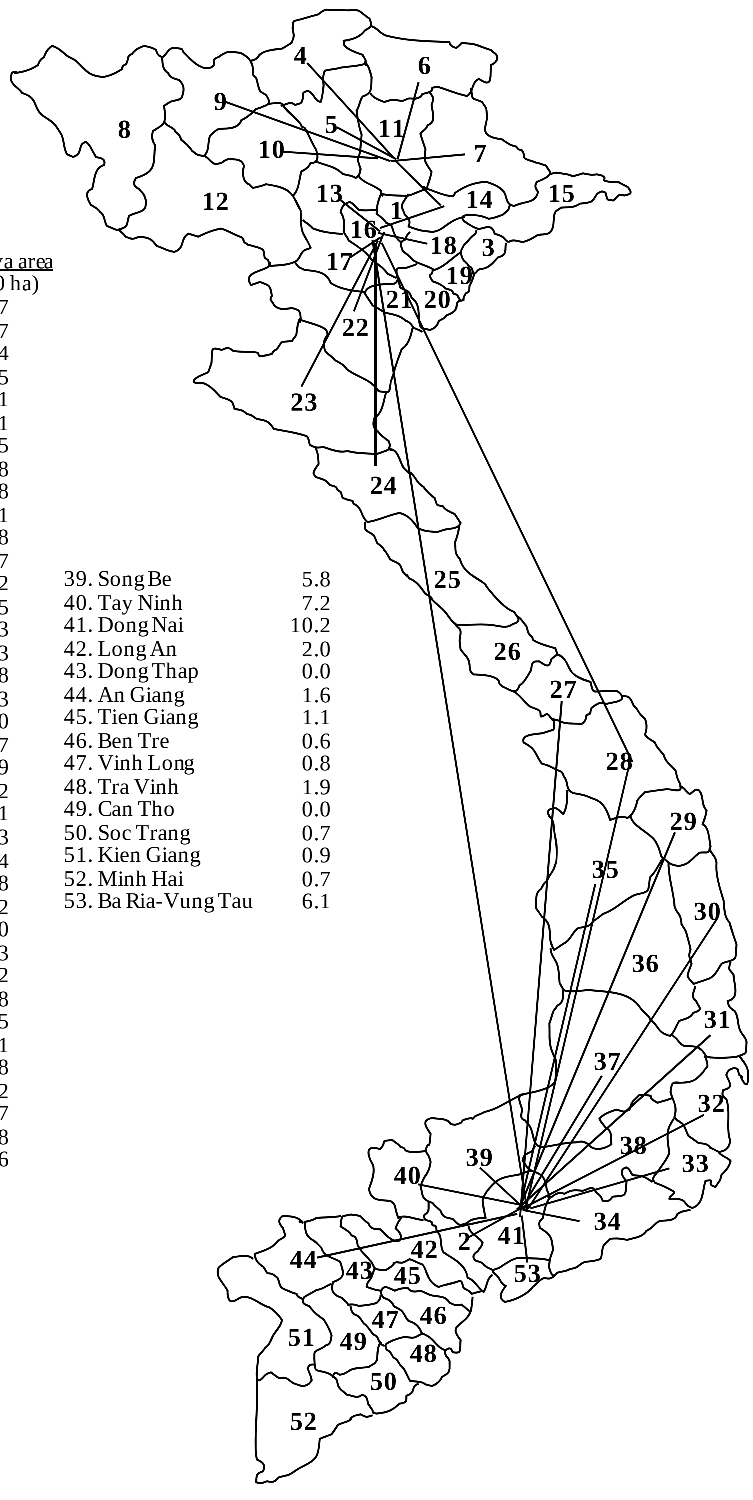
At HARC in Dong Nai province there are ten cassava breeding experiments conducted every year, including two Standard Yield Trials (SYT_1 and SYT_2), three Preliminary Yield Trials (PYT_1, PYT_2 and PYT_3), three Observational Yield Trials (OYT_1, OYT_2, OYT_3), one F_1 Seedling Trial (F_1ST) and one trial to maintain the cassava germplasm. At RCRC in Hanoi and in TNUAF in Thai Nguyen city, similar trials are being conducted. In addition, 18-25 Regional Yield Trials (RYT) are conducted every year in different cassava producing provinces in collaboration with provincial and district extension offices (**Figure 2**). Results of these experiments are presented and discussed during the annual Vietnam Cassava Workshops that have been held in Ho Chi Minh city since 1991.

Table 1. Cassava germplasm of Vietnam in 1999.

Cassava germplasm	Number of clones
Collection of cassava germplasm	
- at VASI	128
- at IAS	72
Number of cassava F1 hybrid seeds received between 1975 and 1999	*74,718*
- from CIAT/Colombia	48,895
- from the Thai-CIAT program	23,180
- from Vietnam cassava program	2,643
Varieties released	
- varieties for industrial processing	KM94
	SM937-26; KM60
- varieties for direct human consumption	KM95, KM95-3,
	KM98-1
Promising varieties being tested in regional yield trials	
- varieties for industrial processing	OMR34-11-43
	OMR34-18-11
	OMR34-35-34
- varieties for direct human consumption	KM98-5, KM98-6
	SM1447-7; SM1717-12
	SM2220-11;SM1862-6
	SM1868-1; SM2060-7

Methods of evaluation. These were standardized for the whole network: the SYT are conducted with plots of 50 m^2 and 4 replicationsin RCBD; the PYT with plots of 40 m^2 and 3 replications in RCBD. The planting density is 10,000 plants/ha (1x1 m) and fertilizers are applied at the rate of 80 kg N + 60 P_2O_5 + 80 K_2O/ha. CIAT and IBPGR methods are used for data collection and evaluation. Starch content is measured by the Reihmann scale. The IRRISTAT statistical program is used for data analysis.

Establishment of Demonstration Fields and On-Farm Research (OFR). The methods used were presented at the 5th Regional Cassava Workshop (Hoang Kim *et al.*, 1998). Funding for those activities was provided by: 1) the provincial Agricultural Extension budget; 2) Investment of processing factories for expanding the areas producing raw material; 3) Agricultural and Rural Development Programs; and 4) the network of advanced cassava farmers.



Provinces	Cassava area ('000 ha)
1. Ha Noi	0.7
2. Ho Chi Minh	0.7
3. Hai Phong	0.4
4. Ha Giang	6.5
5. Tuyen Quang	8.1
6. Cao Bang	2.1
7. Lang Son	3.5
8. Lai Chau	8.8
9. Lao Cai	5.8
10. Yen Bai	10.1
11. Bac Thai	4.8
12. Son La	13.7
13. Vinh Phu	13.2
14. Ha Bac	9.5
15. Quang Ninh	3.3
16. Ha Tay	4.3
17. Hao Binh	14.8
18. Hai Hung	0.3
19. Thai Binh	0.0
20. Nam Ha	0.7
21. Ninh Binh	1.9
22. Thanh Hoa	16.2
23. Nghe An	14.1
24. Ha Tinh	2.3
25. Quang Binh	4.4
26. Quang Tri	3.8
27. Thua Thien-Hue	6.2
28. Quang Nam-Da Nang	17.0
29. Quang Ngai	11.3
30. Binh Dinh	12.2
31. Phu Yen	4.8
32. Khanh Hoa	7.5
33. Ninh Thuan	1.1
34. Binh Thuan	5.8
35. Kon Tum	7.2
36. Gia Lai	9.7
37. Dac Lac	4.8
38. Lam Dong	2.6

39. Song Be	5.8
40. Tay Ninh	7.2
41. Dong Nai	10.2
42. Long An	2.0
43. Dong Thap	0.0
44. An Giang	1.6
45. Tien Giang	1.1
46. Ben Tre	0.6
47. Vinh Long	0.8
48. Tra Vinh	1.9
49. Can Tho	0.0
50. Soc Trang	0.7
51. Kien Giang	0.9
52. Minh Hai	0.7
53. Ba Ria-Vung Tau	6.1

Figure 2. The research and technology transfer network for cassava development in Vietnam.

Applying Ten Mutual Link-up Extension Activities (ten Ts) with investment of processing factories, especially Vedan Vietnam Enterprise Corp. Ltd., for the expansion of areas that will produce raw materials. The extension methodology used by IAS can be summarized by the following ten words starting with the letter T (in Vietnamese):

1) Thu nghiem	(Trials)
2) Trinh dien	(Demonstrations)
3) Tap huan	(Training)
4) Trao doi	(Exchange)
5) Tham vieng	(Farmer tours)
6) Tham quan hoi nghi dau bo	(Farmer field days)
7) Thong tin tuyen truyen	(Information, propaganda)
8) Thi dua	(Competition)
9) Tong ket khen thuong	(Recognition, price and reward)
10) Thanh lap mang luoi nguoi nong dan gioi	(Establish good farmers' network)

Using the above mentioned approach, new cassava varieties were quickly accepted by farmers and were widely adopted.

Vedan Vietnam Enterprise Corp. Ltd., the biggest cassava processing company in Vietnam, has contributed the following: 1) Investment in the production and dissemination of new planting materials of high-yield varieties and of liquid fertilizer (Vedagro) to farmers; 2) Establishment of a support price (for example: factory gate price of fresh roots with 25% starch content: 300 VND/kg in 1998-2000); 3) Sponsorship of the Vietnam annual cassava workshops and the publishing of cassava documents; 4) Support of cassava breeding activities and cassava sustainable production techniques in raw material producing areas.

3. RESULTS AND DISCUSSION

3.1 Progress in Cassava Breeding and Varietal Development

Before 1985, Gon, H34 and Xanh Vinh Phu were the most popular cassava varieties in Vietnam (Tran Ngoc Ngoan *et al*., 1996). From 1986 to 1993, HL20, HL23 and HL24 were selected from the local variety collection by Hung Loc Agricultural Research Center (HARC) and these varieties were grown extensively in South Vietnam with annual areas of about 70,000 to 80,000 ha.

In recent years, the Vietnam Cassava Research and Extension Network has been closely collaborating with CIAT, Vedan Vietnam Enterprise Corp. Ltd. and other cassava processing factories to improve its development of cassava, especially in breeding and varietal dissemination. Six new high-yield varieties were recommended and disseminated for production during 1993-1999 (**Table 2**).

Three high-yield and high-starch varieties for industrial processing are KM94, KM60 and SM937-26. Three multi-purpose use varieties suitable for food, feed and processing, with early harvestability and having extended harvest times are KM98-1, KM95-3 and KM95 (**Table 2**). These varieties were extensively tested and selected mainly for their high yields and high dry matter and starch contents (**Tables 3** and **4**).

The growing area of KM94 and other new improved varieties was about 60,000 ha in the crop year 1999/2000.

Table 2. Background and outstanding characteristics of six released varieties

Variety	Year released	Background and outstanding characteristics
KM60	1993	Orginally named Rayong 60, was introduced from the Thai-CIAT program in 1989. High fresh yield. Recommended for early harvesting. Excellent agronomic traits. Good root shape, but flesh color is slightly yellow.
KM94	1995	Orginally named MKUC 28-77-3 (Kasetsart 50), was introduced from the Thai-CIAT program in 1990. High yield and high starch content. Good root shape and white flesh. Good stake quality. Tolerant to major pests and diseases. Well adapted to unfavorable conditions.
SM937-26	1995	Orginally named SM937-26, was introduced from the Thai-CIAT program in 1990; High fresh yield and high starch content. Good root shape and white flesh. Good plant type. Good stake quality.
KM95	1995	Selected from F_1 hybrid seeds introduced from the Thai-CIAT program in 1991 (originally named OMR33-17-15). High fresh yield. Early harvestability. Multi-purpose use for direct human consumption, feed and processing. Good root shape and white flesh.
KM95-3	1998	Selected from F_1 hybrid seeds introduced from the Thai-CIAT program in 1992 program (orginally named SM1157-3). High fresh yield. Early harvestability. Multi-purpose use for direct human consumption, feed and processing. Good plant type. Good stake quality.
KM98-1	1999	Selected from F_1 hybrid seeds introduced from the Thai-CIAT program in 1995 (pedigrees Rayong 1 x Rayong 5). High fresh yield. Early harvestability. Multi-purpose use for direct human consumption, feed and processing. Good root shape and white flesh. Good plant type.

Table 3. Results of Regional Yield Trials conducted by Hung Loc Agricultural Research Center in Central and South Vietnam (1997-1998).

No. of trials	Variety	Growing period (months)	Dry root yield (t/ha)	Fresh root yield (t/ha)	Root dry matter content (%)	Root starch content (%)	Harvest index
18	KM94	9-11	15.9	39.6	40.2	28.9	0.58
15	KM98-1	7-10	14.9	38.4	38.8	27.8	0.66
14	KM60	7-10	11.7	30.2	38.7	27.4	0.56
18	HL23	8-12	8.6	23.7	36.3	25.4	0.53

Source: *Hoang Kim et al., 2000.*

Table 4. Comparison of average root yields of new cassava varieties with those of local variety in FPR trials[1)] at Thai Nguyen province in 1998.

Variety	Dry root yield (t/ha)	Fresh root yield (t/ha)	Root dry matter content (%)	Relative dry root yield (%)
SM1717-12	10.00	25.44	39.5	154
CM4955-7	9.60	24.62	39.0	148
KM94	9.10	21.91	41.5	140
KM60	8.26	20.40	40.5	128
KM95-3	7.28	18.45	39.5	112
Xanh Vinh Phu	6.50	16.89	38.5	100

[1)]14 farmers x 6 varieties

Source: *Tran Ngoc Ngoan and Kawano, 2000.*

The high-starch yield varieties have provided the producers with higher benefits of about VND 787.50 billion (US$ 60.78 million) during six years (1994-1999) in five southern provinces of Dong Nai, Binh Phuoc, Binh Duong, Tay Ninh and Ba Ria-Vung Tau (**Table 5**). More than one half of the additional benefits went directly to cassava farmers' income. The rest was shared among cassava processing factories and traders.

3.2 Recent Results of Cassava Breeding 1998-1999

HARC has recommended two sets of cassava varieties, i.e. SYT_1 and SYT_2 for national evaluation in 1998/99 (**Tables 6** and **7**). In addition, KM98-1 was released as a new variety for production in 1999 by the Ministry of Agriculture and Rural Development (MARD). Other new promising varieties/lines are being tested and selected (Hoang Kim *et al.*, 2000).

Table 5. Estimated monetary gains from the adoption of new cassava varieties in five provinces of Dong Nai, Binh Duong, Binh Phuoc, Tay Ninh, Ba Ria-Vung Tau during six years from 1994 to 1999.

Year	Total area of new cassava varieties ('000 ha)[1]	Increases in yield and starch content vs HL23		Monetary gain (million VND/ha)		Total monetary gain[6] from planting new varieties (billionVND)
		Fresh root yield (t/ha)[2]	Root starch content (%)[3]	From higher fresh root yield[4]	From higher starch content[5]	
1994	2.75	+ 8.0	+ 2.5	2.67	1.59	11.71
1995	9.68	+ 9.5	+ 3.0	4.55	1.58	60.45
1996	27.36	+ 10.3	+ 3.3	2.84	1.86	128.59
1997	24.57	+ 9.6	+ 2.9	3.80	1.83	138.33
1998	36.68	+ 10.5	+ 3.0	4.18	1.75	217.50
1999	42.45	+ 9.8	+ 3.2	3.57	1.87	230.92
Total						**787.50**

1)Provincial Statistics Office (1994-1999).
2)Means from survey on large plot trials in South East Region Fresh root yield of local varieties about 12 t/ha, KM60 about 20 t/ha, KM94 about 22-24 t/ha.
3)Root starch content of cassava varieties at Vedan factory: HL23 about 24-25%; KM60 about 27-28%, KM94 about 28-30% (Yeh Fang Ten, 1999).
4)Price of fresh roots (at Vedan factory): 11/1994-5/1995:334 VND/kg; 9/1995-5/1996: 479 VND/kg; 9/1996-6/1997: 276 VND/kg; 9/1997-6/1998: 396 VND/kg; 9/1998-6/1999: 398 VND/kg; 9/1999-2/2000: 345 VND/kg (Yeh Fang Ten, 1999; Tran Vien Thong, 2000).
5)Cassava starch price (1994-1999): about 240 USD/tonne.
6)Exchange rate: 1USD=11,040VND (1994); 10,980VND (1995); 11,210VND (1996); 13,170VND (1997); 13,860VND (1998); 13,950VND (1999); 14,030VND (2/2000).

TNU recommended cassava line SM1717-12, which has given a high yield and has a high dry matter content (**Table 8**). This line has been evaluated in FPR trials at Thanh Ba district (Phu Tho province) and Luong Son district (Hoa Binh province) (Tran Ngoc Ngoan and Kawano, 2000). This has now been released under the name KM98-7.

RCRC selected and recommended four new cassava lines SM1862-6, SM1868-1, SM2201-11 and SM2060-7 for on-farm trials and regional yield trials (**Table 9**) (Trinh Phuong Loan *et al*., 2000).

At present in Vietnam the genetic base of cassava is widening and the yield potential of the breeding population is increasing. **Figure 3** shows the change in the mean of the breeding population (all entry mean in standard yield trials) in terms of fresh root yield and root dry matter content at Hung Loc Agricultural Research Center in Dong Nai province of South Vietnam.

Table 6. Results of the Standard Yield Trials (SYT1) at HARC in 1998/99.

Variety	Fresh root yield (t/ha)	Dry starch yield (t/ha)	Root starch content (%)	Root dry matter content (%)	Harvest index
KM98-1	43.1 cd	12.41	27.8 cd	38.1	0.74
KM98-2	39.6 bc	11.09	28.0 cd	38.3	0.59
KM98-3	46.9 d	11.53	24.6 b	36.1	0.59
KM98-4	42.5 bcd	9.05	21.3 a	33.7	0.58
KM98-5	46.0 d	13.02	28.3 cde	38.8	0.58
KM98-6	46.9 d	13.69	29.2 de	39.4	0.59
KM94	43.5 cd	12.26	28.2 cde	40.0	0.57
KM60	38.0 b	11.25	29.6 e	38.2	0.59
HL23	25.4 a	6.98	27.5 c	37.8	0.45
CV (%)	8.1		3.9		
LSD (0.05)	4.9		1.6		

Source: *Hoang Kim et al., 2000.*

Table 7. Results of the Standard Yield Trials (SYT_2) at HARC in 1998/99

Variety	Fresh root yield (t/ha)	Dry starch yield (t/ha)	Root starch content (%)	Root dry matter content (%)	Harvest index
KM99-1	38.3 d-g	11.45	29.9 bc	40.7	0.55
KM99-2	41.7 b-e	12.05	28.9 bcd	39.0	0.54
KM99-3	39.7 c-g	12.26	28.4 bcd	38.8	0.55
KM99-4	42.2 bcd	11.20	28.0 bcd	38.5	0.59
KM99-5	37.1 e-h	11.50	31.0 ab	40.9	0.50
KM99-6	41.4 b-f	12.17	29.4 bc	39.7	0.49
KM94	43.8 abc	12.74	29.1 bcd	39.1	0.56
KM60	35.8 gh	10.63	29.7 bc	40.7	0.54
HL23	24.1 k	6.39	26.5 b-e	37.1	0.43
CV (%)	9.01		12.79		
LSD (0.05)	4.72		5.12		

Source: *Hoang Kim et al., 2000.*

Table 8. Results of three Standard Yield Trials conducted at TGUAF in Thai Nguyen province in 1996, 1997 and 1998.

Variety	Fresh root (t/ha)				Relative root yield (%)
	1996	1997	1998	Av.	
KM94	36.7	25.8	25.7	28.3	142
SM1717-12	31.6	24.7	26.3	27.5	139
KM60	33.3	22.5	23.0	26.3	132
KM95-3	23.9	21.8	22.3	22.7	114
Xanh Vinh Phu	22.2	17.5	19.8	19.8	100

Source: *Tran Ngoc Ngoan and Kawano, 2000.*

Table 9. Results of the Standard Yield Trials conducted in Thach That district, Ha Tay province in 1998.

Variety	Fresh root yield (t/ha)	Dry starch yield (t/ha)	Root starch content (%)	Root dry matter content (%)	Harvest index
SM1862-6	19.78	8.17	23.4	41.3	0.64
SM1868-1	19.17	7.46	21.7	38.9	0.57
SM2220-11	20.74	7.45	19.6	35.9	0.66
SM2060-7	18.39	6.69	18.7	36.4	0.66
KM95-3	22.70	8.83	21.7	38.9	0.64
KM94	20.56	8.70	24.1	42.3	0.71
KM60	21.18	8.03	21.0	37.9	0.66
Xanh Vinh Phu	18.90	7.01	20.4	37.1	0.60
CV (%)	12.96				
LSD (0.05)	2.94				

Source: *Trinh Phuong Loan et al., 2000.*

3.3 Future Research Direction of Cassava Breeding and Varietal Dissemination

Selection and development of high-starch yield varieties are the primary objectives of the global strategy of cassava development (Hershey, 1999). The cassava breeding program is one of the major programs in the Crop and Animal Breeding Project of MARD for 2000-2005 (MARD, 1999).

The future research direction of cassava breeding in Vietnam aims to select varieties with high yield and high starch content and to promote more sustainable production systems by introducing new breeding materials, cross breeding and applying biotechnology to crop improvement.

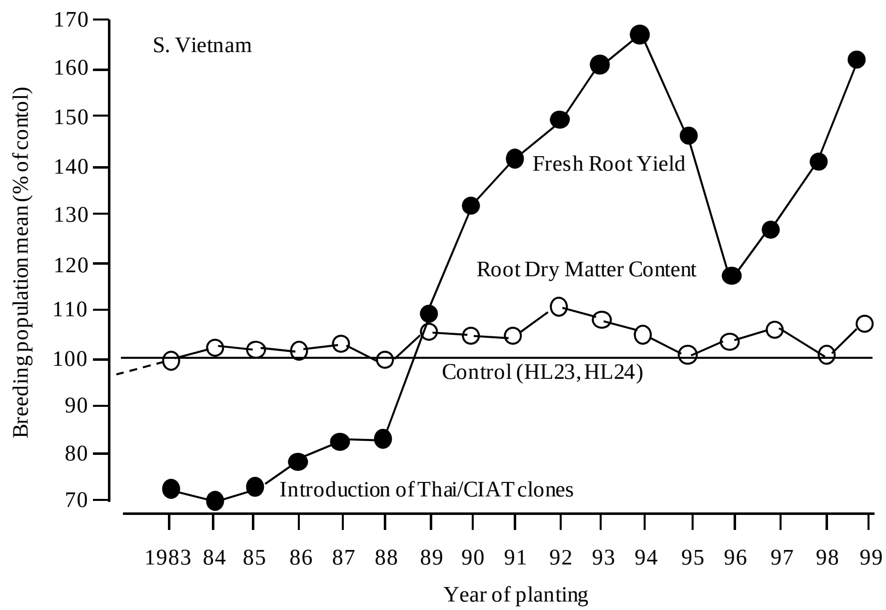


Figure 3. Change in the mean of breeding population (all entry mean in yield trials) in fresh root yield and root dry matter content at Hung Loc Agric. Research Center, South Vietnam.

4. CONCLUSIONS AND SUGGESTIONS

4.1 Conclusions

1. *Cassava breeding and varietal dissemination in Vietnam made considerable progress during the past decade.* In recent years (1993-1999), the Vietnamese Cassava Program (VNCP) cooperated closely with CIAT, Vedan Vietnam Enterprise Corp. Ltd. and other cassava processing factories. The activities of the network were effective in recommending and widely disseminating new cassava varieties. KM94, KM60, SM937-26, KM95, KM95-3, KM98-1 were recommended and released for production.
2. *The contribution of VNCP in the development of cassava production and processing has been significant.* The area planted to KM94 and other new improved varieties reached about 60,000 ha in the crop year 1999/2000. The high starch yield varieties have provided the producers benefits of up to VND 787.50 billion (US$ 60.78 million) during the past six years (1994-1999) in five provinces, i.e. Dong Nai, Binh Phuoc, Binh Duong, Tay Ninh and Ba Ria-Vung Tau. More than half of the additional benefits went directly to cassava farmers' income. The rest was shared among cassava processing factories and traders.
3. *At present, the cassava germplasm base is widening and new varieties are quite promising.* New varieties will be selected and developed to meet the demand of production and processing in the future.

4.2 Suggestions

1. Continue to cooperate closely with CIAT in the introduction and evaluation of breeding materials and the application of biotechnology in cassava breeding.
2. Find research funding from different sources (MARD, CIAT, Vedan, local and provincial governments, NGO's etc.).
3. Organize workshops, training courses and study tours and exchange germplasm and information with other members of the Asian Cassava Research Network.

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The authors wish to express their thanks to MARD, IAS, CIAT, VEDAN, VASI, TNU for helping us carry out the Vietnam Cassava Program. Our thanks are also due to the Department of Science, Technology and Environment of the Department of Agriculture and Rural Development, to Provincial Governments, the Agricultural Extension Centers, Districts and Communes for their assistance in developing the Cassava Breeding Program from 1988 to 1999.

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CASSAVA BREEDING AND VARIETAL DISSEMINATION IN THAILAND - MAJOR ACHIEVEMENTS DURING THE PAST 25 YEARS

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ABSTRACT

The cassava breeding program in Thailand started with the hybridization of local clones, followed by selection, at the Rayong Field Crops Research Center in 1975, and at Sri Racha Research Station of Kasetsart University in 1983. During this initial period of recombining genes available from a narrow genetic base, progress in yield improvement was limited. In 1983, CIAT established its Asian Regional Program in Thailand. CIAT's role in Thailand has been mainly to supply cassava germplasm from Latin America to this country, in order to increase the genetic variability of parental lines and to help develop an efficient and highly effective scheme of hybridization and continuous selection of this germplasm. The Thai germplasm collection also included earlier introductions from the Virgin Islands and Indonesia. This collaborative effort resulted in the official release of six new cassava cultivars during the period 1983-1993: four from the Department of Agriculture (DOA) and two from Kasetsart University. These new cultivars are characterized by high yield capacity, high harvest index, high root starch content and early harvestability. In 1999, DOA released a new cultivar specifically for planting in the northeastern part of the country; it was named Rayong 72.

Regarding varietal dissemination, in 1994 the government established a special program for the rapid multiplication of new recommended cassava cultivars to replace the local cultivar, Rayong 1. This program involved the cooperation of DOA and Kasetsart University for supplying basic planting material, as well as the Department of Agricultural Extension and the Thai Tapioca Development Institute for multiplication and distribution of this material. The success achieved by this program can be gauged by the fact that by 1997 about 64% of the cassava area in Thailand was planted to the new recommended cultivars.

INTRODUCTION

During the past two decades cassava has been one of the most important cash crops in Thailand, occupying a total area ranging from 1.23 to 1.62 million hectares, and producing annually approximately 16-24 million tonnes of fresh roots (Office of Agricultural Economics (1996). The variation in production is almost entirely due to changes in planted area. Minor fluctuations from year to year are mainly caused by price variations, which in turn are due to the world market situation, especially in the European Common Market.

As a major part of cassava exports is destined for the European Union (EU), it is inevitable that any change in agricultural policy in the EU will have a significant impact on Thailand's cassava policy. In 1992, the EU decided to lower its support price for cereals by as much as 30% within the following three years, beginning in late 1993. This has undoubtedly contributed to a significant reduction in the price of Thai cassava.

In response, the Thai government established a policy to reduce the cassava planted area from 1.5 million ha to 1.28 million ha by encouraging farmers to replace cassava with

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fruit trees, fast-growing timber species, pastures and livestock. In addition, the Thai government policy also aimed at increasing cassava productivity by promoting the use of improved cultivars from the cassava breeding program to replace the traditional cultivar, Rayong 1. The Department of Agriculture (DOA) and the Department of Agricultural Extension (DOAE) of the Ministry of Agriculture and Cooperatives initiated a five-year project, starting in 1992, to rapidly multiply stakes of the improved cultivars and to distribute these to the farmers. The Thai Tapioca Development Institute has also helped to implement this project. Since 1997, the adoption rate of new cassava cultivars has increased dramatically.

EARLY PERIOD OF CASSAVA BREEDING

Before the Second World War, cassava was cultivated mainly in the southern part of Thailand, especially in Songkhla province, for use in the production of starch and sago. In those days, an attempt was made to introduce new cassava clones for selection. Komkrid (1939) reported that three clones from the Philippines and 17 from Malaya (now, Malaysia) were introduced for selection at the Southern Field Crops Station in Songkhla (currently, the Songkhla Rubber Research Center). During that period, two cassava cultivars, Local 1 and Local 2, were used for industrial purposes. No further information, however, was reported on these introductions.

As time progressed, the cassava area gradually moved to the eastern part of the country, especially to Chonburi and Rayong provinces. In 1949, 16,000 ha of cassava were planted in Chonburi, according to reports in Agricultural Statistics of Thailand (1955). Since its establishment in 1954, cassava research has been conducted mainly by the Rayong Field Crops Research Center (RFCRC) of DOA.

Early work at RFCRC, from 1956 to 1961, was concerned mainly with local cultivar collections and clonal selection. One of the local clones was officially named Rayong 1 in 1975 (Sinthuprama, 1983). Rayong 1 has by far been the most successful cultivar in Thailand, and until recently accounted for more than 89% of the cassava planted area.

From the 1960s to 1977, about 86 clones (**Table 1**) were introduced from Indonesia, Virgin Islands and from CIAT, Colombia, and were evaluated at RFCRC; however, none of these clones was found to be superior to Rayong 1.

Table 1. Introductions of cassava germplasm into Thailand through the Department of Agriculture (up to 1977).

Year	No. of genotypes introduced	Origin
Before 1960	About 20 accessions	Malaya, Java
1963	7 cultivars	Java
1965	44 clones	Virgin Islands
1970	5 accessions	CIAT
1977	10 hybrid clones	CIAT

Source: *Field Crops Research Institute, Department of Agriculture.*

THE THAI BREEDING PROGRAM IN COOPERATION WITH CIAT

Thailand started the cassava breeding program in earnest with hybridizations of local cultivars, followed by selection, at RFCRC in 1975, as well as at Sri Racha Research Station of Kasetsart University (KU) in 1983. During this initial period of recombining genes available from a narrow locally available genetic base, progress in yield improvement was slow.

Since the establishment of the CIAT Cassava Asian Regional Program in Thailand in 1983, cooperation with Asian national programs, particularly the Thai program, has been greatly enhanced. CIAT's activities contributed to the establishment and improvement of national cassava research programs in many Asian countries. CIAT's role has been mainly to transfer cassava germplasm from Latin America to Asia, in order to increase the genetic variability of parental lines, and to help develop an efficient and highly effective scheme of hybridization and continuous selection of this germplasm. The main objective of the Thai-CIAT cooperation is to improve root yield and starch content in order to satisfy the needs of the farmers and of the processing industry. It was suggested by Kawano *et al.* (1990) and Rojanaridpiched *et al.* (1998) that cassava yield should be improved through the simultaneous improvement of total biomass and harvest index. Aside from these traits, the following characteristics are also our breeding and selection criteria:

- early harvestability
- good plant type (tall and no- or little-branching)
- good stake quality (germination and storage duration)
- good root shape with white flesh
- tolerant to major pests and diseases

MAJOR ACHIEVEMENTS DURING 1975-1999

From 1975-1999, the cassava breeding program, started by DOA at RFCRC in 1975 and by KU at Sri Racha Research Station in 1983, involving Thai-CIAT cooperation, released eight new cultivars, all for industrial use. The background and outstanding characteristics of these cultivars are given in **Table 2**. In addition, a variety suitable for human consumption, called Rayong 2, was released in 1984. This variety, however, was never widely planted as the use of cassava for human consumption is almost negligible in Thailand.

RECENT PROGRESS

In 1999, DOA released its most recent industrial cultivar, named Rayong 72, suitable for planting in the northeastern regions of Thailand.

Rayong 72, previously identified as CMR 33-57-81, was obtained from a cross between Rayong 1 and Rayong 5 made in 1990 at RFCRC. This cultivar has now officially been released by DOA, following the completion of all regulations for the certification of a new cultivar.

Rayong 72 is capable of both high fresh root yield and dry matter yield, it is easy to harvest due to its good root shape and root formation, and has good germination and drought tolerance. However, Rayong 72, when planted in the eastern region has a relatively lower dry matter content than when grown in the northeast. Thus, Rayong 72 is

Table 2. Background and outstanding characteristics of seven released cultivars in Thailand (including Rayong 1).

Cutivar	Year of release	Parents	Background and outstanding characteristics
Rayong 1	1975	Unknown	Selected from a local land race. Excellent agronomic traits. Relatively high yield. Moderately resistant to major pests and diseases. Well-adapted to low inputs.
Rayong 3	1983	(F) MMex 55 (M) MVen 307	Selected from CIAT F_1 hybrid seeds. High dry matter content.
Rayong 2	1984	(F) MCol 113 (M) MCol 22	Selected from CIAT F_1 hybrid seeds. Recommended for human consumption. Relatively high yield and carotene and Vitamin A contents. Low in HCN.
Rayong 60	1987	(F) MCol 1684 (M) Rayong 1	Selected from CIAT F_1 hybrid seeds. High fresh yield. Recommended for early harvest. Excellent agronomic traits.
Sriracha 1	1991	(F) MCol 113 x MCol 22 (M) Rayong 1	Selected from KU F_1 hybrid seeds. Excellent agronomic traits. High dry matter content.
Rayong 90	1991	(F) CMC76 (M) V43	Selected from DOA F_1 hybrid seeds. High dry matter content. Relatively high yield.
Kasetsart 50	1992	(F) Rayong 1 (M) Rayong 90	Selected from KU F_1 hybrid seeds. High yield and high dry matter content. Well-adapted to unfavorable conditions.
Rayong 5	1994	(F) MR27-77-10 (M) Rayong 3	Selected from DOA F_1 hybrid seeds. High dry matter content. Relatively high yield.
Rayong 72	1999	(F) Rayong 1 (M) Rayong 5	Selected from DOA F_1 hybrid seeds. Relatively high dry matter content, high fresh yield. Good germination and drought tolerant. Especially adapted to northeast Thailand.

Note: (F) = female, (M) = male parental line.

Source: *Adapted from Limsila et al., 1998.*

now specifically recommended to be planted in the northeastern part of the country. **Table 3**, showing data compiled from 48 trials in the northeast, indicates that Rayong 72 had a fresh root yield that was 25, 21, 31 and 18% higher than that of Rayong 1, Rayong 5, Rayong 90 and Kasetsart 50, respectively; its dry matter yield was also 30, 19, 28 and 16% higher, respectively, than those of these same varieties. However, the dry matter content of Rayong 72 is similar to those of all the other cultivars, but slightly higher than that of Rayong 1.

Table 3. Agronomic traits of Rayong 72 compared to four recommended cultivars in the northeastern region of Thailand (data from 48 trials conducted from 1993-1998).

Cultivar	Root yield (t/ha)		Dry matter content (%)
	Fresh	Dry	
Rayong 72	34.69 (100)*	11.94 (100)	34.3
Rayong 1	25.88 (75)	8.38 (70)	32.3
Rayong 5	27.50 (79)	9.62 (81)	34.7
Rayong 90	23.94 (69)	8.56 (72)	35.5
Kasetsart 50	28.38 (82)	10.06 (84)	35.3

*Figures in brackets are percentages
Source: *Field Crops Research Institute, Department of Agriculture.*

VARIETAL DISSEMINATION

Since the release of new cultivars for industrial use, namely Rayong 3, Rayong 60, Rayong 90, Kasetsart 50 and Rayong 5 from 1983 to 1994, DOAE has had projects for multiplication and distribution of stakes of these cultivars to farmers, with the aim of increasing cassava yields. Klakhaeng *et al*. (1995) estimated that the area planted to Rayong 3 in 1993/94 was 108,000 ha or about 7.3% of the total cassava area. Subsequently, Rojanaridpiched *et al*. (1998) reported that there were two major programs for cassava multiplication and distribution to the farmers, with the following objectives: “To increase the potential of cassava production” by DOAE, and “To reduce costs in cassava production” by the Thai Tapioca Development Institute. These two programs succeeded in increasing the cassava area planted to the new cultivars in 1994/95 to 28%.

The rapid expansion of cultivated area occupied by the new cultivars is not only a consequence of those two programs, but also partly due to the farmers’ own efforts. Thus, by 1997/98, the area planted to new cultivars was increased to about 56% and in 1999/00 to 81% of the total planted area (**Table 4**).

In 1999/00 only about 20% of the total area was still planted with local varieties, basically Rayong 1, while 32% was planted to Kasetsart 50, 18% each to Rayong 90 and Rayong 60, and 10% to Rayong 5. Rayong 3 and Sri Racha 1 have almost disappeared, while the two eating varieties, Rayong 2 and Hanatee, are planted only in very small areas, mainly for the preparation of some special snack foods.

Table 5. Spread of new cassava varieties in Thailand from 1989/90 to 1999/00.

Variety	Area (ha)						% in
	1989/90	1991/92	1994/95	1995/96	1997/98	1999/00	1999/00
Local variety[1)]	1,470,382	1,400,256	949,204	840,253	416,113	146,297	12.7
Rayong 3	17,158	50,283	135,421	14,953	NA	27,004	2.3
Rayong 60	-	-	125,049	207,589	206,057	216,897	18.8
Rayong 90	-	-	35,461	81,049	143,055	220,926	19.2
Kasetsart 50	-	-	322	17,846	149,270	410,852	35.7
Sri Racha 1	-	-	NA	NA	NA	4,125	0.4
Rayong 5	-	-	NA	66,424	129,594	125,823	10.9
Total new varieties	**17,158**	**50,283**	**296,253**	**387,861**	**627,976**	**1,005,627**	**87.3**
Total cassava area	1,487,540	1,450,539	1,245,457	1,228,114	1,044,089	1,151,924	
% with new varieties	1.1	3.5	23.8	31.6	60.1	87.3	

[1)] >90% Rayong 1

Source: *Klakhaeng et al., 1995; Rojanaridpiched et al., 1998; Office of Agric. Economics, 2000.*

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CASSAVA BREEDING AND VARIETAL DISSEMINATION IN INDONESIA DURING 1975-2000

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ABSTRACT

High-yielding varieties, adapted to local conditions and satisfying local preferences, is one of the most important components of improved technologies. Since cassava is propagated vegetatively using farmers' own planting material, the use of high-yielding varieties will give substantial economic gains without much additional costs. However, the suitability of certain high-yielding varieties could be limited and farmers will continuously require higher yields in order to remain competitive. Thus, breeding and varietal improvement will continue to be necessary.

Progress in cassava breeding in Indonesia has been relatively slow, since it depends to some extent on the conscientiousness of the scientists as well as on the priorities of the government. Because of a very limited number of people involved in cassava breeding and recent changes in institutional responsibilities, only six cassava varieties have been officially released since 1978. One of these no longer exists, while some other released varieties were the result of natural hybridization. Two of the six varieties officially released were selected from hybrid seed introduced from CIAT/Colombia. Possibly, two new varieties introduced from the Thai-CIAT program will be released in 2000.

In 1995, the national mandate for cassava research was assigned to RILET. The institute's cassava breeding program was established according to CIAT's conventional methodology, which consists of hybridization, single plant selection, single row selection, preliminary yield trial, advanced yield trials, multilocational trials and proposal for varietal release. Collaboration with other institutes, universities and private companies were enhanced to try to achieve the release of one new variety each year.

Varietal multiplication and dissemination by the government are still very limited. However, since 1999 there has been an aggressive multiplication program as a means to support varietal dissemination. When this program is correctly implemented there will be an exponential increase in the area planted to high-yielding varieties. Since 1995 the government of Indonesia has established provincial-level institutes, called Assessment Institute for Agricultural Technology, with the responsibility to adapt new technologies to local conditions and enhance their dissemination and adoption. Collaboration with international as well as other national research centers dealing with cassava will strengthen the research capability and further enrich genetic variability.

INTRODUCTION

Cassava is grown throughout Indonesia, but is highly concentrated in Java and the Southern part of Sumatra. The variability of the physical environments, either soils or climates, are very wide. Howeler (1992), estimated that cassava in Indonesia is grown on the following soil orders: 24% on Alfisols, 22% on Ultisols, 20% on Entisols, 18% on Inceptisols, 8% on Vertisols, 6% on Mollisols, 2% on Histosols and 1% on Oxisols. The proportion of soil orders on Java island is much larger than on the other islands except for Oxisols and Histosols, which are not found on Java.

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Climatic conditions which are characterized mainly by the intensity and distribution of rainfall, also vary. In general, there are wetter areas which extend from West Java to the western parts, and drier areas which extend from Central Java to the eastern parts of Indonesia. As a rule of thumb, the northern areas are also relatively wetter compared to the southern areas.

Most of the soil orders planted with cassava, especially the Ultisols, have a low organic matter content and have very low levels of P, K, Ca, and Mg. If the topography is undulating or hilly and there is high rainfall intensity, erosion can be serious. Continuous cassava planting without appropriate soil management will lead to declining yields. Farmers usually apply only small amounts of chemical fertilizers to cassava, while the crop is very efficient in exploiding scarce nutrients in the soil.

Cassava is grown mainly by small farmers with labor-intensive methods, making little use of purchased inputs because they have limited financial resources. The technology most necessary under these socio-economic conditions is a high-yielding variety. Indeed, an improved variety is the most useful and cheapest technology component for farmers. Puspitorini *et al*. (1998), and Kawano (1998), provided evidence that the socio-economic contribution of high yielding cassava varieties in increasing farmers' income was substantial.

Considering the diverse ecological conditions as well as the various ways of cassava utilization, a wide range of different varieties is required. The existence of hundreds of local cassava varieties, which have been selected by farmers and are still mostly used, is a useful guide for future germplasm improvement. A great and ambitious task to serve the people's needs by providing improved cassava varieties was launched in 1995. Unfortunately, even though many activities continued, others were interrupted due to various circumstances.

HISTORICAL REVIEW OF CASSAVA BREEDING IN INDONESIA

Regardless of the activities performed, the mandate for developing high yielding varieties is the task of governmental institutes, because high yielding varieties should be the property of the general public, especially the poor. Of course, this does not mean that the private sector can not breed new varieties for their own use.

Cassava breeding and the release of new varieties already began during Dutch colonial times; Dutch varietal names such as Faroka and Vandrum are an indication of this. Since 1984, Brawijaya University in Malang has undertaken collaborative research with the Research Institutes for Food Crops located in Bogor and Malang, as well as with a private enterprise which had previously developed a cassava plantation in Lampung called Umas Jaya Farm (UJF); all three entities worked in collaboration with the CIAT Cassava Program in Asia (Poespodarsono, 1998).

Such collaboration has many advantages, and has resulted in the release of several new varieties. Professional capabilities were strengthened through training and personal communication, while the participation in workshops in other countries broadened the scientists' vision. Unfortunately, many of the senior scientists thus trained were assigned to other tasks not directly related to cassava breeding.

A new phase of action began in April, 1995. At that time, several new Research Institutes were established, even though they are basically new only in name and in their specific mandates. The Research Institute for Legumes and Tuber Crops (RILET), which was previously called the Malang Research Institute for Food Crops (MARIF) is one of these new institutes. RILET was assigned the national mandate to generate technologies for legumes and tuber crops, including the generation of new varieties. Because of limitations in personnel and financial resources, research on tuber crops has concentrated mainly on cassava and sweetpotato.

CASSAVA BREEDING ACTIVITIES

Using germplasm locally available, a rudimentary cassava varietal improvement program was started in 1985. Fortunately, a breeding methodology had already been developed by CIAT, which we slightly adapted and adopted. The methodology started with parent selection, followed by hybridization. Fortunately, we have an opportunity to make crosses, since there is a research station nearby RILET's headquarters, located at about 800 masl, where cassava will flower. The selection process starts with selection of seedlings resulting from those hybrid seeds, followed by selection in single rows, single plots, preliminary yield trials, advanced yield trials, and multi-locational yield trials; eventually this may culminate in a varietal release.

From 1995 until 1998, hybridizations made in 1994, either through controlled or open pollination, have produced more than 10,000 seeds. This means that the number of seeds locally produced was equal to, or slightly more than, the number of seeds received by Umas Jaya Farm (9,272) from CIAT during the same period. However, our crosses involved a much smaller number of parents. New collaboration, which is expected to be more viable, between RILET and UJF is about to start. RILET uses the code OMM for open pollinated crosses and CMM for controlled pollination, while UJF keeps their own code, which is UJ.

The objective of the cassava breeding program is to satisfy the need for two distinct groups of varieties i.e. non-bitter and bitter varieties. The two groups have common characteristics which are:

1. High fresh root yield
2. High dry mattter and starch content
3. Tolerance to red mites
4. Tolerance to *Cercospora* blight
5. Adaptation to marginal soils
6. Good root shape
7. Non-branching

Specific characteristics for non-bitter varieties only are:

1. Low cyanogenic potential, i.e. less than 40 ppm HCN as determined by the quick picrate acid method
2. Good flesh texture after being boiled or fried
3. Yellowish flesh
4. Varied harvestability

In addition, there are some special requirements for special utilization purposes. Specific requirements with respect to roots are: they should have a uniform size from the top to the bottom, six centimeters in diameter, 20 centimeters in length, easy to peel, non-bitter and with good flesh texture. Specific requirements for leaves are: non-bitter, high-leaf productivity, preferably multi-branched. There is great demand for cassava leaves and the price is high, especially in urban areas.

The schemes for breeding non-bitter and bitter varieties are slightly different. For non-bitter varieties, a taste test is conducted at the single plant selection step as this character is of high priority. Whatever other good characters other than taste it may have, the line will be rejected if the taste is bitter; in that case the material will be moved to the scheme used for breeding bitter varieties. If the taste is acceptable, the next character to be determined is flesh texture. If the texture is not acceptable, the material will also be allocated to the scheme for bitter varieties. If these two main requirements are satisfied, the next steps are the same as those recommended by CIAT. The selection scheme for bitter varieties is completely the same as the CIAT procedure, as described by Hersey (1988).

Inter-institutional or multi-disciplinary collaboration is also encouraged. Scientists of other disciplines, especially entomologists and plant pathologists, become involved in the breeding scheme to evaluate for tolerance to pests and diseases. This collaboration is essential for the selection of cross parents, while pest and disease tolerances are also evaluated prior to conducting the preliminary yield trial. Soil scientists also may become involved in the breeding scheme for evaluating the adaptation to marginal soils, while food technologists are involved either in quality evaluation or in product development.

Problems and their Solutions

1. The factor most constraining the growth of the program is lack of personnel. This problem is not easy to solve.
2. Research capabilities. We must admit that many cassava breeders are not trained as such but have become breeders through practice. This constraint, of course, should be considered as a challenge. Self-study and personal communication, as well as guidance by more authoritative professionals, are very important.
3. The available genetic diversity is limited. Since the diversity of the genetic stock will determine the prospect of breeders' success, the limitation of genetic diversity is likely to slow down the process. However, there is also an advantage. The funds required for managing the germplasm collection is also limited. In an attempt to reduce this limitation, we always use *in situ* genetic stocks, which are the farmers' local varieties. Since most of the characters needed by farmers are already present in these varieties the chance of success is expected to be high.
4. International concern for cassava breeding will not last forever. Strengthening professionalism and increasing collaboration are urgently needed, but CIAT's role in this is diminishing, while the battle against poverty has not yet been won. What can be done about this?

BREEDING ACHIEVEMENTS

Six high yielding cassava varieties, having different characteristics, have officially been released in Indonesia between 1978 and 1998 (**Table 1**). However, one of these, Adira 2, no longer exists. Two of the six, i.e. Malang 1 and Malang 2, were selected from hybrid seed introduced from CIAT/Colombia; their original codes were CM4049-2 and CM4031-10, respectively. Adira 1, the first high yielding variety released was generated through open pollination. Its female parent is named Mentega, because the flesh color is yellow. Mentega means "butter" in Indonesian. This variety has spread mainly in the area around Bogor in West Java, as well as in Pati district in Central Java. It is grown in thousands of hectares, mainly near household- and small-scale starch processing centers. The yellowish flesh does not have an effect on starch color and quality. It seems that Adira 1 is best adapted to higher rainfall areas.

Table 1. High yielding cassava varieties officially released in Indonesia.

Variety name	Type of crosses	Year of release	Taste	Outer skin color	Flesh color
1. Adira 1	Open	1978	Non-bitter	Reddish brown	Yellow
2. Adira 2	Open	1978	Bitter	Dark brown	White
3. Adira 4	Open	1986	Bitter	Dark brown	White
4. Malang 1	Controlled	1992	Slightly bitter	Creamy white	Yellowish white
5. Malang 2	Controlled	1992	Non-bitter	Brown	Pale yellow
6. Darul Hidayah	Selfed	1998	Non-bitter	Creamy white	White

Adira 4, released in 1986, is very popular. But because of its bitter taste, its acceptability is limited to industrial and dried form utilization only. Adira 4 is especially well accepted in areas where wild pigs and theft of cassava roots are serious problems. Adira 4 appears to be more widely adapted as compared to Adira 1. The characteristics of Malang 1 and Malang 2 have been described by Kawano (1998).

The last variety listed in **Table 1**, Darul Hidayah, was generated by "chance breeding" in Lampung. This variety originated from the seed of grafted cassava. A cassava plant discovered in the forest was grafted onto root stock of *Manihot glaziovii*. Surprisingly, the grafted cassava produced flowers and seed, even though it was planted at a lower elevation (less than 100 masl). When one of the seeds was planted and then propagated vegetatively by the grafter (Haji Jamil), the root yield was enormous (about 70 kg per plant). Even though this variety has high yielding potential, it is very susceptible to mites and has a narrow adaptability.

Possibly, two other varieties will be released in the year 2000, both introduced from Thailand. The original names of these varieties are Rayong 90 and Kasetsart 50 which were released in Thailand in 1989 and 1992, respectively. In several yield evaluation trials Kasetsart 50 was found to be very drought tolerant.

Table 2 shows the most recent breeding achievements. Twelf promising cassava lines are being tested in multi-locational trials which will be harvested in October 2000. In previous Advanced Yield Trials the fresh root yield was about 50 t/ha. The root dry matter content was 30-37%. Some clones (PT 4 and BIC 108) are non-bitter and have good taste.

Table 2. Promising cassava clones tested in multi-locational trials in 1999/2000.

Clone	Fresh root yield (t/ha)	Dry matter content (%)	Harvest index	Taste	Parents
CMM95075-6	58	32.43	0.55	slightly bitter	MLG 10075/10006
CMM95032-12	58	30.56	0.56	slightly bitter	MLG 10020/10152
CMM95032-8	58	30.95	0.56	slightly bitter	MLG 10020/10152
CMM90-6-72	56	31.93	0.60	bitter	Adira 4
CMM95066-1	55	32.65	0.64	bitter	MLG 10071/10032
CMM95089-11	55	30.27	0.54	slightly bitter	MLG 10152/10033
CMM95023-5	55	35.69	0.60	slightly bitter	MLG 10018/10075
CMM95014-19	55	37.89	0.55	slightly bitter	MLG 10012/10075
CMM95014-3	53	36.80	0.45	bitter	MLG 10012/10075
PT-4	53	n.a.	n.a.	non bitter	Local Malang
BIC-108	52	n.a.	n.a.	non bitter	n.a.
PT-6	50	n.a.	n.a.	slightly bitter	Local Malang

Notes: n.a. = not available

VARIETAL DISSEMINATION

There has not been an aggressive program to disseminate new cassava varieties in Indonesia. The slow varietal dissemination was caused by institutional problems. Dimyati (1995) ascribed the problems of dissemination of cassava varieties mostly to strict governmental control on varietal releases.

It is expected that the newly founded Provincial Research Institute, called the Assessment Institute for Agricultural Technology, will help to speed up varietal dissemination.

CONCLUSIONS

1. Cassava breeding activities in Indonesia are still rather limited in scope. Even though cassava breeding is very important, there is a serious limitation of resources, such as scientists, laboratories and breeding materials.
2. However, several high-yielding varieties have already been released. Other promising clones will be released in the near future.
3. Collaboration between researchers, both domestically and internationally, are urgently needed.

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CASSAVA BREEDING AND VARIETAL DISSEMINATION IN INDIA-MAJOR ACHIEVEMENTS DURING THE PAST 25-30 YEARS

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) has been grown in India for more than a century. Although cassava breeding was initiated during the 1940s in Kerala, intensive research on breeding of superior varieties began only after the establishment of the Central Tuber Crops Research Institute (CTCRI) in 1963 in Trivandrum, Kerala. The Institute has an immense wealth of cassava germplasm, both indigenous and exotic. Nine superior varieties were released by CTCRI, three of them developed by selection, five by intervarietal hybridization and one by triploidy breeding. The high yielding hybrids not only increased cassava cultivation but also spread the crop outside Kerala. At present cassava is cultivated in 12 states and two union territories of the country, but the major producer is Kerala followed by the neighboring states of Tamil Nadu and Andhra Pradesh. The hybrids H-226 and H-165 are the most popular varieties in the industrial areas of Tamil Nadu and Andhra Pradesh, but the recently released triploid hybrid 'Sree Harsha', with its high yield, high starch and good culinary quality, holds great potential for both industrial use and human consumption. The three short-duration varieties are highly preferred by farmers as a rotation crop in the paddy-based cropping system. Very recently, two superior top-cross hybrids, having high yield and good culinary quality, were developed from inbreds and are ready for formal release.

In recent years the spread of cassava outside Kerala has been quite substantial. In Tamil Nadu and Andra Pradesh, where cassava is mainly used as an industrial crop for starch and sago manufacture, cassava area and production are expanding. In the northeastern states, where it is used mainly as a food crop, cultivation is also gradually increasing. In non-traditional areas of central India, the crop is being introduced through the true seed program. Nevertheless, the total area and production of cassava in India is declining, especially in Kerala, due to the prominence gained by plantation crops like rubber, black pepper, coffee etc. which provide more cash income. Therefore, the future increase in cassava production seems possible only by increasing the productivity in the existing areas of cultivation, expanding its adoption in different cropping systems and introducing the crop to new, non-traditional areas. To fulfil this goal, a new challenge in cassava breeding would be the development of gene pools with adaptation to the main biological and physical environmental stresses, development of varieties having resistance to CMD and red mite as well as drought tolerance, the nutritional improvement of cassava roots by protein enrichment, as well as the development of high-yielding, high-starch and high eating-quality hybrids, which will be acceptable to farmers, processors and consumers. Among the conventional breeding techniques, triploidy and top crossing are probably better tools for this. However, biotechnological approaches through gene transfer might tackle the challenges in a shorter time, but this will require coordinated research efforts among international and national agricultural institutions.

INTRODUCTION

In India, cassava occupies about 0.26 million ha of land producing 5.868 million tonnes of fresh roots. It is cultivated in 12 states and two union territories, but the major producers are the three states of the southern peninsular region, i.e. Kerala, Tamil Nadu and Andhra Pradesh. These three states make up 88% of the cultivated area and 99.3% of the production volume. Kerala holds the key position in cassava cultivation in India, probably

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because it was to this state that the crop was first introduced into the country in the 17^{th} century. In the latter part of the 19^{th} century, cassava became an important food crop of Kerala, often forming life-saving sustenance during periods of famine. It gradually spread to the neighboring states of Tamil Nadu and Andhra Pradesh. Contributions to the breeding research on cassava in India have been made almost entirely by the Central Tuber Crops Research Institute (CTCRI) in Trivandrum, Kerala, and its Regional Center at Bhubaneswar in the north-eastern state of Orissa. Contributions to varietal development were also made by the Agricultural Universities of the states of Kerala and Tamil Nadu. Beside this, the All India Co-ordinated Research Project on Tuber Crops with its 11 centers, also contributes to varietal improvement by regional testing of varieties at an advanced stage of development.

Early Research

Cassava research in India started in the 1940s. The first phase consisted of a period of about 20 years from the 1940s to the 1960s, before the inception of CTCRI. The Tapioca Research Station of the State Government was established in Trivandrum in 1944, which initiated organized research on cassava breeding and produced the earliest improved varieties of the crop. The most significant and lasting contribution of the initial phase of cassava research was the selection of the Malayan clone, M4, revolutionizing cassava cultivation in Kerala (Abraham, 1956). Even after 44 years, M4 remains the best table variety with unmatched culinary quality. Its cooked roots are mealy, soft and highly palatable with negligible cyanogen content. Although several varieties and breeding lines have culinary qualities comparable to that of M4, none is as stable in yield performance as the latter, especially under different soil and climatic conditions. A major hindrance in transferring the culinary quality of M4 through conventional breeding is the limited flowering capacity of the variety, apart from the complexity of the character itself.

RESEARCH AT THE CENTRAL TUBER CROPS RESEARCH INSTITUTE

In 1963, the Central Tuber Crops Research Institute (CTCRI) of the Indian Council of Agricultural Research (ICAR) was established for research on tropical tuber crops, with main emphasis on cassava. Achievements in cassava breeding and varietal dissemination in India have since been largely due to the contributions from CTCRI.

Genetic Resources

An exhaustive collection of the genetic resources of cassava was assembled at the Institute. Local varieties and types from within the country and accessions from abroad were collected. The major sources of exotic genetic stocks are from Colombia, Madagascar, Nigeria, Thailand, Ghana, Uganda, Malaysia, Indonesia, Sri Lanka, Senegal and Gabon. The genetic resources have been the precious starting material of CTCRI, which became instrumental in subsequent breeding achievements. At present the germplasm collection consists of 781 exotic and 806 indigenous accessions, making a total of 1587. In addition, there are eight wild relatives of cassava: *M. anomala*, *M. caerulescence*, *M. euprinosa*, *M. flabellifolia*, *M. glaziovii*, *M. grahami*, *M. tristis* and *M. peruviana*.

Enrichment of germplasm by collecting varieties and types from within the country and abroad, and their evaluation, is a continuing process. During 1996, twenty-seven combinations of F_1 seeds of cassava were received from CIAT, Colombia. Seeds germinated from 25 combinations. Germination ranged from 2-100%, with the majority of the combinations recording more than 50% germination. First clonal plants of 21 combinations were evaluated, recording root yields ranging from 0.41 to 3.01 kg per plant. The highest root yield was achieved by SM2371 (3.01 kg), followed by CM8809 (2.24 kg). The roots of these entries were sweet to the taste.

High-Yielding Varieties

Extensive intervarietal hybridization between superior varieties, and selection among recombinants resulted in the isolation and release of the first three high-yielding varieties of cassava from CTCRI in 1971. They are H-97, H-165 and H-226 (Magoon *et al*., 1970). As the emphasis in breeding was on yield improvement, the culinary quality of those hybrids was not as good as that of the preferred local varieties; hence, they could not establish well as table varieties in Kerala. Nevertheless, they are the most preferred varieties in the neighboring states. In 1977, two higher yielding hybrids with improved culinary quality were released as Sree Sahya and Sree Visakham (Jos *et al*., 1981).

H-97 is a hybrid between a local variety and a Brazilian selection. It has conical, short roots, yielding 25-35 t/ha, and has a crop duration of ten months.

H-165 is a hybrid between two local cultivars. The roots are relatively short and conical, yielding 33-38 t/ha. The variety is comparatively early maturing and can be harvested after 8-9 months.

H-226 is a hybrid between a local cultivar and the Malayan introduction, M4. The root yield is 30-35 t/ha, and crop duration is ten months. Both H-165 and H-226 are the predominant varieties cultivated in the states neighboring Kerala. H-226 has a high yield under irrigated cultivation in Tamil Nadu.

Sree Visakham is a hybrid between a local cultivar and a Madagascar variety. It has compact roots, which have yellow flesh due to a high carotene content (466 IU/100 g). Crop duration is ten months, and the root yield is 35-38 t/ha.

Sree Sahya is a multiple hybrid involving five parents, two of which are exotic and three indigenous. The roots are long-necked, yielding 35-40 t/ha. Crop duration is 10-11 months. Both Sree Visakham and Sree Sahya are improved table varieties, having better palatability than the former three hybrids.

Early Maturing Varieties

Over the last two decades the cultivation of cassava as a monocrop in the uplands started to decline in Kerala due to the cultivation of plantation crops which give higher income to the farmers. On the other hand, cassava is more and more being cultivated in low-lying areas after the main crop of rice, and for this short-duration varieties are needed. The early maturing (7 months) selection, Sree Prakash, released in 1987 (Nair *et al*., 1988) was quickly adopted in paddy-based cropping systems in the low-lying areas. As cultivation of cassava in low-lying areas started to increase, better short-duration varieties were needed. Sree Jaya and Sree Vijaya are two short-duration varieties which were released in 1988 for this purpose.

Sree Prakash is an indigenous selection. The plants are relatively short with high leaf retention. Its crop duration is 7-8 months and its root yield 35-40 t/ha.

Sree Jaya is a selection from indigenous germplasm. The plants are medium in height, yielding conical roots with white flesh. Its crop duration is six months and root yield 26-30 t/ha.

Sree Vijaya is a selection from indigenous germplasm. It has conical roots with yellow flesh and a root yield of 25-28 t/ha. Crop duration is six months.

The three short-duration varieties, having higher yield and excellent culinary quality, are much preferred by the farmers in Kerala, as they are ideally suited to cultivation in low-lying areas as a rotational crop after the paddy harvest. As the industrial belts of Tamil Nadu and Andhra Pradesh are continually in need of cassava roots, the short duration varieties are also becoming popular in those states.

Triploid Variety

As the role of cassava started changing from a human food item to an industrial raw material in the neighboring states, especially Tamil Nadu and Andhra Pradesh, higher yield became the most important factor. As a result, the high-yielding hybrids like H-165 and H-226 quickly dominated the industrial belts of Tamil Nadu and Andhra Pradesh. The demand was for higher dry matter and starch contents. Among the artificially produced polyploids, triploids were found to combine higher yield and higher starch content.

Sree Harsha is the first triploid variety of cassava, released in 1996 (Sreekumari *et al.*, 1999). It is a hybrid between a diploid selection and induced tetraploid of the released variety Sree Sahya. The plants are short, vigorous and non-branching or top-branching. The leaves are broad, thick and dark green in color. Its roots are very compact, yielding 35-40 t/ha. Crop duration is ten months, but because of its early bulking nature it can be harvested as early as the 7th month without any yield loss or starch reduction in the roots. Sree Harsha has recorded the highest starch content of 39.1% among the released cassava varieties.

Triploids are produced by crossing diploids with colchicine-induced tetraploids. Use of diploids as female parents was found to be more successful in the production of triploids while reciprocal crosses were unsuccessful. Certain parental combinations were found to be more fruitful in producing triploids.

Triploidy *per se* was found to be related to a number of desirable attributes in cassava, such as higher yield, higher harvest index, greater dry matter and starch contents in roots, rapid bulking, early harvestability, shade tolerance and tolerance to cassava mosaic disease (CMD). The triploid hybrid has made substantial advances in the breeding of cassava as it also combines high yield with excellent culinary quality, making it suitable as a dual purpose variety for both industrial and table purposes. Triploidy breeding in cassava offers enhanced frequency of higher yielders in the progeny compared to other breeding methods, thus providing better opportunities for selection. Being vegetatively propagated but with a sexual reproduction system, cassava is a suitable plant for triploidy breeding. Although induction of tetraploidy, interploidy crosses, seed set, germination and recovery of triploids are beset with several hindrances, triploid breeding is worth the effort. All practical aspects of triploidy breeding in cassava have been standardized at CTCRI.

Heterotic Varieties

Cassava, which is highly heterozygous and cross-pollinated, is also found to be a suitable plant for exploitation of heterosis. Inbreds were produced up to the 5th generation. Although considerable inbreeding depression was manifested in varying degrees for almost all the characters, certain genetic stocks tolerated inbreeding depression to a great extent. Studies show that root yield and most of the yield components in cassava are governed by dominant gene action, suggesting the scope for exploitation of heterosis in cassava improvement. Heterosis for root yield, in different varieties, was found to range from 10-100% over the better parent. Two superior selections from top-cross hybrids of inbreds with the released variety Sree Visakham (TCH-1 and TCH-2) were found to have very palatable root quality, higher yield (42-44 t/ha), higher harvest index (69-71%) and lower cyanogen content (74-80 ppm). They have been tested in yield trials, on-farm trials and multi-location trials, and are now recommended for formal release (Easwari Amma *et al*., 2000).

Other On-going Programs

1. Interspecific hybridization

Interspecific hybridization was carried out to transfer genes for CMD resistance, protein enrichment of roots, and stress tolerance to cassava from its wild relatives. The hybrids of cassava with *M. flabellifolia*, *M.tristis*, *M. caerulescence* and *M. peruviana* were backcrossed to elite cassava varieties. The BC_2 clones showed considerable improvement in starch content and root quality. Of the 1056 backcross hybrids, 147 showed storage root formation, and 35 were free from CMD. Cyanogen content of roots ranged from 24-64 ppm. Ten CMD-free BC_2 clones, having a lower cyanogen content and fairly good root quality, have been identified. The backcross breeding program is still in progress.

2. Tissue culture

Tissue culture programs are aimed at eliminating CMD through meristem culture, *in vitro* conservation of germplasm, micro-propagation, and anther/pollen culture for production of haploids. Lower levels of benzyl adenine, NAA and GA were found to be better for the development of meristem cultures in cassava (Unnikrishnan and Sheela, 1998). Sago made from cassava flour was found to be an excellent substitute for agar used in tissue culture medium (Nair and Makeshkumar, 2000).

Of the 1587 germplasm accessions maintained in the field gene bank, 985 accessions (62.1%) are conserved as *in vitro* slow growth cultures. Work is in progress to conserve the rest of the accessions also in this manner. Slow growth up to ten months was induced with an osmotic retardant medium containing sorbitol or mannitol (0.5-3.0 g/l). The 24 accessions received as *in vitro* cultures from the CIAT-Thai program have been micro-propagated and transferred to the field. One accession, MNGA-1, showed very low incidence of CMD under field conditions, and is being evaluated in multi-location trials.

3. Mutation breeding

Mutation studies are underway with the specific objectives of developing varieties with CMD resistance, and reducing the cyanogen content in the roots. Studies have indicated the possibility of reducing the level of cyanogen in cassava roots.

4. True seed program

The program for the propagation of cassava by true seeds has been taken up to popularize the crop in far-flung areas of the country with marginal soil conditions. This will help in reducing the bulk of initial planting material to be transported as well as in preventing the spread of CMD. In three non-traditional areas of the country, i.e. Coimbatore, Peddapuram and Jagadalpur, seedlings from true seeds have been raised and their first clonal progenies are being evaluated.

5. Field production of healthy planting material

A simple nursery and field screening technique was found to be useful in producing healthy planting materials of cassava in bulk. Stakes of 7-10 cm length and with 3-4 nodes are planted closely together in nursery beds. On sprouting, only the symptom-free setts are retained for transplantation into the field while the rest are destroyed. Regular rouging of infected plants in the field is carried out. Spraying of insecticides at 40-day intervals is followed to control the vector population of CMD. By practizing this technique for three seasons, field incidence of CMD was reduced from 70% to 12% among ten varieties. Symptom-free plants can be obtained by this method even from infected plants (Mohankumar and Unnikrishnan, 1999).

BREEDING WORK ELSEWHERE

Apart from CTCRI, breeding research at the Agricultural Universities of Kerala (KAU) and Tamil Nadu (TNAU), and the Tamil Nadu Horticulture Department has resulted in the release of several other cassava varieties. KAU has released two short-duration varieties, i.e. Nidhi in1993 and KMC-1 in 1998. TNAU released three varieties, i.e. CO-1, CO-2 and CO-3 in 1977, 1984 and 1993, respectively, and the Horticulture Department of Tamil Nadu released one variety, MVD-1, in 1993.

Nidhi is a clonal selection suited to areas of sandy loam soils of central Kerala. Crop duration is six months and its mean yield is 25 t/ha.

KMC-1 is a clonal selection suitable for intercropping in coconut gardens of central Kerala. Its crop duration is six months and its mean yield 30.5 t/ha.

CO-1 is a clonal selection from a local variety. Crop duration is 8-9 months and the mean yield is 30 t/ha.

CO-2 is a clonal selection from an open-pollinated seedling progeny of a local type. It has compact roots. Crop duration is 8-9 months and its mean yield is 35 t/ha.

CO-3 is a clonal selection from open-pollinated seedlings of Nigerian origin. Crop duration is eight months. Mean yield under irrigation is 42.6 t/ha and under rainfed conditions is 27.3 t/ha.

MVD-1 is a clonal selection exhibiting field tolerance to CMD. Crop duration is nine months and mean yield is 34.5 t/ha.

DISSEMINATION OF VARIETIES

Varietal dissemination of cassava in India is the epitome of a need-based spread of a backyard crop, from its obscure status as a subsistence or famine food to the more elevated status of an industrial raw material and cash crop. Cassava is the major tropical root crop cultivated in the country, occupying 63% of the total area under root and tuber crops.

Varietal Spread in Kerala

All the varieties released by CTCRI have been popularized in Kerala through extension activities. Sree Visakham, Sree Jaya, Sree Vijaya, H-165 and H-226 are cultivated in different areas, depending on the farmer’s choice of specific varieties. M4 is still very popular due to its excellent and stable culinary quality. Besides, there are more than 125 recorded local varieties that have evolved over the centuries through farmer selection of clones, chance hybrids or mutants. However, the extensive spread of CMD has led many excellent varieties like Kalikalan to the verge of extinction.

Kerala accounts for about 55% of the cassava cultivated area (142,000 ha) in India. But the majority of the area (69%) is planted to local varieties which are still preferred in the central and northern regions (80-90%); in the south, there are fewer local varieties (13-53%) with 40-50% of the area planted to M4. H-226 is cultivated up to 22% in the Pathanamthitta district in the south. In general, the high-yielding varieties are not very popular in the state because of their inferior culinary quality compared to M4 and other local varieties (Ramanathan *et al*., 1989). The short duration varieties Sree Prakash, Sree Jaya and Sree Vijaya are becoming popular in the low lying areas of southern and central districts of Kerala but data on the extent of their adaption is not available.

Varietal Spread in Tamil Nadu

Tamil Nadu accounts for about 31% of the cassava area (65,700 ha) in India. Here, the crop is used as an industrial raw material, and nearly 85% of the cultivated area is planted to high-yielding varieties, mainly H-165 and H-226, followed by Sree Visakham, Sree Prakash, Sree Jaya, Sree Harsha and CO-3. The largest number of cassava-based industrial units is concentrated in Salem district of Tamil Nadu, where cassava is largely (55%) cultivated under irrigation, resulting in the highest mean yield (46.3 t/ha in 1997) in the country.

Varietal Spread in Andhra Pradesh

Andhra Pradesh accounts for 7% of the cassava cultivated area (22,000 ha) in India. Cassava emerged as an industrial crop in the 1960s with the setting up of five sago factories; now, there are 63 factories. H-165 and H-226 are the major varieties. Also, local varieties and M4 are grown on a limited scale. The crop is mostly cultivated as a monocrop and also as an intercrop in cashew, mango and coconut orchards during the juvenile stage of the latter crops. Schemes for modernization of cassava cultivation to ensure root availability for sago units have been launched jointly by CTCRI and a nationalized bank (State Bank of India). It is a unique venture covering both agriculture and manufacturing. With technical support from CTCRI, seven units have implemented the first stage of modernization by process improvements, resulting in a yield increase of 10%. In addition, new varieties are being tried out with a modified fertilizer package based on soil analyses. There is great demand for planting materials of the improved varieties.

Varietal Spread in Other States

In Karnataka, cassava cultivation is restricted to certain districts, and mostly local varieties are grown. Karnataka has congenial conditions for extensive cultivation of cassava, such as high annual rainfall, high temperature and humidity during the summer. Introduction of improved varieties, and adoption of required cultural practices can substantially increase production. However, processing industries have yet to be established in Karnataka.

In the other states, the area under cassava ranges from 200-4,000 hectares, and root production from 300-22,200 metric tonnes. The varietal coverage of those states is not exactly known, except in Assam where H-165 and Sree Prakash are prevailing. In the northeastern states, cassava is mostly used for human consumption, which means improved table varieties may have better acceptance.

Very recently, the states of Gujrat and Maharashtra have started producing cassava, and the crop is gaining importance there. The states also procure cassava starch from Salem (Tamil Nadu) for further processing and utilization.

NEW CHALLENGES

The Present Scenario

Both area and production of cassava in India have recorded steady increases up to the year 1975/76, after which they started to decline. Statistics show that 33.5% of the cassava area in the country has switched to other crops from 1975 up to the present. This is a reflection of the trend in the major cassava-producing state of Kerala, where 56.6% of the areas traditionally grown with cassava have been replaced by cash crops. Production has also declined by 52%. At the same time, Andhra Pradesh and Tamil Nadu have together recorded a tremendous increase in cultivated area by 45.7%, and production by 166.8% over the same period, with the highest yields recorded in Tamil Nadu, reaching an impressive figure of 46.3 t/ha in 1997. In short, the production slump in the country is due to a production decline in Kerala State. This decline is the result of a number of factors such as: 1) cassava in Kerala is not a cash crop; 2) higher income-generating plantation crops such as rubber, coconut, black pepper and coffee have been replacing cassava; 3) there is practically no industrial utilization of cassava to retain this crop as an income-earner in Kerala; 4) the crop is almost entirely used for table purpose, so palatability is very important; 5) the table varieties grown in Kerala are only average or moderate yielders; 6) considerable changes in dietary patterns and taste preferences have taken place due to the general improvement in the standard of living, and 7) the ready availability of cereals and other items has lessened the importance of cassava as a food.

Remedies for Boosting Cassava Production

The International Food Policy Research Institute (IFPRI) in 1999 has projected an increase in the global demand for cassava of 68% by the year 2020 (Scott *et al*., 2000). Therefore, technologies to increase production have to be devised. Though the chances for expansion of the cassava area (as a sole crop) are very limited in Kerala, the possibility of incorporating cassava as a component in existing cropping systems is very high. The crop is traditionally cultivated under complex and diversified systems in homesteads and gardens, which are shaded by crops such as coconut, areca nut and fruit trees like jackfruit and mango. Replacement of traditional varieties by efficient, shade-tolerant, palatable varieties in coconut or areca nut-based cropping systems can enhance production without any area expansion in the uplands. The triploid hybrid Sree Harsha is palatable and shade-tolerant, and can be popularized for home-garden cultivation. The short-duration varieties need to be further tailored for still shorter crop duration to facilitate better utilization in low-lying areas after the paddy harvest. Since the existing short-duration varieties are cultivars which have resulted from only simple selection, it should be possible to genetically shorten crop duration further by secondary breeding using appropriate techniques.

The other states too have the potential of increasing cassava production further. In Tamil Nadu, since 80% of the produce is utilized by the starch and sago industries, high-yielding, high starch varieties like Sree Harsha and other short-duration varieties can further enhance production. In Andhra Pradesh, where yield are currently less than 10 t/ha, introduction of high-yielding, high starch varieties and scientific crop management practices can boost production substantially. Drought tolerant varieties in Tamil Nadu and Andhra Pradesh can boost up the production in non-irrigated areas. Karnataka, which has a favorable climate for cassava cultivation, should be encouraged to step up cultivation and to set up processing industries. In the northeastern states where cassava is used for human consumption, more palatable varieties should be introduced and popularized.

The Universal Problem

Yield in cassava has been steadily climbing as in the case of most crops, and it has as yet shown no signs of reaching a plateau. Hence, the major challenge and the imminent need of the day are for the development of varieties resistant to the CMD virus. Eradication of CMD alone can step up cassava production to a great extent. In CTCRI, comparison of CMD-infected and symptom-free plants of improved varieties has indicated a yield loss ranging from 10-20% due to the disease (Nair and Malathi, 1987). When meristem-derived, virus-free plants of the same varieties were compared to field-propagated, symptom-free plants (probably carrying latent infection), the former outyielded the latter by 12-24% (Nair, 1990). Obviously eradication of the virus from the plants can bring about an absolute increase in yield of 25-50%. In African countries, yield loss due to CMD has been reported to range from 44-88%. The magnitude of the devastating loss due to the disease is not often realized. Utmost priority should be given for the incorporation of genetic resistance in cassava against CMD.

Studies show that genetic erosion occurs in cassava for many characters and hence they have to be enriched continuously by introgressing genes from wild relatives (Nassar *et al*., 2000). Many wild relatives of cassava exhibit a vast array of genetic variation which is yet to be exploited for crop improvement. Apart from *M. glaziovii* which was utilized in the 1940s as a source of virus resistance, other useful species are *M. pseudoglaziovii*, *M. anomala*, *M. oligantha* and *M. nausana* from which valuable attributes like high productivity under semi-arid and arid conditions, shade tolerance, protein enrichment in roots, low cyanogen content, and high vigor could be incorporated into cassava by introgressive hybridization (Nassar, 1997; Nassar and Dorea, 1981).

Need for Biotechnology

Wherever vertical gene transfer or parent-offspring gene transfer by traditional methods is not possible, horizontal gene transfer or transfer of genes from one species to another, without passing through the sexual process, has to be made through biotechnological procedures. As one of the most frequent transgenic traits incorporated in crop plants is virus resistance, the know-how can be made use of in cassava as a top priority project. Biotechnology can augment conventional technologies to tackle serious limiting factors to productivity. Some other areas which require greater biotechnological attention are protein enrichment of roots, enhancement of root shelf life, and drought tolerance. The ability of cassava to thrive on marginal lands and poor soils has to be further improved by breeding varieties adapted to abiotic stresses. Only then can cassava cultivation be extended to vast, unused, tracts of land.

True Seeds

The use of true seed instead of stem cuttings will reduce production costs and also help eliminate pests and pathogens. True seed can also be employed to extend cultivation into non-traditional areas. The transfer of apomictic genes from wild species can produce uniform plants from seeds without any genetic segregation (Nassar *et al*., 2000).

EPILOGUE

Genetic, technical, intellectual and financial resources are not evenly distributed around the globe. No single organization, nation or region has the complete supply of resources needed to breed the most productive varieties. There is a long history of international collaboration, germplasm exchange and interdependence in agriculture. What is needed today is a greater and more fruitful collaboration to make the most effective use of resources. Advances in agricultural technology could have its greatest impact as an effective instrument against poverty, hunger, malnutrition and environmental degradation. It is particularly pertinent to point out that some 700 million of the world's more than one billion poverty-stricken people are in Asia, and that about 500 million of them live in absolute poverty. Increasing cassava production in Asia and improvement of product quality can have a humble but beneficial effect on a hungry world.

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A HISTORICAL ACCOUNT OF PROGRESS MADE IN CASSAVA VARIETAL IMPROVEMENT IN CHINA

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ABSTRACT

Cassava varietal improvement in China has historically been conducted by collecting and evaluating local varieties, by introducing and testing of cassava germplasm from abroad, followed by the establishment of a cassava cross-breeding program. Considerable progresses has been made in the following areas:

a) Collection and evaluation of the local varieties, SC205 and SC201 and their extension over a wide range of growing conditions, so as to expand their growing range and planting area
b) Setting up a cassava germplasm bank to conduct cross-breeding of cassava
c) Establishing a nation-wide cassava regional trial network, which forms an integral part of the breeding program, in order to develop improved varieties, test and demonstrate as well as extent new higher-yielding cassava varieties
d) Selection of many promising clones
e) Release of some improved varieties.

The cassava breeding program in China was started in the 1960s when several good local varieties were collected, evaluated and released. It was shown that cassava can be planted in the region south of Qinling Huaihe and the Yangtse river basin, in those areas having a mean annual temperature above 18^{o}C and a frost-free period of more than 8 months of the year. Since the 1970s marked progress has been made by adopting an integrated system of germplasm introduction and breeding, with the major objectives of high yield, high starch content and resistance to wind. A nation-wide cassava trial network was established to form part of this integrated breeding system to produce improved varieties, test, select and demonstrate as well as extend these new varieties. Some of these improved varieties, such as SC6068, SC124, SC8002, SC8013, Nanzhi-188, GR891 and GR911, have been released. They are now grown in an area of about 50,000 ha and outyield the local clones by about 20%, increasing farmers' income by more than 3.4 million yuan.

In recent years the cassava breeding program in China has been capable of annually producing more than 3000 hybrid seeds from 80-100 cross combinations, as well as evaluating 2000-3000 hybrid seeds introduced from CIAT/Colombia and the Thai-CIAT program. More than 500 promising clones have been selected, of which OMR33-10-4, ZM8641 and ZM9057 will be further tested and examined for release. In addition, many promising clones, such as CMR34-11-4, OMR36-63-6, OMR37-103-1, OMR37-14-9, CMR38-163-4, SM2323-6 and ZM9244, which are characterized by high yield and high dry matter content, can be used in the future in the cassava varietal improvement program in China.

INTRODUCTION

Cassava is the fifth most important crop in southern China, following rice, sweetpotato, sugarcane and maize. It is used mainly as animal feed and for starch manufacturing which both play an important role in the upland agricultural economy. Cassava has been cultivated in China for over 180 years. Presently the production area is

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about 400,000 ha. There are only two major local varieties: SC205 and SC201. However, good progress has been made in developing other high-yield and high-starch cassava varieties, and several improved varieties have recently been released in southern China.

HISTORICAL REVIEW

It is still unknown when cassava was first introduced into China, but most reports indicate that cassava was first introduced from southeast Asia into China in about 1820. Up to 1840, cassava was grown mainly by slash-and-burn cultivation or as a backyard crop. After 1851, cassava was widely grown in the eastern areas of Guangdong province and cassava-based products were sold at the local markets. Cassava stems were then taken to Hainan island and Guangxi province and spread throughout most regions of south China. Now, cassava has become the fifth most important crop, used mainly as animal feed and as raw material for industrial processing.

The earliest research on cassava cultivation was carried out at the Guangdong Agriculture and Sericulture Experimental Farm, where local cassava varieties were collected and evaluated, for two crop cycles, and roots analyzed for their nutritive value during 1914 to 1919. From 1940 to 1944, the collection and evaluation of local cassava varieties was continued by Li You Kai in Guangxi province, where HCN content and its distribution in cassava plants was determined (Li You Kai, 1943). The book entitled "Research on Cassava Toxins" was published. However, a systematic and intensive investigation about cassava cultivation was first conducted in 1958 with the objective of stimulating China's cassava production. Twelf local varieties were collected and some good ones were recommended and released, such as "Yinshanhongpi" and "Nanyangqingpi". Cassava breeding and agronomy research was later conducted by Li You Kai, Liang Guang Chang and Wun Jian at other research institutes in Guangdong, Guangxi and Hainan provinces. Based on trials conducted in 1958-1964, Wun Jian *et al.* (1964) pointed out that in China cassava could be planted in the Yangtze river basin in those areas where the mean annual temperature was above 18^{o}C and where there was a frost-free period of more than eight months of the year. The suitable area was about 1,200,000 km^2 (Liang Guang Chang, 1982). Also, some local varieties with high yield and wide adaptability, such as SC205 and SC201, were evaluated and released.

After 1980, several research institutes, such as CATAS, UCRI and GSCRI, established their cassava breeding programs. With good international cooperation, cassava breeding and agronomy research were systematically conducted, and good progress has been made.

PRESENT SITUATION AND PROGRESS

Cassava varietal improvement in China has historically been conducted by introducing and testing of cassava germplasm, collecting and evaluating local varieties, followed by cassava cross-breeding.

1. Collection and introduction of cassava germplasm and establishment of a cassava germplasm bank for cross-breeding

In China the number of local cassava varieties was minimal before 1996. Many cassava varieties that were planted at a large scale had been introduced from abroad. Some local clonal progenies, which had evolved through natural or artifical selection from natural crosses, also existed but these were quite limited and scattered, with less than 20 accessions in total. Therefore, cassava germplasm in China can mainly be attributed to direct introductions or to cross-breeding of local with introduced germplasm. Over the years, China has introduced more than 30 accessions of cassava from CIAT/Colombia or from the Thai-CIAT program (**Table 1**) and a number of cross parents from CIAT's breeding materials have also been evaluated and are now being conserved. A cassava germplasm bank has been set up at CATAS, which presently has more than 120 accessions; their major characteristics have been evaluated, and these are being catalogued and documented. This fills in the gaps in the fields of cassava science and technology in China, forms the foundation for cassava breeding, and is a source of genetic diversity for selecting cross parents. Presently, the cassava programs in China are capable of annually producing more than 3000 hybrid seeds from 80-100 cross combinations, as well as evaluating 2000-3000 hybrid seeds introduced from CIAT/Colombia and the Thai-CIAT program. These are very important to cassava varietal improvement in China.

Table 1. Cassava germplasm introduced to CATAS from 1982 to 1999.

Accessions	Year of introduction	Origins	Utilization
Rayong1	1982	CIAT	Cross parent
MCol 22	1982	CIAT	up parent
CM1585-13	1982	CIAT	up parent
MCol 1468	1982	CIAT	up parent
CM1372-15	1986	CIAT	up parent
CM2399-4	1986	CIAT	up parent
CM1568-2	1986	CIAT	up parent
CM26-07-15	1986	CIAT	up parent
CM4054-40	1986	CIAT	up parent
CM7530-3	1986	CIAT	up parent
MCUB32	1997	CIAT	Propagation and testing
MBRA900	1997	CIAT	Propagation and testing
SG104-264	1997	CIAT	Propagation and testing
CM5253-1	1997	CIAT	Propagation and testing
Rayong 5	1999	Rayong/Thailand	Propagation and testing
Rayong 60	1999	Rayong/Thailand	Propagation and testing
Rayong 72	1999	Rayong/Thailand	Propagation and testing
KU 50	1999	Rayong/Thailand	Propagation and testing

2. Establishing a national cassava trial network, forming an integrated breeding system of improved varieties, testing and demonstration as well as extension of cassava

In China, a national cassava network has been set up, of which CATAS and GSCRI are mainly in charge of cassava sciences and technologies research work, such as cassava breeding, agronomic research and extension. Some experiment stations in Guangdong (Zhanzhang and Zhaoqing districts), Guangxi (Nanning and Liuzhou districts), Hainan (Beisha, Tunchang and Dingan counties) and Yunnan (Honghe district) have been conducting regional trials and production tests. Over the years, more than 100 promising clones have been evaluated in regional trials and about 15 good clones have been tested in the network. Those found to have high yield and wide adaptability, such as OMR33-10-4, ZM9057, ZM8641, ZM8639 and ZM9242 have been selected for propagation and will be released as new varieties when they are approved. Now, CATAS has become the center of the national cassava research program and a national cassava trial network has been established, thus forming an integrated breeding system of varietal improvement, evaluation, demonstration and dissemination of new cassava varieties in China.

3. Multiplication and dissemination of improved varieties

Several improved varieties have been selected and released. Based on previous varietal improvement work, the first improved variety, namely SC6068, with high starch and low HCN content was bred and released for human food and animal feed by CATAS in 1980. This variety was widely distributed in southern China, but with a limited area of about 6000 ha in total (**Table 2**), mainly planted on Guangdong, Hainan and Fujian provinces. It is an early maturing variety, which can be harvested in 7-8 months after planting. However, its fresh root yield is about 15-20 t/ha, while its root dry matter and starch contents reaches 40 and 30%, respectively. In 1992, another new variety, SC124, with high yield and resistance to cold was recommended by CATAS. This variety has been released in most cassava planting areas in south China, mainly in Guangxi and Yunnan provinces, with a total extension area of about 30,000 ha (**Table 2**). In 1994, two new improved varieties, SC8002 and SC8013 from CATAS, were released in south China. Of these, SC8002 was mainly released in Guangdong province with an extension area of about 6000 ha, while SC8013 was released in the coastal regions of Hainan, Guangdong and Guangxi provinces with an extension area of about 5000 ha. However, SC8013 has become a major variety in those regions affected by typhoons, due to its good wind resistance.

In 1998, two new varieties, named GR891 and GR911, selected from CIAT's breeding materials, were selected and released by GSCRI. They were mainly released in Beihai, Nanning and Liuzhou districts of Guangxi province with a total area of 100 ha each until now. However, they will become important varieties for commercial cassava production in Guangxi, due to their good performance in terms of high yield and high starch content.

In addition, the South China Institute of Botany in Guangzhou recommended two varieties, named Nanzhi-188 and Nanzhi-199, selected from CIAT germplasm introduced as tissue culture in 1984.

Table 2. Improved cassava varieties released in China, their yield characteristics and the area grown in 1999.

Varieties	Fresh root yield (t/ha)	Dry root yield (t/ha)	Root dry matter content (%)	Area grown (ha)
SC6068	20.6	8.3	40.5	6,000
SC124	32.5	19.2	37.6	30,000
SC8002	28.7	10.5	36.7	6,000
SC8013	29.5	11.6	39.2	5,000
Nanzhi-188	22.5	8.7	38.5	200
GR891	23.2	9.1	39.2	100
GR911	28.9	10.3	35.5	100
SC205	28.6	10.6	37.0	-

Promising clones in the pipeline for further testing

Over the years, 2500 cross parents were introduced and evaluated in China, in the form of 120,000 true seeds, of which 70,000 seeds from CIAT/Colombia and 50,000 from the Thai-CIAT program. More than 40,000 F_1 seeddlings were obtained. After evaluation and step by step selection, many promising clones have been identified in addition to those improved varieties mentioned above (**Table 3**). Of these, OMR33-10-4, ZM9057 and ZM8641 have been evaluated on farmers' fields and may soon be approved for release (**Table 4**). They have been planted on a small scale in many locations.

Table 3. Yield characteristics of some promising clones.

Clones	Fresh root yield (t/ha)	Dry root yield (t/ha)	Root dry matter content (%)
ZM9036	31.3	12.4	39.5
ZM9242	31.1	11.5	37.1
ZM9244	32.1	11.7	36.6
ZM92157	29.4	10.1	34.5
OMR36-36-6	35.0	14.7	41.9
OMR36-63-6	25.8	11.1	43.2
OMR36-40-9	27.5	11.7	42.7
OMR36-40-12	30.8	12.1	39.4
CMR35-70-6	31.3	12.1	38.7
CMR35-70-1	28.7	12.4	43.1
OMR36-40-13	27.1	11.7	43.1

Table 4. Clones which are being considered for release in the near future in comparison with two check varieties[1].

Clones	Fresh root yield (t/ha)	Dry root yield (t/ha)	Root dry matter content (%)
OMR33-10-4	31.4	12.3	39.3
ZM9057	30.9	11.8	38.2
ZM8641	28.3	10.9	38.4
SC205 (check)	24.07	9.2	37.4
SC201 (check)	21.50	7.8	36.1

[1]Data are average values from eight Regional Trials.

DEVELOPMENT POTENTIAL AND STRATEGIES

Development Potential

Cassava is a very important food and animal feed crop. It can be planted in the southern part of China in those areas with a mean annual temperature above 18°C and a frost-free period of more than eight months of the year. The suitable area is about 1.2 million km^2, including Guangdong, Guangxi and Hainan provinces, as well as the southern parts of Yunnan, Fujian, Jiangxi, Hunan and Sichuan provinces. Therefore, it is very important and necessary for cassava breeders to select new varieties that are suitable for these different regions. Although several improved varieties have been selected and released, they were found to be not all suitable for the various cassava production areas. In addition, their root dry matter content and starch content had not significantly increased. Thus, cassava varietal improvement needs to be continued in order to meet the requirements of intensive and commercial cultivation. Greater attention should be paid to cassava breeding programs, as there is indeed a very bright future for cassava cultivation in China.

Development Strategies

The following strategies have been formulated to enhance cassava varietal improvement and dissemination in China:

- The main objective of cassava varietal improvement in China remains the selection of new varieties which are characterized by high yield, high starch content, strong wind-resistance and early maturity.
- CATAS might be considered as the center of cassava varietal improvement in China, working together with other research institutes, production units and cooperating stations to form a national cassava network. All units have to be united together to conduct cassava research, so as to form an integrated breeding system for improving varieties, testing, demonstrating and disseminating new cassava varieties in China.
- A recommended management system would be the combination of "research institutes + companies + farmers" in order to speed up the dissemination and transfer of improved varieties and new technologies.

- Set up a cassava biotechnology laboratory to develop new breeding technologies to facilitate the breeding for early maturity and starch quality.
- Use as a guiding principle the need to combine cassava breeding with germplasm introductions.

This is a very important strategy for cassava varietal improvement in China. Cross-breeding is the best way to achieve yield improvements in China, while germplasm introduction is the best way to widen the genetic base needed to make progress in cassava breeding. It is very difficult for breeders to make any breakthrough by using only the very limited native genetic resources. Therefore, a combination of native germplasm with those coming from abroad, so as to produce better cross parents, should be most successful. From **Tables 5** and **6**, we can see that many elite clones of CATAS were selected from the hybrids between native materials with those introduced from CIAT/Colombia or the Thai-CIAT program. The materials from abroad have shown over the years a high selection efficiency and a very high root dry matter content. Those from the Thai-CIAT program have shown the best performance, both in terms of root yield and root dry matter content.

Table 5. Average yield characteristics of new clones according to their origin in comparison with those of SC205.

Origin of germplasm	No. of clones	Fresh root yield (t/ha)	Dry root yield (t/ha)	Root dry matter content (%)
CATAS	394	22.3	7.7	34.6
CIAT/Colombia	55	18.1	6.2	34.2
Thai-CIAT	165	20.5	7.7	38.7
SC205 (check)		20.5	7.3	35.7

Table 6. Results of the Preliminary Yield Trials (PYT) and Advanced Yield Trials (AYT) conducted at CATAS in 1998.

Trail	Origin/ name of clones	No. of tested clones	No. of selections	Fresh root yield (t/ha)	Dry root yield (t/ha)	Root dry matter content (%)	Harvest index
PYT	CATAS	33	18	25.4	9.8	38.5	0.65
	Thai-CIAT	28	15	25.5	10.8	42.5	0.63
	CIAT/Colombia	8	4	25.9	10.7	41.3	0.57
	SC205			22.0	8.6	39.1	
AYT	CATAS	28	17	28.0	10.4	37.0	
	Thai-CIAT	16	8	24.4	9.8	40.7	
	SC205			22.1	8.6	39.2	

Strengthen international cooperation

The exchange of cassava germplasm and experiences with other cassava-growing countries, through active international cooperation and training courses, will further strengthen the breeding effort and enhance the development of new varieties and technologies.

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CASSAVA BREEDING AND VARIETAL DISSEMINATION IN THE PHILIPPINES - MAJOR ACHIEVEMENTS DURING THE PAST 20 YEARS

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ASTRACT

During the past 20 years of close collaboration with CIAT in the cassava breeding program in the Philippines, much has been achieved, not only in terms of human capacity building but also in the acquisition of improved cassava germplasm. These materials were used in a multy-year selection scheme, which culminated in the release of several improved cassava varieties recommended for cultivation in the country, in order to support the need for food, feed and various industrial products.

Since 1982 a total of 40,809 cassava hybrid seeds were received from CIAT headquarters in Colombia and 11,280 hybrid seeds rom the Thai-CIAT cassava program. These were evaluated in all stages of selection under Philippine conditions. Three cassava varieties were released by the Center during the early years of establishment and 16 varieties were subsequently released by the National Seed Industry Council. From these released varieties, six are of local origin, eight are from CIAT materials and five from locally developed hybrids.

Progress in the selection of the materials received has been quite positive, meaning that a lot of the elite genetic materials introduced were selected for possible varietal release or as parental material for the breeding program. Considering the source of the two genetic populations we received, it was noted that hybrid seeds from Thailand performed very well in the Philippines; in fact, some of the elite materials have superior characteristics compared to the best Philippine varieties. About 0.15% of hybrid seeds received from CIAT/Colombia were eventually selected and maintained, while about 0.38% of seed received from the Thai-CIAT program were maintained for further trials and possible varietal release.

The dissemination of new cassava varieties has been intensified during recent years through the conducting of adaptation trials in various parts of the country in collaboration with farmers and individuals in the private sector. The involvement of the private sector in the industrial use of cassava for processing into various products has triggered widespread planting of the new cassava varieties. San Miguel Corporation has promoted the planting of cassava for production of animal feeds and for alcohol, to be used in the manufacture of gin, a popular alcoholic drink in the Philippines. In 1997, about 5,000 hectares were planted to cassava primarily using Lakan and Golden Yellow varieties. New clones, KU-50, Rayong 5 and PSB Cv-12 (SM972-20) are rapidly being multiplied to provide part of the planting materials required for San Miguel’s cassava project expansion in Negros Occidental. In addition to this, starch factories continuously plant high yielding cassava (VC-5) for the starch industry. Starch factories now have an approximate combined area of 10,000 hectares of cassava planted to the recommended cassava varieties.

Future breeding work and selection will focus on the identification of superior varieties, not only with high yield but with high starch content, tolerance to existing pests and diseases, and other characters that will satisfy the requirements of the cassava-based industry.

INTRODUCTION

Cassava, (*Manihot esculenta* Crantz) has been cultivated in the Philippines even before World War I as a food source using the traditional varieties. Several early workers attempted to investigate the crop’s potential in the production of starch, flour, animal feed

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and alcohol (Roxas and Mario, 1921; Sison, 1921). Realizing the multiple uses of cassava, the Philippine Congress passed the Republic Act 657, known as the Cassava Flour Law, in 1951 (Acena, 1953). This Act encouraged and promoted the production, processing and consumption of cassava flour as a measure to conserve dollars and reduce the importation of wheat. Since then, very little effort has been made to support the cassava industry and to fully implement the law.

Cassava varietal improvement in the Philippines started in the 1960s at the Institute of Plant Breeding (IPB) at Los Baños, Laguna (Bacusmo and Bader, 1992). However, activities consisted mainly of variety trials of a few local and introduced varieties (Mariscal, 1987). It was only when the Philippine Root Crop Research and Training Center (PhilRootcrops) was established in 1977 at Visayas State College of Agriculture, Baybay, Leyte, by virtue of Presidential Decree No. 1107, that a more organized and relatively well-supported cassava breeding program started. This resulted in the assemblage of various cassava germplasm collections, subsequent screening, and the identification and release of superior local varieties. The breeding program was further enhanced when PhilRootcrops established a strong linkage with CIAT's cassava program in 1982 through the leadership of Dr. Kazuo Kawano, CIAT's erstwhile cassava breeder, who initiated the CIAT Regional Cassava Program in Asia in 1983. CIAT provided the national program with improved cassava populations. This resulted in the release of several cassava varieties with parental origin from CIAT. More than that, CIAT has helped the center in strengthening the capability of its breeders to spearhead systematic evaluation and selection of the improved materials, and their subsequent utilization in breeding.

For the last 20 years of cassava research, a modest increase of the national average yield of cassava from 6.0 t/ha in 1977 to 9.0 t/ha in 1997 was attained. This yield, however, is one of the lowest in Southeast Asia. The modest yield increase is attributed to gradual adoption of high-yielding cassava varieties and improved cultural practices (Rootcrops National RDE Agenda, 1999).

With globalization, governments around the world are increasingly dismantling tariff barriers and eliminating protective subsidies in preparation of the full implementation of the General Agreement on Tariffs and Trade (GATT). For ASEAN member countries such as the Philippines, trade liberalization is even more accelerated as signatories of the Asean Free Trade Area's (AFTA) move to reduce tariffs ahead of other regions. This provides new opportunities and poses new challenges to producers, traders and consumers. In this context, the potential of cassava shall be exploited mainly in terms of domestic utilization for food, feed and industrial products. Walters (1983), Lynam (1986) and Singh (1986) emphasized that cassava will play a major role in satisfying the domestic needs of the country, and that any future increase in output by the cassava producing countries in Asia should be aimed primarily at their domestic markets, such as for animal feed and starch production (food processing, textiles, paper and board, sweeteners and ethanol). True to the projections of the economists, recently in the Philippines a tremendous demand for cassava was observed for production of animal feed, starch and alcohol. With the present unstable production of sugar in the Philippines, La Tondena Distillers Incorporated, which consumes 60% of the molasses in the Philippines, has turned to cassava as an alternative raw material. The existing demand for cassava, therefore, needs backstopping in terms of superior varieties from the varietal improvement program.

This paper, therefore, highlights the research accomplishments of cassava breeding in the Philippines over the last 20 years (1979-1999).

CASSAVA BREEDING OBJECTIVES

The breeding objectives for cassava in the Philippines for the last 20 years aim to satisfy the needs of farmers who grow cassava in diverse agro-climatic conditions, as well as those of the processors who utilize the storage roots in a variety of ways. The breeding objectives are as follows:

1. High yield
2. High dry matter and starch content
3. Early harvestability
4. Resistance to pests and diseases
5. Tolerance to environmental stresses
6. Good plant type (root formation, root shape and branching habit).

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

MAJOR ACHIEVEMENTS (1979-1999)

Germplasm Collection

The nucleus of a successful breeding program is the availability of a wide-based germplasm collection. As such, PhilRootcrops has maintained and upgraded its genetic stocks of cassava since its establishment. After more than twenty years of existence, the center has a field genebank of 354 cassava accessions. These include local and introduced foreign germplasm, together with elite materials selected from the advanced trials of both introduced and local hybrids. There are 107 elite cassava materials that possess desirable characters important for breeding. Of these materials, 53 come from CIAT/Colombia, 43 from the Thai-CIAT program, and 12 from locally developed hybrids (**Table 1**).

Breeding and Selection Strategies

1. F_1 field selection

Hybrids that are developed in the project, including those introduced from CIAT, are subjected to individual plant selection at the F_1 stage. Entries are planted at 2 m between rows and 1 m between hills. Harvest is at ten months after planting and selection criteria are limited to harvest index, plant type, and general appearance of the crop.

Table 1. Germplasm collections maintained at PhilRootcrops,ViSCA, Baybay, Leyte (Jan, 2000).

Source	No. of Accessions	
Local	86	
Foreign	131	
Tissue culture (CIAT)	30	
Elite clones	107	
-CIAT/ Colombia		(52)
-Thai-CIAT program CIAT		(43)
-PhilRootcrops		(12)
Total collection	**354**	

2. Observational trial

Selections from F_1 field-testing are entered into this stage of evaluation. Normally, five to seven stakes are prepared and planted for each selected clone in a 1 x 1 m planting pattern without replication. One row of a check variety is planted after every ten rows. Selection criteria include yield per plant, harvest index, dry matter content, and reaction to pests.

3. Preliminary yield trial

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

4. General yield trial

Selections from the preliminary yield trial are entered into this trial. Test clones are planted in four to five rows per plot, replicated three to four times. Planting distance is 1.0 x 0.75 m. Harvesting is at ten months after planting. Important economic characters are closely monitored at this stage, and yield per hectare is computed.

5. Advanced yield trial

This is the last stage of evaluation before clones are included in the regional trials of the National Root Crop Cooperative Testing Program. A plot measuring 5 x 6 m is used for each entry and replicated three to four times. A minimum of three different testing sites is required for each entry before it is included in the next cycle of evaluation. Harvesting is at ten months after planting, and parameters considered are yield per hectare, dry matter content, HCN content, plant architecture, and general reaction to pests.

6. Regional yield trial

The number of entries at this stage of evaluation is determined by the Technical Working Group for Root Crops. Agencies involved in variety development submit lists of entries to the group for inclusion in this trial. Potential entries should have passed the advanced yield trial evaluation. A minimum of six locations throughout the country is required per set of entries, and testing is over two cropping seasons. Normally, twelve entries are allowed per cropping, replicated four times. Results of this trial provide the basis for recommendation for varietal release to the National Seed Industry Council (NSIC).

Varietal Release

During the early years of cassava breeding in the Philippines, six local varieties were released for cultivation (**Table 2**). Three of these varieties were released by the Philippine Root Crops Research and Training Center, ViSCA, Baybay, Leyte in March, 1980. These were PR-C 13 (Kadabao), PR-C 24 (Golden Yellow) and PR-C 62 (Colombia). All three varieties are high-yielding and widely grown by farmers for food. The three other varieties were released by the University of the Philippines at Los Baños, College, Laguna, the most famous of which is UPL Ca 2 (Lakan) that is widely grown for food, feed and starch.

Table 2. Recommended cassava varieties selected from local accessions in the Philippines.

Variety	Maturity (months)	Fresh root yield (t/ha)	Root dry matter (%)	Starch content (%)	Uses
1. PR-C 13 (Kadabao)	10-12	42.0	34.3	20.3	Food/feed
2. PR-C 24 (Golden Yellow)	8-10	43.0	39.3	21.5	Food/feed
3. PR-C 62 (Colombia)	10-12	46.0	33.0	19.8	Food/feed
4. UPL Ca 1 (Datu)	9-10	35.0	33.8	22.4	Starch
5. UPL Ca 2 (Lakan)	10-12	40.0	35.0	20.4	Food/feed/starch
6. UPL Ca 4 (Vassourinha)	8-10	30.0	33.8	21.4	Food/feed

Source: *PhilRootcrops, 2000.*

Close collaboration with CIAT in the introduction of improved hybrid populations has resulted in the release of eight cassava varieties of CIAT origin (**Table 3**). These varieties have yields ranging from 24 to 40 t/ha with dry matter contents ranging from 32 to 34%. The major use of these varieties is for starch processing. VC-5 (MCol 1684) is widely used by starch millers in Mindanao. The other varieties have yet to find their niche in the countryside.

Table 3. Recommended cassava varieties selected from CIAT clones and hybrid seed.

Variety name	Maturity (months)	Fresh root yield (t/ha)	Root dry matter (%)	Starch content (%)	Uses
1. VC-1 (CM323-52)	9-10	40.8	33.8	22.4	starch/flour
2. VC-2 (CMC 40)	8-10	40.2	33.0	20.3	food/flour
3. VC-3 (CM3590-1)	10-12	30.0	33.5	20.9	starch/flour
4. VC-4 (CM4014-3)	8-10	30.2	33.8	21.4	starch/flour
5. VC-5 (MCol 1684)	8-10	35.7	34.0	26.5	starch
6. PSB Cv-11 (CM3419-2A)	10-12	25.0	32.1	22.4	starch/flour
7. PSB Cv-12 (SM972-20)	10-12	24.1	33.9	21.5	food/flour
8. PSB Cv-15 (CM3422-1)	10-12	24.0	34.2	21.9	starch/flour

Source: *PhilRootcrops, 2000.*

Aside from evaluation of the introduced materials from CIAT, hybridization work was carried out utilizing elite materials from CIAT and local germplasm. At present there are five locally developed hybrids that were released by the National Seed Industry Council as new cassava varieties (**Table 4**). Among these hybrid varieties, PSB Cv-14 was found to be high-yielding with a high dry matter content that is suitable for starch extraction. It has an average yield of 29 t/ha with a dry matter content of 34.8%.

The 20 years of breeding and selection of cassava in the Philippines have produced a total of 19 cassava varieties, which can be broken down as follows: six local varieties, eight CIAT varieties and five locally developed varieties.

Table 4. Recommended cassava varieties selected from locally developed hybrids in the Philippines.

Variety name	Maturity (months)	Fresh root yield (t/ha)	Root dry matter (%)	Starch content (%)	Uses
1. PSB Cv-13 (CMP62-15)	10-12	26.4	33.0	22.8	starch/flour
2. PSB Cv-14 (CMP21-15)	10-12	29.3	34.8	20.3	starch/flour
3. PSB Cv-16 (CMP32-10)	10-12	33.6	33.4	20.8	starch/flour
4. UPL Ca 3 (G50-3)	10-12	45.0	33.5	20.9	starch/flour
5. UPL Ca 5 (G29 r-3)	8-10	25.0	33.6	22.5	starch/flour

Source: *PhilRootcrops, 2000.*

Advances in Selection

Since 1982, a total of 40,199 hybrid seeds from CIAT/Colombia have been introduced to PhilRootcrops, comprising 736 crosses (**Table 5**). These materials were subjected to the different stages of selection until the advanced yield trial. From these populations only 0.13% was retained and placed in the genebank as elite materials for further breeding and possible varietal release. Moreover, two varieties have been released from these populations introduced from CIAT/Colombia, namely: VC-3 (CM3590-1) and VC-4 (CM4014-3).

Table 5. Hybrid seeds from CIAT/Colombia supplied to PhilRootcrops, ViSCA, Baybay, Leyte, Philippines from 1982 to 1998.

Date	Number of seeds	Number of crosses
1. June, 1982	2,200	43
2. November, 1982	5,550	100
3. January, 1985	2,800	56
4. October, 1985	3,000	60
5. January, 1987	2,100	42
6. February, 1988	2,350	41
7. October, 1988	2,000	40
8. February, 1989	2,386	48
9. January, 1991	4,079	89
10. January, 1992	2,794	44
11. June, 1993	2,361	35
12. July, 1994	2,038	35
13. March, 1995	2,043	35
14. January, 1996	2,230	31
15. February, 1997	2,268	37
Total	**40,199**	**736**

Source: *PhilRootcrops, 2000.*

In addition, the Thai-CIAT cassava program has provided PhilRootcrops with a total of 11,190 hybrid seeds since 1990, comprising 189 crosses (**Table 6**). Similarly, these materials were subjected to various stages of selection. It was observed that these populations performed better than the CIAT/Colombia populations. In fact, the program has selected elite clones from about 0.38% of the total populations evaluated. Generally, they have high yield and high dry matter content with good plant architecture. It is expected that in the next few years several of the elite clones from the Thai-CIAT cassava program will be released as new varieties in the Philippines.

Progress in selection among improved populations has been very encouraging. Results from the advanced yield trial of Thai-CIAT materials (**Table 7**) show that performance of the elite clones surpassed the check cultivars, which are all newly released varieties. The elite clones have yields ranging from 32 to 56 t/ha and with dry matter contents ranging from 33 to 35%; the check cultivars have yields ranging from 29 to 48 t/ha and with dry matter contents ranging from 30 to 32%. There was an improvement of 106% in terms of dry matter content and 116% in yield over the best check variety.

Table 6. Hybrid seeds from the Thai-CIAT program supplied to PhilRootcrops, ViSCA, Baybay, Leyte Philippines from 1990 to 1998.

Date	Number of seeds	Number of crosses
1. April, 1990	1,550	21
2. June, 1993	1,050	29
3. July, 1994	1,250	26
4. May, 1995	1,190	17
5. April, 1996	1,350	19
6. July, 1996	1,450	19
7. April, 1997	1,100	20
8. July, 1998	2,250	38
Total	**11,190**	**189**

Source: *PhilRootcrops, 2000.*

Table 7. Yield parameters[1)] of ten cassava hybrids from the Thai-CIAT program evaluated with local checks in an Advanced Yield Trial at the PhilRootcrops Center, ViSCA, Baybay, Leyte, Philippines in 1999/2000.

Entry	Fresh root yield (t/ha)	Root dry matter (%)	Harvest index	HCN score[2)]
1. CMR37-16-8	56.2	34.6	0.70	6.0
2. CMR37-50-26	47.4	33.8	0.59	5.0
3. CMR37-24-1	55.2	33.8	0.63	5.0
4. CMR38-109-24	24.2	34.8	0.41	5.0
5. CMR38-136-15	36.0	33.9	0.54	3.0
6. OMR38-10-8	36.8	34.0	0.63	6.0
7. OMR38-64-3	40.4	33.6	0.60	3.0
8. OMR38-64-4A	41.4	33.3	0.59	7.0
9. OMR38-65-13	32.3	35.8	0.45	6.0
10. OMR38-65-5	39.8	34.2	0.52	6.0
11. Lakan (Check)	39.0	32.0	0.54	4.0
12. VC-5 (Check)	30.6	29.4	0.47	8.0
13. PSB Cv-13 (Check)	34.6	31.7	0.44	4.0
14. PSB Cv-14 (Check)	48.3	30.1	0.60	5.0
15. PSB Cv-16 (Check)	28.7	31.1	0.43	4.0
Mean across hybrids	**41.0**	**34.2**	**0.57**	**5.0**

[1)]Data averaged over four replications
[2)]Picrate test rating of 1 to 9: 1= very low, 9=very high
Source: *PhilRootcrops, 2000.*

On the other hand, results from the advanced yield trial of elite clones from CIAT/Colombia also show that yields are considerably higher compared to check varieties. Yields of the elite clones ranged from 29 to 47 t/ha and with dry matter contents ranging from 30 to 35%; the check cultivars had yields ranging from 30 to 45 t/ha and with dry matter contents of 29-32 %. It is expected that some of these materials will also be released as new varieties for the food, feed and starch industries.

There are a lot of elite materials right now that are next in line for regional trials, which is the final stage of testing prior to varietal release. These materials are envisioned to cater to the needs of the feed and industrial sectors.

Variety Dissemination

The available recommended cassava varieties have not been fully utilized at present. Reasons for this include: lack of information on the varieties, low availability of planting material and low demand for the product. Through the years, farmers tend to plant cassava varieties which are familiar to them, even though these are of low productivity. It was only in the 1990s that demand for cassava started to pick up due to utilization of the crop for feed as well as starch and its derivatives. Nowadays, the demand for planting material of high-yielding cassava varieties continues to rise. This is the outcome of the involvement of the private business sector in the widespread commercial production of cassava. The San Miguel Corporation, through its La Tondena Distillery, plans to utilize cassava alcohol for the liquor industry. Initially they need 2,000 ha for the distillery plant in Negros Occidental. Furthermore, the starch millers have at least 10,000 ha of cassava. The Starch Millers' Association in the Philippines also include cassava growers cultivating about 50,000 ha. At present, these areas are planted with Golden Yellow, Lakan, VC-5, Datu and other available cassava varieties.

To help disseminate improved varieties of cassava to the farmers, several activities were undertaken: on-farm trials of recommended varieties, adaptation trials of recommended varieties, and establishment of model farms in strategic places where cassava is grown.

Results from an on-farm trial of recommended cassava varieties such as VC-1, VC-2, VC-3 and Lakan have drawn a positive response among farmers in southern Leyte. Farmers readily plant these varieties to supply the feedmill and piggery of a multipurpose cooperative to which they are affiliated.

One-hectare model farms were established in Mindanao where the bulk of cassava is grown. These model farms showcase the recommended varieties plus the necessary cultural management practices. They also serve as a source of planting material for subsequent planting. One model farm in Bukidnon, Mindanao has produced an average yield of 40 t/ha.

The adaptation trial of recommended cassava varieties is another activity that screens varieties that will truly fit a specific growing environment. This serves as an avenue whereby a farmer can select the best variety in the locality. Results from the adaptation trial of recommended cassava varieties conducted in Ilijan, Bago City, Negros Occidental, show that of the nine varieties tested, three were found to be the best for the area (**Table 8**). These were PSB Cv-12 (SM972-20), PSB Cv-14 (CMP21-15) and Rayong 5 from Thailand. As far as dry matter content is concerned, KU-50 and Rayong 5 had the highest dry matter of 45.2 and 44.6%, respectively. The alcohol industry needs varieties, that are high in dry matter content. Thus, it appears that these varieties, together with PSB Cv-12 and PSB Cv-14, are suitable for alcohol production as well as starch.

As a result of the campaign for utilization of new improved varieties, in 1997 about 5,000 ha of land were planted to Lakan and Golden Yellow to support the San Miguel Corporation's demand for cassava for production of animal feed and alcohol. VC-5 was planted to more than 3,000 ha in Lanao for starch. Gradually, adoption of other varieties have started to pick up, resulting in rapid multiplication of identified superior varieties, such as KU-50, Rayong 5 and PSB CV-12, in order to satisfy the requirements of planting material for expanding the cassava project of San Miguel Corporation in Negros Island.

Table 8. Yield parameters[1)] of eight cassava hybrids from CIAT/Colombia evaluated with local checks in an Advanced Yield Trial at the PhilRootcrops Center, ViSCA, Baybay, Leyte, Philippines in 1999/2000.

Entry	Fresh root yield (t/ha)	Root dry matter (%)	Harvest index	HCN score[2)]
1. SM 2085-9	45.0	32.2	0.58	5.0
2. SM 2100-15	43.0	32.9	0.64	5.0
3. SM 2102-23	40.8	34.5	0.53	8.0
4. SM 2116-16	47.2	30.5	0.64	5.0
5. SM 2160-27	36.3	31.4	0.52	5.0
6. SM 2160-43	38.7	31.8	0.55	3.0
7. SM 2065-2	38.4	35.0	0.50	5.0
8. SM 2080-9	28.9	31.8	0.44	3.0
9. Lakan (Check)	31.4	31.8	0.48	4.0
10.VC-5 (Check)	30.1	28.8	0.46	6.0
11.PSB Cv-12 (Check)	38.5	32.0	0.49	2.0
12.PSB Cv-14 (Check)	44.8	29.8	0.56	8.0
Mean across hybrids	39.8	32.5	0.55	5.0

[1)]Data averaged over four replications
[2)]Picrate rating scale of 1 to 9: 1 = very low, 9 = very high
Source: *PhilRootcrops, 2000.*

FUTURE DIRECTION

With the passing by Congress of the 1997 Agriculture and Fishery Modernization Act (AFMA), root crops research and development in the Philippines will play a role in food security, poverty alleviation, productivity improvement, global competitiveness and environmental protection and sustainability.

Considering the versatility of cassava in production and use, the PhilRootcrops Center will have to double its efforts in monitoring the performance of cassava varieties planted in various areas, and aggressively promote the adoption of new improved varieties through adaptation trials and on-farm trials. Furthermore, the center will strengthen its hybridization work utilizing elite materials from CIAT together with local varieties.

Emphasized in the selection will be the identification of superior varieties with high yield, high starch content and low HCN content that will suit the various needs for the food, feed and starch industries, which are the National Root Crops Research and Development Agenda.

Table 9. Performance of nine cassava varieties tested in an adaptability trial at Ilijan, Bago City, Negros Occidental in 1999.

Variety name	Fresh root yield (t/ha)	Dry matter content (%)
1. PSB Cv-11 (CM3419-2A)	18.27	38.7
2. PSB Cv-12 (SM972-20)	34.30	35.8
3. PSB Cv-13 (CMP62-15)	21.73	32.4
4. PSB Cv-14 (CMP21-15)	44.32	37.8
5. PSB Cv-15 (CM3422-1)	19.40	31.4
6. KU-50 (Kasetsart 50)	13.63	45.2
7. Rayong 5	23.13	44.6
8. Lakan	24.00	39.4
9. Golden Yellow	15.90	37.1

Source: *La Tondena, Inc.-PhilRootcrops, 2000.*

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CASSAVA BREEDING AND AGRONOMY RESEARCH IN MALAYSIA DURING THE PAST 15 YEARS

Tan Swee Lian[1]

ABSTRACT

The paper reviews cassava breeding and agronomy research carried out by MARDI over the 15-year period, 1984-1999. Evaluation of seedling clones derived from sexual seeds introduced from CIAT/Colombia and the Thai-CIAT program has culminated in the release of two varieties: Perintis (in 1988), which is a very high-yielding variety, and MM 92 (in 1992), which is a six-month variety; both varieties are widely adaptable. The shortcoming of both varieties is their rather low root starch contents compared to the local commercial starch variety, Black Twig. In the pipeline are two new clones: one with potential as a table variety, having low root cyanide content and showing suitability for making oil-fried crisps, a popular snack; the other, having a higher root yield than Black Twig while having a similar starch content.

Agronomy research has given attention to: (a) reduction of production costs, (b) maximization of profits, and (c) expansion of cassava production into marginal areas. Strategies to reduce costs include the use of machines in field operations to reduce labor requirements, especially for planting and harvesting; development of a computer software package to diagnose major nutrient insufficiencies and to recommend fertilizer rates instead of using blanket fertilizer rates; decreasing the fertilizer recommendations and frequency of application when growing the early variety MM 92 on drained peat. In order to maximize profits, intercropping with sweet corn and the recycling of starch factory solid wastes as a supplementary fertilizer are advocated. With difficulties in accessing arable land for planting cassava, drained peat was found to be a potential area provided that specific agronomic practices are adopted. Likewise, planting on slopes requires the adoption of certain cultural practices, like the planting of contour grass barriers, to minimize soil erosion and sustain root yields.

INTRODUCTION

As cassava has long been used as a starch source in Malaysia (Tan and Khatijah, 2000), cassava research at the Malaysian Agricultural Research and Development Institute (MARDI) has addressed itself to cassava production technology for starch processing. This translates into selection of high-yielding varieties and reduction of production costs through appropriate agronomic practices.

This paper attempts to review the breeding and agronomy research on cassava carried out by MARDI over the last 15 years.

Production Scenario

Cassava has been grown both on small-holdings and on a plantation scale; the latter by companies who run a starch-processing factory, while the former by farmers who sell their produce to these starch factories.

The main area of cassava production has been Perak state in Peninsular Malaysia, which accounts for more than 40% of the total production area (Anon, 1996). Most of the plantings are on upland, well-drained mineral soils, with a few on tin-tailings (resultant

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from tin-mining activities). With the difficulty in accessing suitable land for growing cassava, in recent years some farmers have been forced to cultivate the crop on hilly areas, thus encountering problems of soil erosion.

Last year, the price for cassava roots (delivered to the factory) dropped from the 1998 price of RM 0.18 per kilogram (equivalent to 4.7 US cents/kg) to RM 0.13 (3.4 US cents/kg). At this price, it is anticipated that fewer farmers will replant cassava after this year's harvest. This is because it is difficult to make a profit, especially if the small-holding is located some distance from the factory, entailing transport costs of RM0.03/kg which will reduce the actual price of the roots to RM0.10/kg (2.6 US cents/kg). The last two starch factories in operation will probably face worse problems of root supply in the future, and may be forced out of the starch processing business if there are no new plantings of cassava.

BREEDING RESEARCH

The breeding and selection program for cassava at MARDI started in earnest in 1975 with the first importation of seed from CIAT, Colombia. This reliance on imported seed – hybrid and open-pollinated in origin – has been necessary, given the poor flowering characteristics of the local germplasm, and the limited research resources (staff and funding) allocated to cassava.

The main emphasis of the program has been to produce clones which were higher yielding than the commercial starch variety, Black Twig. It was not easy to select for clones with high root dry matter content in the early years because of the focus given to high root yield in the materials disseminated by CIAT at that time. The result of the breeding and selection program, which tested seedling clones in diverse environments (three on mineral soils, three on drained peat), culminated in the release of variety Perintis by MARDI in 1988. Perintis was a clone selected from a cross between CM 321-170 and MCol 1684 (Tan, 1987), and introduced in a seed batch in 1977. The outstanding features of Perintis are:

- wide adaptability to mineral soils and drained peat, as well as to climatic conditions (ranging from a distinct dry season of 2-3 months in a year, to a well-distributed rainfall pattern) (Tan, 1989)
- high root yield of 50-60 t/ha compared to Black Twig (30-35 t/ha)
- lower susceptibility to *Cercospora* brown leafspot.

Despite its remarkable root yield, Perintis did not find favor with the starch processors because of its low starch content (20-22%) compared to Black Twig (24-28%). This poorer conversion rate meant that a larger volume of roots had to be processed to produce an equivalent amount of starch. Moreover, the factory root price is discounted by RM 3.85 per tonne for every 1% lower starch content than the "standard" 28%. This poses a disincentive to farmers to grow Perintis.

In 1992, MM 92 was released by MARDI. MM 92 is a progeny of the cross CM1362-6 x CM586-1 introduced in a seed batch in 1982. Its outstanding qualities are:

- wide adaptability to mineral soils and drained peat
- early harvestability, producing a root yield of 30-35 t/ha after six months (which is comparable to the yield of Black Twig at 12 months)
- flexibility in harvest (can be delayed till 12 months) to take advantage of prevailing market prices for roots.

Unfortunately, MM92 went the way of Perintis because of its low root starch content (20% or lower).

Fortunately, after 1990 seed introductions from CIAT/Colombia and the Thai-CIAT program increasingly included materials with high root dry matter content. This made it possible to select for higher starch-containing clones in tandem with high or moderate root yields. Evaluation trials have succeeded in identifying two clones of promise which were introduced in 1991 and 1992. Due to a management decision in MARDI to discontinue research on cassava in 1995, no further seed introductions have been carried out since then. Work on cassava breeding and selection has wound down with the objective of finishing the last stages of evaluation and selection of the existing introduced materials.

As it became clear that growing cassava for starch may not be the only way to exploit the crop, attention has shifted to the selection of clones with lower levels of cyanogen in the roots, making them suitable as table varieties or for processing into food products. Main forms of processed cassava foods are *kerepek* (oil-fried crisps) and *keropok* (variously flavored puffed crackers). Both are popular traditional snacks. Currently, farmers grow two or three varieties of cassava for making *kerepek*, i.e.. Medan, Ubi Kuning and Ubi Putih. The root yields of these clones tend to be low to moderate (**Table 1**). One clone, SM1562-19, introduced in a seed batch from CIAT/ Colombia in 1992, has a low root cyanogen content and has shown in a preliminary test good acceptability by a *kerepek* processor. The clone is currently being multiplied for wider testing for this form of utilization.

Table 1. Root yields of farmer varieties for making *kerepek* compared with root yields of SM 1562-19 and other high yielding starch varieties at 6 and 12 months after planting.

	Fresh root yield (t/ha)	
Variety/Clone	6-months	12-months
Medan*	3.4	18.1
Ubi Putih*	18.8	25.6
Ubi Kuning*	15.1	27.7
SM 1562-19	**23.6**	**36.8**
Black Twig	11.4	38.1
Perintis	23.1	50.8
MM 92	29.6	45.7

*Not in same trial

Another clone, CM6149-30, introduced in a seed batch in 1991 has shown promise as a starch variety, having high root yields and a starch content equivalent to that of Black Twig (**Table 2**). It is currently under final evaluation, and if its good agronomic performance is confirmed, it will be released as a new variety soon.

Table 2. Performance of CM 6149-30 in comparison with other clones and check varieties at the Pontian Peat Station, Johor, Malaysia, in 1995-1997.

Clone	Fresh root yield (t/ha)		Harvest index		Starch content (%)		Starch yield (t/ha)	
	6-mo	12-mo	6-mo	12-mo	6-mo	12-mo	6-mo	12-mo
Rayong 3	12.3	13.5	0.72	0.68	27.2	22.8	3.35	3.18
Rayong 60	17.0	23.4	0.63	0.64	27.0	22.8	4.56	5.42
CMR 28-67-76	18.2	19.8	0.66	0.61	27.3	24.1	4.96	4.78
MKUC28-77-3	18.0	22.6	0.65	0.64	28.1	23.4	4.98	5.39
CM 6149-23	15.3	27.0	0.60	0.60	27.5	21.6	4.20	5.91
CM 6149-30	**22.3**	**37.6**	**0.58**	**0.63**	**24.5**	**23.0**	**5.44**	**8.74**
CM 6149-54	18.3	30.5	0.59	0.62	26.9	23.8	4.95	7.26
CM 6149-55	13.6	17.0	0.59	0.58	26.8	23.0	3.64	3.86
CM 6885-75	13.7	23.0	0.60	0.61	27.2	24.1	4.08	5.58
CM 7752-4	13.5	19.0	0.58	0.57	27.8	24.7	3.78	4.69
CM 8061-2	15.0	21.4	0.59	0.68	25.2	21.7	3.94	4.55
Checks								
Black Twig	19.0	28.2	0.57	0.58	25.6	23.0	4.68	6.70
Perintis	23.1	35.5	0.67	0.74	22.6	19.2	5.32	6.90
MM92	25.4	32.0	0.72	0.69	22.7	16.7	5.86	5.38
LSD (p=0.05)	3.9	5.5	0.04	0.03	1.9	1.2	1.03	1.25

AGRONOMY RESEARCH

Agronomy research on cassava in MARDI has given attention to three main areas:

- reduction of production costs
- maximization of profits
- expansion of production into marginal areas.

Reduction of Production Costs

1. Mechanization in field production

One of the main production costs is labor, which has become expensive because of a shortage arising from competing demand from the manufacturing and construction sectors. To counter this problem, research has investigated the mechanization of field production operations, especially for planting and harvesting – two of the operations most demanding of labor (**Table 3**). Most jobs can be mechanized, except:

- the collection of healthy stems from a crop to be harvested for use as planting materials for the next crop
- bundling cuttings
- destumping the stems from the roots after they have been dug out from the ground

Machine packages can be assembled to suit the location, terrain and scale of planting (Sukra and Tan, 1994). Savings in labor requirements for each operation are given in **Table 3**.

Table 3. Estimated labor required per day for a 400-ha cassava farm on mineral soils.

Field operation	Labor (men/day)	
	Mechanized	Manual
Primary tillage	(2)	(2)*
Secondary tillage	(2)	(2)*
Stem harvesting	4	4
Gathering and stacking stems	8, (2)	15
Stem cutting	2	15
Bundling cuttings	2	2
Transporting cuttings and fertilizers	1, (1)	1, (1)
Planting and fertilizer application	3, (1)	32 + 21
Pre-emergence herbicide spraying	(1)	6
Weeding at 2 months	(1)	56
Post-emergence herbicide spraying	(1)	22
Tops and weed cover destruction	(1)	-
Digging roots	(3)	100
Destumping roots	16	16
Gathering roots and transport	12, (10)	10, (6)
Clearing stems from field	-	8
Total	**73**	**317**

*contract job, using tractors
Figures in parentheses represent number of tractor drivers
Source: *Sukra and Tan, 1994.*

2. Fertilizer recommendations using DRIS

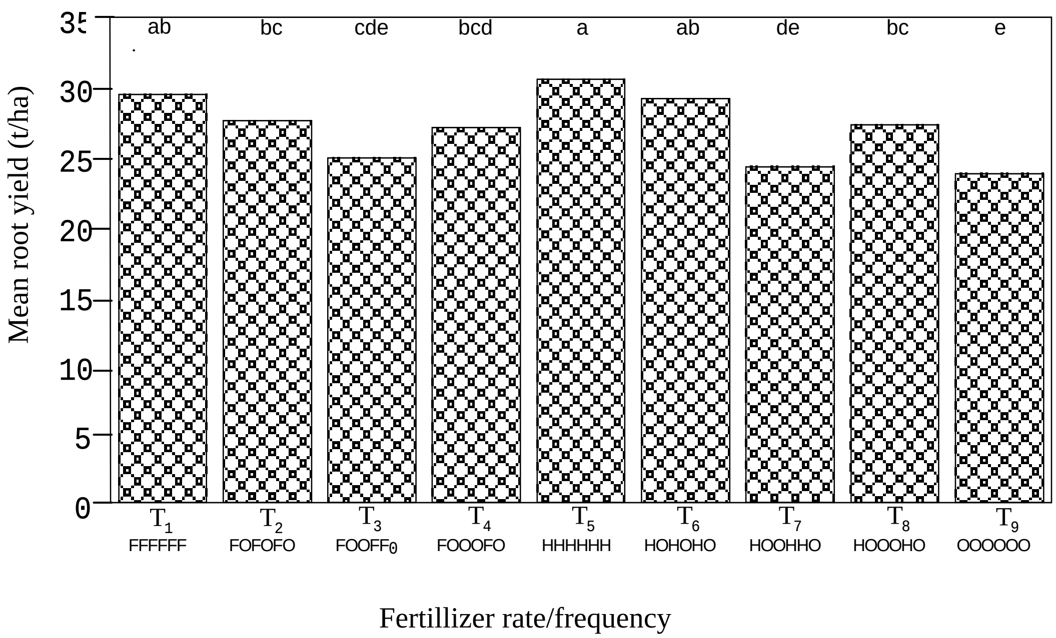
In the past, fertilizer recommendations for cassava have been blanket in nature:

60 kg N, 30 kg P_2O_5, 160 kg K_2O per ha on mineral soils (Chan *et al*., 1983)
250 kg N, 30 kg P_2O_5, 160 kg K_2O per ha on drained peat (Tan and Chan, 1989)

In order to save on costs and to maximize profits, a computer program based on DRIS (Diagnosis and Recommendation Integrated System (Sumner, 1986) was developed for diagnosis of nutrient insufficiencies and for formulating fertilizer recommendations, using data from long-term fertility trials. These trials had tested different levels of N, P and K (and lime in the case of peat), and had been carried out on mineral soils (Chan, 1980) and on drained peat (Tan and Chan, 1989). By collecting leaf samples at around 3 months after planting, and analyzing certain major nutrients, it was possible through inputting these values into the computer program to correct any nutrient insufficiencies in the standing crop to optimize yield performance (Chan, 1992).

3. Fertilizer practices with early variety MM 92

It was found that for variety MM 92 planted on drained peat it was not necessary to apply fertilizers every season to consecutive crops. It was possible to sustain root yields by supplying half the rate of fertilizers formerly recommended for cassava (i.e. 125 kg N, 15 P_2O_5 and 80 K_2O/ha) on peat to every alternate crop (T_6 in **Figure 1**). This practice produced average root yields over six crops which were not significantly different from applying the full fertilizer rate to every crop (T_1 in **Figure 1**).



F=full rate (250:30:160) H=half rate (125:15:80) O=no fertilizer

Note: Bars bearing the same letter are not significantly different from one another according to LSD test (p=0.05)

Figure 1. Mean fresh root yields (over 6 crops) of cv. MM 92 planted on drained peat using different rates of fertilizers and frequency of application at the Pontian Peat Station, Johor, Malaysia, from 1991 to 1995.
Source: *Adapted from Tan, 1995.*

Maximization of Profits

1. Intercropping cassava with short-term crops

It is possible to increase farm income by intercropping cassava with sweet corn, either by planting a single row of corn between cassava in square planting at 0.9x0.9 m, or by adopting the double-row planting system with two rows of corn as shown in **Figure 2**. Groundnut was found not to be suitable as an intercrop because of its susceptibility to shade (**Table 4**). These practices are well suited to small farmers growing cassava on peat by manual means.

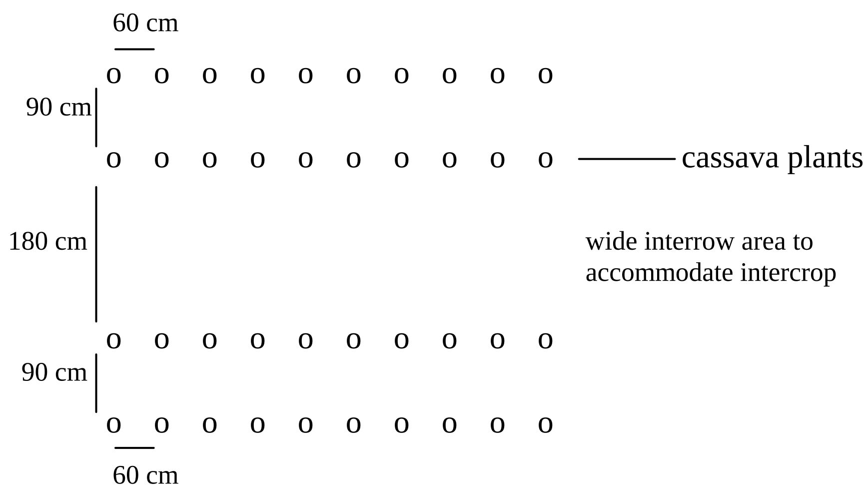


Figure 2. Layout for double-row planting (gives same cassava population as normal square planting at 0.9 x 0.9 m).

2. Recycling of starch factory solid wastes

Starch factories produce solid wastes, amounting to 40 kg (dried form) for every tonne of roots processed (Ti and Chua, 1972). These wastes can constitute a serious pollutant if dumped indiscriminately into waterways. They still contain a fair amount of nutrients (**Table 5**).

A two-season trial on drained peat showed that chemical fertilizer costs may be reduced by supplementing the use of 1 t of starch factory wastes per ha of cassava (**Table 6**), resulting in savings of RM 195 or US$ 51 per ha (Tan *et al*., 1997).

Expansion of Cassava Cultivation into Marginal Areas

1. Exploitation of peat land

Difficulties in getting land to grow cassava because of its lower value compared to other short-term crops such as fruits and vegetables have led to investigating the use of drained peat as an alternative. Cassava shows good adaptability to peat, as long as it is adequately (but not over-) drained and cleared. An efficient drainage system is required to quickly remove water from the field following heavy rain, as studies have shown that cassava roots will rot and yields will decline drastically with four days or more of standing flood water (Tan, 1998). A package of agronomic practices has been developed for successful cultivation of cassava on drained peat (Tan, 1993b).

Table 4. Costs and returns of production per hectare in monocropping and intercropping cassava with groundnut and sweet corn using two planting arrangements in Jalan Kebun Peat Station, Selangor, Malaysia.

	Monocropped cassava	Intercropped cassava			
		Square		Double-row	
		GN	SC	GN	SC
Production costs (US$/ha)	415	535	548	535	491
Yields					
-cassava (t/ha)	30-35	30	30	30	35
-groundnut (kg/ha)		672		791	
-sweet corn (cobs/ha)			36,000		24,500
Gross returns (US$/ha)					
-cassava	632-737	632	632	632	737
-groundnut		170		200	
-sweet corn			1 040		710
Net returns (US$/ha)	217-322	267	1 124	297	956

Note: GN=groundnut; SC=sweet corn; monocropped cassava planted in square arrangement.
Source: *Tan, 1988.*

Table 5. Nutrient composition of dried cassava starch factory solid wastes.

Nutrient	Concentration
Total N	1.34 %
P_2O_5	1.28%
K_2O	7.72%
Ca	3.12%
Mg	11.30%
Mn	20.90 ppm
Fe	2.30 ppm
Zn	0.52 ppm
B	0.48 ppm
S	21.90 ppm

Source: *Kwong Yik Lee Tapioca Sdn.Bhd.,Chemor, Perak, 1992.(peronal. communication)*

Table 6. Fresh root yield, root starch content and starch yield from treatments receiving various combinations of chemical fertilizers and starch factory solid wastes at the Pontian Peat Station, Johor, Malaysia, in 1994/95..

Treatment	Chemical fertilizers (kg/ha)	Starch wastes (t/ha)	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)
M1W0	50:30:40	0	24.0a	24.5b	5.96b
M1W1	50:30:40	0.5	26.1a	24.1b	6.36ab
M1W2	**50:30:40**	**1.0**	**26.6a**	**25.3ab**	**6.79ab**
M1W3	50:30:40	1.5	25.2a	23.9b	6.08ab
M2W0	100:30:80	0	27.6a	26.4a	7.30a
M2W1	100:30:80	0.5	26.3a	24.2b	6.45ab
M2W2	100:30:80	1.0	27.4a	23.8b	6.55ab
M2W3	100:30:80	1.5	25.6a	25.4ab	6.53ab

Mean values within the same column with the same letter are not significantly different from one another according to the new Duncan's multiple range test (p=0.05)
Source: *Tan et al., 1997.*

Evaluation and selection of clones adapted to drained peat has shown that root yields obtained are comparable to yields from mineral soils, but that root starch contents tend to be lower because of higher root moisture content (**Table 7**).

It must, however, be stated that mechanization is not possible on drained peat with existing machines and field equipment because of the low bearing capacity of peat and the abundance of wood debris and tree stumps in newly cleared peat land.

2. *Control of soil erosion*

As cassava cultivation is forced into more hilly terrain due to lack of suitable arable land, it is essential that the problem of soil erosion be addressed. Various tillage and crop management combinations have been tested for their efficacy in reducing soil erosion. It was found that on a moderate slope of 5.5-10.5%, the most practical method – which was least detrimental to root yield (15% reduction compared to control) and caused an acceptable level of soil loss – was by leaving strips of natural grass to grow between cassava planted in double rows (**Table 8**).

CONCLUDING REMARKS

Although research on cassava production by MARDI has slowed down considerably, work still continues on the use of cassava in processing, e.g. modification of starches and their utilization. In drafting a recent proposal for a National R&D Program for Root Crops, the task force delegated the job decided that cassava is the cheapest source of starch compared to other root crops in

Malaysia. It proposed research on cassava be continued (not necessarily by MARDI alone), giving emphasis to certain specific areas. Furthermore, MARDI has moved on to providing feasibility studies (soil suitability assessment as well as financial analyses) and consultancy services to those parties interested in embarking on growing cassava for starch or processed food products, and who are able to gain access to farmland of a commensurate size. Such consultancies also provide MARDI with the opportunity to put into practice all the agronomic recommendations she has formulated over the years, to test out their effectiveness on a large enough scale, and to overcome day-to-day practical problems, while building up more expertise in the management of cassava plantations. Probably, some fine-tuning will be required before the package of production technologies on offer will be completely applicable and economically successful.

Table 7. Average performance of cassava clones on three mineral and three drained peat soils (1986-1989).

Clone	Fresh root yield (t/ha)		Starch content (%)[1]	
	Mineral soils[1]	Drained peat[2]	Mineral soils	Drained peat
CM 305-8	36.9	27.2	23.4	21.5
CM 378-17	33.4	26.6	26.5	23.0
CM 621-7	37.4	38.0	23.9	21.5
CM 621-22	36.6	30.6	23.7	21.4
CM 621-42	40.0	29.3	25.0	22.8
CM 845-13	29.2	24.8	28.5	24.8
CM 942-28	37.2	30.6	24.7	22.7
CM 982-2	29.4	34.4	25.6	23.9
MMex 1-20	29.7	29.0	26.2	24.6
17/A	36.9	33.7	25.6	23.3
CM 462-6	39.8	30.6	22.5	17.5
Black Twig	34.6	33.4	25.8	23.9
Red Twig	27.8	24.6	26.6	24.2
C 5	33.4	26.9	24.6	22.6
Perintis	48.4	45.9	23.3	19.7

1) Bukit Tangga, Kedah; Kluang, Johor; and Serdang, Selangor.
2) Jalan Kebun, Selangor; Pontian, Johor; and Teluk Intan, Perak.
Source: *Tan, 1993a.*

Table 8. Cassava yield and cumulative soil loss as affected by various tillage and crop management practices when planted on 6-10% slope at MARDI, Serdang, Malaysia in 1989-1991.

Treatment	Mean root yield (t/ha)[1)]	Cumulative soil loss (t/ha)		
		1st season	2nd season	Mean
High tillage	26.8bc	4.56	24.80	14.68
Normal tillage (control)	32.7a	4.49	21.45	12.97
No fertilizer	24.2c	2.73	14.12	8.42
Reduced tillage	26.2b	5.18	26.63	15.90
Zero tillage	21.2d	2.13	14.82	8.48
Subsoiling	27.6b	3.26	14.70	8.98
Grass barriers	27.8b	3.11	7.17	5.14
Groundnut intercrop	27.7b	3.98	10.43	7.20
Citronella intercrop	27.5b	4.22	13.80	9.01

[1)]over two seasons

Note: Values in the same column bearing the same letter are not significantly different from one another according to the new Duncan multiple range test (p=0.05)

Source: *Chan et al., 1994.*

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CASSAVA AGRONOMY RESEARCH AND ADOPTION OF IMPROVED PRACTICES IN VIETNAM

Nguyen Huu Hy[1], Nguyen The Dang[2] and Pham Van Bien[3]

ABSTRACT

In the past few years, the economy of Vietnam has developed very rapidly, and in agriculture, food production has been quite successful, especially that of rice. At the same time cassava production has changed from being a crop providing food for humans to being a cash crop. The planting of new cassava varieties has increased the net income of farmers in some regions of Vietnam.

In the area of agronomy, research conducted in some regions of the north and south of Vietnam had the objective of increasing cassava yields and income for the farmer, while maintaining the productivity of the soil. This included:

- Soil research in South Vietnam showed that planting of cassava on the same land for many years reduced soil fertility more than with some other crops, trees or natural forest, resulting in soil degradation.
- In fertilizer trials, the response of cassava depends on the type of soil and the kind of fertilizers. In both north and south Vietnam cassava showed strong responses to application of N and K, while there was a response to P in only one site. In long-term NPK trials conducted in Thai Nguyen University and in Hung Loc Center the application of 80:40:80 and 160:80:160 kg/ha of $N\text{-}P_2O_5\text{-}K_2O$ gave higher yields and higher economic returns than other treatments.
- In intercropping trials conducted on research stations and on farmers' fields with flat land, cassava intercropped with food crops and grain legumes increased income. In sloping areas cassava intercropping with peanuts or planting contour hedgerows of legume trees like *Tephrosia candida* or *Gliricidia sepium* reduced soil loss due to erosion and maintained or improved soil fertility.
- In order to reduce the cost of production, the use of pre-emergence herbicides to control weeds was very effective and controlled about 90% of the weeds for the first 3-4 months after planting, resulting in higher profits than when cassava was weeded by hand or when post-emergence herbicides were applied.

1. INTRODUCTION

In the past few years, the annual rate of economic development in Vietnam was about 4-6%. Among the various sectors, agriculture has been quite successful, especially the production of rice. Presently, Vietnam is the second largest rice exporting country in the world.

In the area of food crop production, cassava has remained important in providing food for poor people in the marginal areas, but the crop has changed from being a crop providing food for humans to being a cash crop. The planting of new cassava varieties has markedly increased the net income of farmers in some regions of Vietnam, especially in the Southeastern region.

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In the last decade of the 20th century, the area planted to cassava in Vietnam was around 250 thousand ha, comprising about 25% of the total area dedicated to food crop production; the cassava growing areas are rather evenly distributed over all regions of Vietnam. Because of the low value of cassava products, cassava is usually planted on sloping land and on poor soils, and in areas lacking investment, so that the cassava yield in Vietnam is still very low, with an average of around 8 t/ha.

Upto now, following the strategies of the National Root Crops Program and with technical and some financial support from CIAT, cassava breeding and agronomy research in Vietnam have strengthened significantly, and this has contributed to the increase in cassava yields and production in some regions of Vietnam.

2. RESULTS OF THE RESEARCH

2.1 Effect of Cassava Production on Soil Productivity

Research on the effect of cassava production on soil physical and chemical characteristics has been conducted in several regions of Vietnam (Cong Doan Sat and Deturck, 1998; Khanh, 1997; Nguyen Bich Thu, 1998). The results show that most of the soils used for long-term cassava growing in Vietnam had been degraded. The main reason for this deterioration of the soil is the lack of adoption of more sustainable technologies for cassava production. Thus, it is necessary to develop new technologies that can be adopted for cassava production and that will maintain soil fertility.

Results of a study about the sustainability of various cropping systems used on Haplic Acrisols in the uplands of South Vietnam (**Table 1**) indicate that different cropping systems had a differential long-term effect on pH, on macronutrient contents and on cation exchange capacity. Cassava cropping resulted in the lowest pH, the lowest levels of total N, total P and exchangeable K in the surface soil when compared with rubber or cashew cropping. The cation exchange capacity of the soil declined in the following order: sugarcane >forest >rubber >cashew >cassava (Hoang Van Tam, 1997).

Another report from North Vietnam (Thai Phien and Nguyen Cong Vinh, 1998) indicate that the reason for a reduction in production capacity of the soil when cassava was planted continuously in monoculture in the same site for many years is that at harvest time farmers usually remove both cassava roots and stems resulting in removal of about 60-153 kg N, 36-38 kg P_2O_5 and 56-122 kg K_2O/ha for one crop, while these nutrients are seldom returned in the form of fertilizers or manures.

Table 1. Long-term effect of various cropping systems on soil fertility parameters of Haplic Acrisols of Dong Nai province, Vietnam.

	Forest	Rubber	Sugarcane	Cashew	Cassava
pH	-	4.7	-	4.3	4.2
Total N (%)	0.058	0.054	0.039	0.034	0.024
Total P (%)	-	0.017	-	0.006	0.005
Exchangeable K (me/100 g)	-	0.129	-	0.089	0.063

Source: *Nguyen Bich Thu, 1998.*

2.2 Soil Fertility Maintenance through Fertilizer Application

To maintain or improve the productivity of soils used for cassava production, it is necessary to determine the response of cassava to NPK fertilizers and the level of macronutrient absorption by the crop. Many experiments, including both long-term and short-term NPK trials, have been conducted in various locations of Vietnam. It can be concluded that the response of cassava depended on the type and fertility of the soil.

In North Vietnam, at Thai Nguyen University, the response of cassava to N, P and K was already significant in the first year, and after ten years of continuous cassava cultivation without fertilizer application, the yield of two cassava varieties had decreased to only about 3 t/ha (**Figure 1**), while with adequate fertilization yields of 20 t/ha could be maintained. Application of K in the presence of N and P increased the yield of cassava, KM60 variety, from about 1.4 t/ha to 22 t/ha (Howeler and Thai Phien, 2000).

Other long-term NPK trials have been conducted on rather fertile Red Latosols at Hung Loc Agric. Research Center in Dong Nai province of South Vietnam. The results indicate that the response of cassava was not significant in the first four years and the yield could be maintained at about 15 t/ha without fertilizer application. However, in subsequent years yields increased significantly with fertilizer application. After the 8th year of cropping there was a highly significant response to N and K, but no response to P as the yield without P was not significantly different to that obtained with P application. The available P of the soil remained much above the critical level, while the exchangeable K level had dropped to below the critical soil K-level during the last two years of cropping (**Figure 2**).

In the whole country, the best fertilizers for cassava were in the ratio 2: 1: 2 of N: P_2O_5: K_2O, and the optimum level varied from 80-40-80 kg/ha to 160-80-160 kg/ha. These levels gave the highest yields and economic returns (Nguyen Huu Hy *et al*., 1998).

Besides long-term NPK fertilizer trials, other short-term trials have been conducted in some regions of South Vietnam.

In the Central Highlands of Vietnam, the optimum level of N-P_2O_5-K_2O were about 100-100-150 kg/ha and 70-50-100 kg/ha (Nguyen Thanh Thuy, 1999; Lich and Oanh, 2000).

In the South Central Coastal Region, Nguyen Thanh Thuy (1999) found that cassava responded strongly to fertilizers on the grey podzolic soils, and the application of 80 kg N, 50 P_2O_5, 100 K_2O and 5 tonnes of manure/ha gave the highest net returns (**Table 2**).

However, in the Southeastern Region and on Haplic Acrisols, Tam (1997) found that the application of 120 kg N, 120 P_2O_5 and 180 K_2O/ha gave the highest yields (**Table 3**).

Nguyen Hong Linh (1999) reported that on peat soils with low pH and high organic matter content in the Mekong Delta, the application of N, P_2O_5, K_2O at 80-40-80 kg/ha gave the highest cassava yields and net income (**Table 4**).

To improve the soil's physical characteristics, results of a manure and green manure trial indicate that the application of manure and green manure can improve soil structure, reduce soil bulk density and maintain soil temperature and soil moisture more constant. Thus, applying manure and green manures can improve the soil's production capacity (Nguyen The Dang *et al*., 1998).

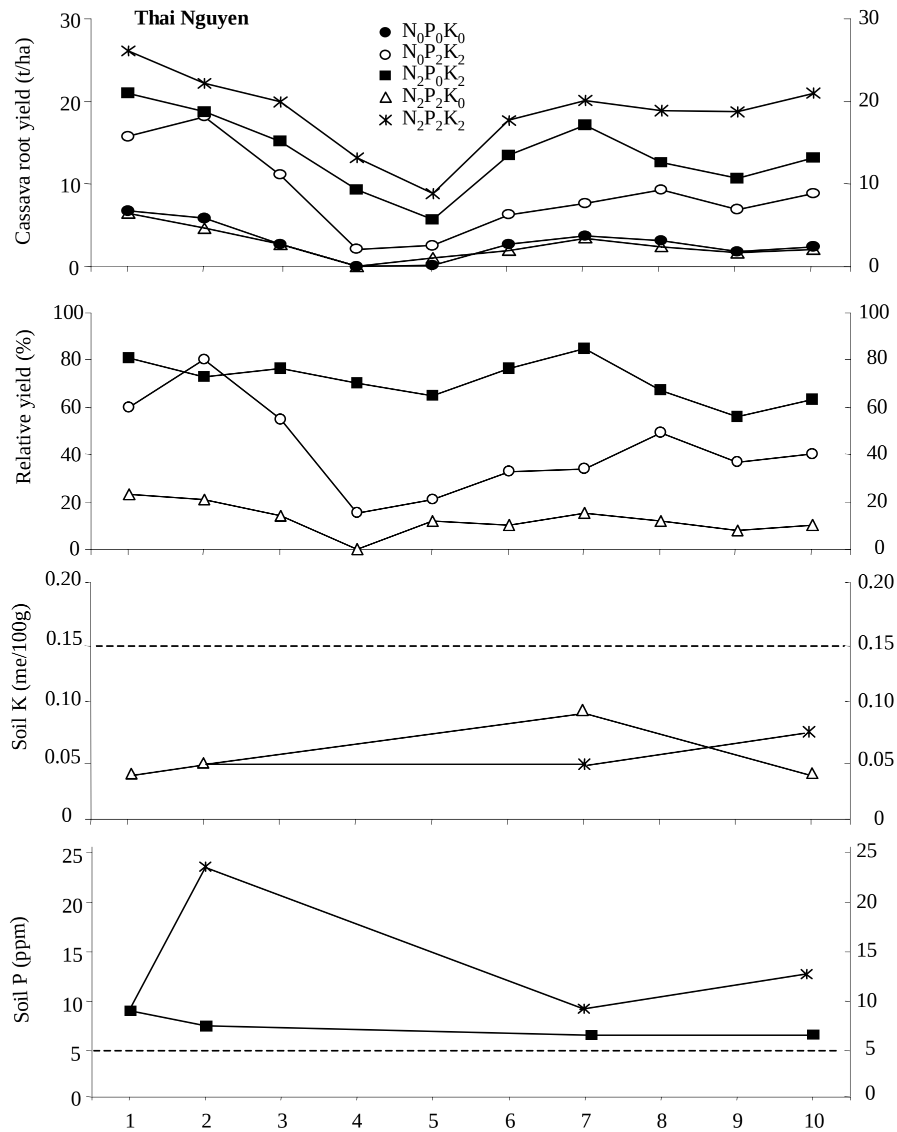

Figure 1. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during ten years of continuous cropping in Agro-forestry College of Thai Nguyen University, Thai Nguyen, Vietnam.

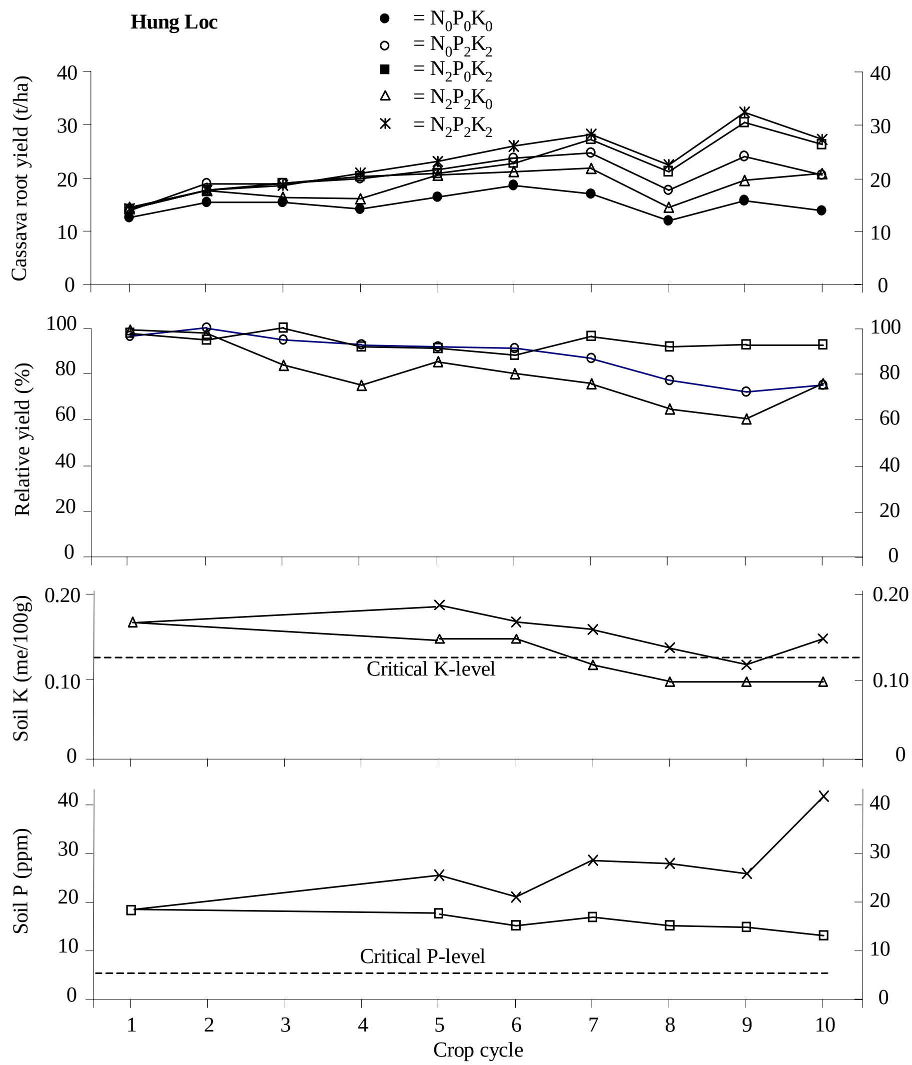

Figure 2. Effect of annual appplications of N, P and K on cassva root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during eight years of continuous cropping in Hung Loc Agric. Research Center, Dong Nai, Vietnam.

Table 2. Effect of increasing levels of N on the root yield and economic returns of cassava grown in grey podzolic soil at Thinh Teo, Son Tinh, Quang Ngai province, Vietnam, in 1996/97.

Treatments (kg $N-P_2O_5-K_2O$/ha)[1)]	Root yield (t/ha)	Net income (mil. d/ha)
0-50-100	33.5 b	6.65
40-50-100	35.9 b	7.05
80-50-100	42.6 a	8.74
120-50-100	46.6 a	9.64
160-50-100	44.4 a	8.86
CV (%)	6.8	
LSD 0.05	5.03	

[1)]in addition to 5 tonnes manure/ha.

Source: *Nguyen Thanh Thuy. 1998.*

Table 3. Effect various rates of fertilizer application on root yield (t/ha) of cassava, KM94, planted on two Haplic Acrisols in the Southeastern Region of south Vietnam in 1995/96.

Treatments	Province	
(kg $N-P_2O_5-K_2O$/ha)	Tay Ninh	Dong Nai
0-0-0	12.31 c	15.04 c
30-30-45	18.75 b	22.14 b
60-60-90	19.49 b	23.44 b
120-120-180	26.35 a	28.00 a

Source: *Hoang Van Tam, 1997.*

Table 4. Effect of various rates of NPK application on the yield and income obtained from cassava grown on peat soil in Tri Ton, An Giang province, Vietnam, in 1998/99.

Treatments	Root yield (t/ha)		Gross income		Production	Net income	
(kg $N-P_2O_5-K_2O$/ha)	KM60	KM94	KM60	KM94	costs	KM60	KM94
			('000 dong/ha)				
0-0-0	11.67	9.52	3,380	2,760	1,300	2,080	1,460
40-20-40	19.37	16.07	5,620	4,660	1,750	3,870	2,910
80-40-80	23.33	20.77	6,770	6,020	2,300	4,470	3,720
60-60-120	22.14	20.47	6,420	5,940	2,520	3,900	3,420
100-100-0	19.49	17.59	5,650	5,100	2,530	3,120	2,570
40-100-100	18.30	16.40	5,320	4,760	2,640	2,680	2,120

[1)]Prices: urea: 2000 d/kg; DAP: 4000 d/kg; KCl: 2200 d/kg; cassava 290 d/kg fresh roots.

Source: *Nguyen Hong Linh, 1999.*

Comparing the response to manure and green manure with that of chemical fertilizers it was concluded that the response of cassava to chemical fertilizers was faster than to manures and green manures (Dinh Ngoc Land and Nguyen The Dang, 2000).

2.3 Soil Fertility Maintenance by Intercropping

In Vietnam, farmers usually intercrop cassava with other food crops, especially grain legumes. The results of trials conducted at research stations and in farmer participatory research (FPR) trials indicate that cassava intercropping with maize and peanut or mungbean in fertile soils, and with peanut or black bean in poor soils, can increase net income and maintain soil fertility (Hoang Kim, 1991; Nguyen Huu Hy *et al*., 1995; 1998; Nguyen The Dang *et al*., 1998; Le Sy Loi, 2000).

Others concluded that intercropping or crop rotations also improve soil fertility through the return of crop residues of the intercrop to the surface soil; this practice can also reduce soil losses by erosion and increase income when cassava is grown on sloping land (**Tables 5** and **6**). Cassava intercropping with grain legumes has become very important for many farmers because the cassava production area is often far from the home; in that case the application of chemical fertilizers is minimal or the transport of fertilizers is a problem.

When intercropping or planting hedgerows of legume trees, the prunings can be used for mulching; also, some other materials, such as straw, residues of cassava peel or cassava leaves and stem can be used to improve the soil's chemical and physical conditions (Howeler and Thai Phien, 2000).

2.4 Soil Erosion Control

In tropical regions the degradation of soil is often a serious problem in agricultural production. Ernst and Fairhurst (1997) concluded that the loss of the soil surface and the decrease in soil fertility by human activity when no nutrients are returned to the soil is the biggest challenge facing agricultural production in the future.

Table 5. Effect of intercropping and alley cropping on soil chemical characteristics[1] after four years of consecutive cassava planting on red Latosols at Hung Loc Agric. Research Center in Dong Nai, Vietnam, in 1992-1996.

Treatments	pH	OM (%)	P (ppm)	Ca	Mg (me/100 g)	K
Soil before planting (1992)	5.0	2.1	5.0	1.68	0.54	0.28
Soil after four years (1996)						
-Cassava monoculture	4.6	2.5	9.3	1.70	0.58	0.24
-Cassava + peanut intercrop	4.6	2.9	10.2	1.50	0.51	0.27
-Cassava + cowpea intercrop	4.4	3.0	11.3	2.80	0.69	0.32
-Cassava + *Canavalia* intercrop	5.1	2.7	9.7	1.80	0.65	0.27
-Cassava + *Leucaena* hedgerows	4.7	3.0	19.2	2.10	0.75	0.38
-Cassava + *Gliricidia* hedgerows	4.7	2.9	11.3	1.90	0.72	0.37

[1]Data from IAS soil testing laboratory, HCM city, Vietnam.

Table 6. Effect of intercropping cassava with various grain legumes on the yield of crops, on gross and net income, as well as on dry soil loss due to erosion when grown on 10% slope at Agro-forestry College of Thai Nguyen Univ., Thai Nguyen, Vietnam in 1997.

Intercropping treatments	Yield (t/ha)		Gross income[1)]	Costs fert. +seed[1)]	Net income	Dry soil loss
	cassava	intercrop	(mil. d/ha)			(t/ha)
1. Cassava monoculture	18.67	-	7.47	6.22	1.25	31.24
2. C+peanut	16.50	1.08	12.00	8.77	3.23	24.03
3. C+soybean	18.42	0.15	8.27	7.98	0.29	28.50
4. C+mungbean	20.83	0.27	10.49	7.84	2.65	28.61
5. C+black bean	17.92	0.35	9.62	7.94	1.68	28.64
6. C+cuoc bean	17.67	0.17	7.92	7.87	0.05	28.14

1)Prices: cassava: d 400/kg fresh roots

peanut:	5000/kg dry pods	peanut seeds:	d 7000/kg dry pod
soybean:	6000/kg dry grain	soybean seeds:	7000/kg dry grain
mungbean:	8000/kg dry grain	mungbean seeds:	8000/kg dry grain
black bean:	7000/kg dry grain	black bean seeds:	7000/kg dry grain
cuoc bean:	5000/kg dry grain	cuoc bean seeds:	5000/kg dry grain

Source: *Le Sy Loi, 2000.*

In Vietnam mountainous areas occupy about 75% of the total area. According to a farm-level survey conducted in 1990-1991 of over 1100 households in 45 districts of the major cassava growing regions of Vietnam (Pham Van Bien *et al*., 1996), 59% of cassava is grown on sandy soils, 3.9% on loamy soils, 11.7% on clayey soils and 25.3% on rocky soils; also, about 45% of cassava is grown on sloping land.

To develop measures to control soil erosion, erosion control trials have been conducted in both North and South Vietnam. The results of these trials indicate that soil loss and runoff can be reduced by intercropping and by the planting of contour hedgerows. Intercropping with peanut was generally more effective in reducing erosion than intercropping with other crops (**Tables 7** and **8**). Contour ridging and no- or reduced-tillage as well as adequate fertilization are also effective practices to reduce erosion (**Figure 3**).

2.5 Chemical Weed Control

In order to reduce the cost of cassava production, chemical weed control trials have been conducted in the red Latosols at Hung Loc Agricultural Research Center in Dong Nai province. Results of the trials show that when the pre-emergence herbicide metolachlor (Dual) was used to control weeds from planting to three months after planting, better yields and net income were obtained than weeding by hand or using post-emergence herbicides. The treatment with 2.4 l Dual/ha gave the highest yield and net income compared with other treatments. This result is important when cassava is planted in regions where there is a lack of labor or where cassava production is done on a large scale (**Table 9**). However, when using chemicals to control weeds one needs to consider the potential pollution of the environment.

Table 7. Effect of intercropping and hedgerows on cassava yield and soil loss due to erosion in cassava planted on about 8% slope in Hung Loc Agric. Research Center in Dong Nai province, Vietnam, in 1998/99.

Treatments	Root yield (t/ha)	Stem yield (t/ha)	Root starch content (%)	Dry soil loss (t/ha)
Cassava monoculture	36.51 c	21.61 c	29.8	23.3
Cassava + mungbean intercrop	35.84 c	23.60 bc	30.0	22.5
Cassava + peanut intercrop	39.51 bc	23.54 bc	29.8	19.3
Cassava + vetiver grass hedgerows	51.78 a	28.44 ab	29.8	22.7
Cassava + *Gliricidia* hedgerows	45.67 ab	30.22 a	30.9	18.5
Cassava + *Leucaena* hedgerows	45.06 ab	30.89 a	29.8	19.4
CV (%)	8.61	10.66		
LSD 0.05	7.61	5.86		NS

Table 8. Effect of intercropping on cassava yield and soil loss when cassava was grown on yellow-red soil at Thai Nguyen University in Thai Nguyen province, Vietnam, in 1998.

Treatments[1]	Yield (t/ha) cassava	Yield (t/ha) peanut	Gross income[1] (mil. d/ha)	Production costs[3] (mil. d/ha)	Net income (mil. d/ha)	Dry soil loss (t/ha)
1. Cassava monoculture	17.96	-	8.98	1.25	7.73	24.1
2. C+peanut intercrop	21.72	0.39	12.81	1.67	11.14	13.3
3. C+peanut+*Tephrosia*	22.38	0.27	12.54	1.67	10.87	5.6
4. C+peanut+vetiver grass	21.50	0.30	12.25	1.67	10.58	5.4
5. C+peanut+V+T	21.04	0.38	12.42	1.67	10.75	5.2

[1] T = *Tephrosia candida*
V = vetiver grass
[2] Prices: cassava dong 500/kg fresh roots
peanut 5000/kg dry pods
[3] Production cost = fertilizer cost + cost of grain legume seed
Source: *Dinh Ngoc Lan and Nguyen The Dang, 2000.*

3. FUTURE DIRECTION

Considering the results obtained during the past decade, future cassava agronomy research in Vietnam will focus on the following research topics:

- Maintenance of soil fertility by intercropping and fertilizer application, and erosion control in cassava areas with sloping land in various parts of the country.
- Using FPR methods to develop practical agronomic practices and enhance the adoption of these practices by other farmers.

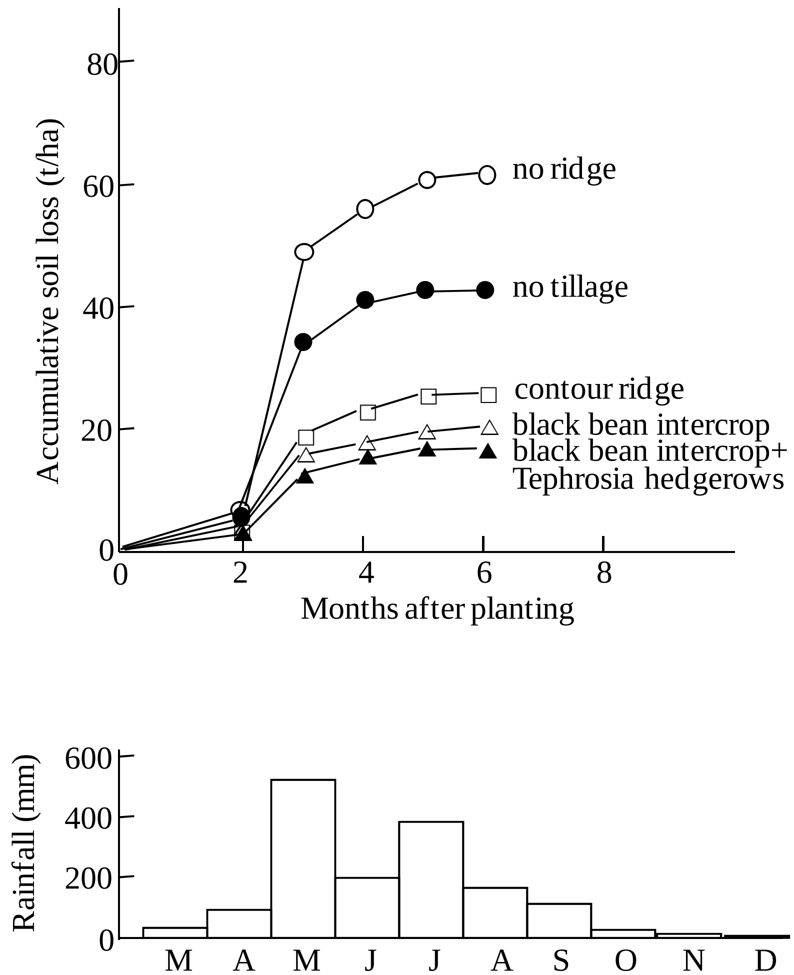

Figure 3. Effect of various soil/crop management practices on dry soil loss due to erosion in cassava planted on about 10% slope in Agro-forestry College of Thai Nguyen University, Thai Nguyen, Vietnam, in 1993.

Table 9. Effect of various weed control practices on cassava yield and economic return when cassava was grown on red Latosols at Hung Loc Agric. Research Center in Dong Nai province of Vietnam in 1997/98.

Treatments	Cassava yield (t/ha)	Gross income[1)]	Cost for weeding	Total production costs	Net income	MBCR
		('000 d/ha)				
Hand weeding	21.22	8,488	1,200	3,215	5,272	-
Dual (0.8 l/ha)	22.61	9,044	0,270	2,685	6,359	4.0
Dual (1.6 l/ha)	24.23	9,692	0,390	2,805	6,887	4.1
Dual (2.4 l/ha)	27.53	11,012	0,510	2,925	8,087	5.5
Roundup (2 l/ha)	24.38	9,752	0,414	2,829	6,923	3.9
Gramoxone (2 l/ha)	21.61	8,644	0,382	2,797	5,847	1.5

[1)]cassava price: 400 d/kg fresh roots.

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CASSAVA AGRONOMY RESEARCH AND ADOPTION OF IMPROVED PRACTICES IN THAILAND - MAJOR ACHIEVEMENTS DURING THE PAST 35 YEARS

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ABSTRACT

This paper reviews the results of past research conducted from 1965 to 2000 in two major cassava growing areas, the northeastern and eastern parts of Thailand. This research was carried out by the Field Crops Research Institute, Department of Agriculture (DOA), in collaboration with Kasetsart University and the Centro Internacional de Agricultura Tropical CIAT). The major achievements are described under the following three topics:

Methods of cultivation, which tested and developed all the necessary components of cassava cultural practices, such as land preparation, planting time, age of harvest, spacing and plant population, planting method, stake size and storage, as well as weed control.

Cassava-based cropping systems, which showed the feasibility of intercropping cassava with short-duration crops such as mungbean, peanut, soybean and sweet corn.

Cassava soil conservation and fertility maintenance, which tested and developed appropriate production practices that both reduce soil loss by erosion and maintain high cassava yields. Long-term experiments on the effect of various fertilizer applications and soil management treatments showed the crop's nutritional requirements, and indicate soil/crop management practices that will maintain high levels of cassava productivity as well as adequate soil fertility.

INTRODUCTION

In 1976 the cassava planted area in Thailand was only 692,320 ha. Ten years later in 1985 the area had increased to 1,476,800 ha (OAE, 1985), and in 1997 this had slightly decreased again to 1,265,120 ha (OAE, 1998). Cassava replaced some other crops like kenaf and its area expanded greatly due to its ease of cultivation and tolerance to drought and infertile soils. Research on technologies for enhancing cassava production until the early 1990s was limited to the local variety Rayong 1, with most emphasis placed on agronomic practices for increasing yields. Since then the cassava breeding program has released several new high-yielding cultivars, and agronomy research has focused mainly on developing appropriate technologies, which could produce a high level of productivity of these varieties and maintain soil fertility in cassava growing areas. This paper reviews the results of many experiments in cassava agronomy which have been conducted from 1965 to 2000.

METHODS OF CULTIVATION

Agronomy research initially concentrated on the testing and development of the necessary components in cassava cultural practices:

1. Planting Time

In Thailand cassava can be planted all year round. A survey conducted in 1975 (Sinthuprama and Tiraporn, 1984) shows that 59% of cassava was planted in March to

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June, 15% during the heavy rains of July to Oct, and 26% during the dry season. However, an experiment conducted from 1965 to 1969 at Rayong Field Crops Research Center in the eastern part of Thailand to determine the appropriate planting time for cassava (**Table 1**), indicate that the highest root yields of cassava were obtained from planting in the rainy season (June to Oct); this resulted in higher root yields ranging from 22.9 to 28.7 t/ha. Planting either before or after the rainy season resulted in lower yields, ranging from 15.2 to 21.2 t/ha. The rainy season in Thailand lasts from May to Oct. **Table 2** shows that the average yield of cassava planted in the rainy season (May-Oct) was 25% higher than that obtained when planted in the dry season (Nov-April). Planting cassava before the rainy season (Feb-April) resulted in 10% higher yield than planting after the rainy season (Nov-Jan).

Table 1. Fresh root yield of Rayong 1 obtained when planted at various times at Rayong Field Crops Research Center, 1965-1969.

Month of planting	Average rainfall during 5 years (mm)[1)]	Fresh root yield (t/ha)
February	87	19.69
March	39	20.69
April	65	18.44
May	297	13.56
June	118	22.87
July	131	28.69
August	97	24.06
September	199	25.81
October	247	24.69
November	78	21.25
December	18	17.12
January	39	15.19

[1)]Average monthly rainfall from 1965 to 1969. Huaipong Meteorological Station, Rayong.
Source: *Field Crops Research Institute, Annual Reports 1965-1969.*

Table 2. Average fresh root yield when cassava was planted before, during and at the end of the rainy seasons at Rayong Field Crops Research Center, 1965-1969.

Planting periods	Fresh root yield (t/ha)	%
Before rainy season (February-April)	19.63	110
In rainy season (May-October)	23.31	130
After rainy season (November-January)	17.81	100
In dry season (November-April)	18.69	100
In rainy season (May-October)	23.31	125

Source: *Derived from Table 1.*

A similar trial conducted from 1975 to 1979 (**Table 3**) indicates that the highest yields were obtained by planting in the early rainy season (May-June), while yields decreased when planting was delayed to the later part of the wet season (Sinthuprama, 1980). The same studies were conducted using Rayong 2 and Rayong 3 in 1983-1985. **Figure 1** shows that the root yields of Rayong 2 and Rayong 3 were highest when planted in May. Root yields increased significantly when the age at harvest increased from 6 to 12 months. These results were similar to those observed with Rayong 1. Planting cassava early in the rainy season produced the highest yields, especially when the roots were harvested at 12 months.

Table 3. Fresh and dry root yield and starch yield of Rayong 1 when planted in different months during the rainy season at Rayong Field Crops Research Center, 1975-1979.

Planting time	Fresh root yield	Dry root yield (t/ha)	Starch yield
May	38.75 a[1)]	14.00 a	8.00 a
June	39.81 a	14.56 a	8.12 a
July	36.19 b	12.94 b	7.44 b
August	31.38 c	10.69 c	6.00 c
September	27.00 d	9.62 d	5.31 d
October	22.19 e	8.12 e	4.81 e

Mean separation within each column: DMRT, 0.01
Source: *Sinthuprama et al., 1983.*

Rojanaridpiched *et al*. (1986) also studied the effect of planting time, planting in Feb, May and Nov of 1987 at Sri Racha Research Station. The results (**Table 4**) indicate that the highest yield was obtained from the Nov planting. These differences in results may be due to the high percentage of sand in the Mapbon soil found in Sri Racha. Land preparation in the dry season is possible in sandy soils but is very difficult in clay soils. Planting in the dry season tends to reduce erosion and weed problems. In 1987-1988 the optimum planting time for cassava was again studied using the new varieties Rayong 60 and Rayong 90. The results indicate the same trend as in the previous trials of Rayong 1 and Rayong 3. Planting Rayong 60 and Rayong 90 in the early to mid rainy season (June-Sept) resulted in higher yields than planting in the late rainy season or dry season (**Table 5**).

2. Age at Harvest

Although in Thailand cassava is harvested all year round (Sinthuprama and Tiraporn, 1984), the peak harvesting period is from Feb to May (53%), while less is harvested during the heavy rains of July to Oct due to a low root starch content and difficulty in drying for the chip factories. Experiments on optimum age at harvest were conducted from 1976 to 1978 at Rayong Field Crops Research Center. Results, shown in **Table 6**, indicate that the root yield increased with an increase in age at harvest from 8 to 18 months. However, if harvesting is delayed beyond 12 months the planting date for the next crop in the same area would be shifted and would no longer fit in the annual production cycle (Sinthuprama, 1980).

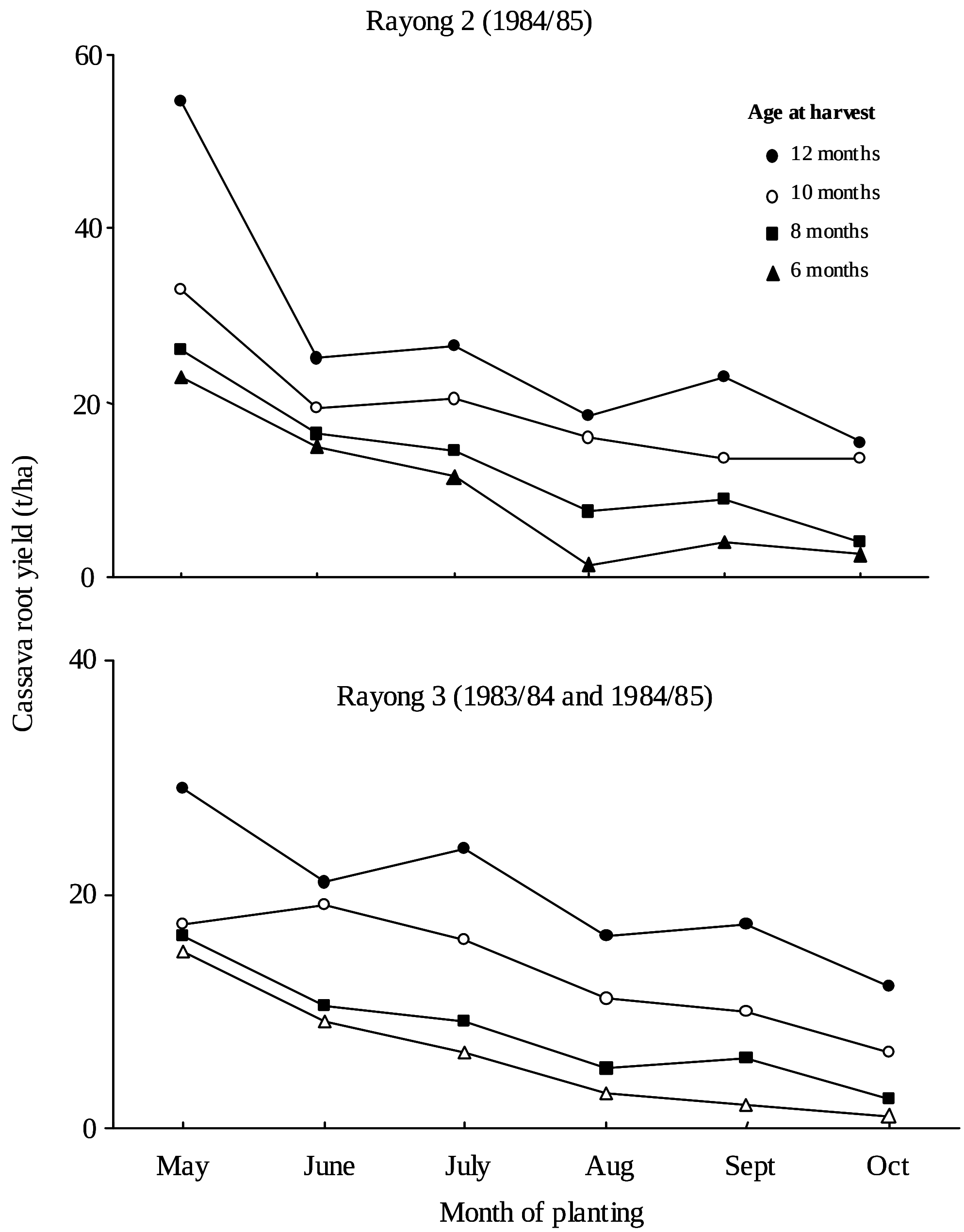


Figure 1. Effect of month of planting and age at harvest on root yields of cassava cultivars Rayong 2 and Rayong 3 planted at Rayong Field Crops Research Center in 1983-1985.
Source: *Field Crops Research Institute, Annual Report 1986.*

Table 4. Fresh and dry root yield and starch content of cassava planted in February, May or November at Sri Racha Research Station, 1987.

Planting time	Fresh root yield (t/ha)	Dry root yield (t/ha)	Root starch content (%)
February	23.11 b[1)]	7.91 b	20.24
May	27.59 b	6.99 b	15.90
November	34.28 a	11.12 a	19.75

[1)]Mean separation within each column: DMRT, 0.01
Source: *Rojanaridhipichet et al., 1986.*

Table 5. Fresh root yield (t/ha) of recommended cassava cultivars when planted in different periods at Rayong Field Crops Research Center, 1987-1988.

	Cultivars				Average
Planting periods	Rayong 1	Rayong 3	Rayong 60	Rayong 90	
April-May	18.56	19.94	23.31	24.00	21.44 c[1)]
June-July	20.81	24.25	27.63	29.31	25.50 ab
August-Sept	22.31	24.44	32.31	27.81	26.75 a
Oct-Nov	21.81	26.62	30.19	26.06	26.19 a
Dec-Jan	19.38	20.38	29.44	23.87	23.25 bc
Feb-March	20.75	20.50	26.25	25.44	23.25 bc
Average	20.62 d	22.69 c	28.19 a	26.06 b	

[1)]Mean separation: DMRT, 0.01
Source: *Field Crops Research Institute, Annual Report 1989.*

Table 6. Average fresh root yield of Rayong 1 as effected by age at harvest when planted at Rayong Field Crops Research Center, 1975-1979.

Age at harvest (months)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Starch yield (t/ha)
8	16.19 f[1)]	6.44 f	2.31 f
10	23.06 e	8.31 e	4.81 e
12	31.31 d	10.69 d	5.94 d
14	37.56 c	13.06 c	7.38 c
16	41.50 b	15.00 b	8.69 b
18	45.25 a	16.44 a	9.19 a

[1)]Mean separation within each column: DMRT, 0.01
Source: *Sinthuprama et al., 1983.*

The optimum age at harvest were also studied at Sri Racha Research Station during 1986-1994. The results reported by Rojanaridpiched *et al*. (1986) show that the root yield depended on rainfall; if there was no rainfall, delaying the harvest would not increase cassava yields (**Table 7**). Another trial by Vichukit *et al*. (1994) was conducted to determine the best harvest time for high root starch content. They reported that when four cassava varieties, i.e. Rayong 1, Sriracha 1, Kasetsart 50, and Rayong 60, were planted in May, the root starch content was still very low at four months after planting (MAP), increased in the late rainy and early dry season, reaching a maximum at 8-9 MAP in Jan-Feb. Since there were some rains in March, the starch content in March and April decreased due to sprouting of new leaves, but increased again in May as the dry period continued. The results indicate that the starch content increased with an increase in age at harvest up to 7-9 months, after which it would depend on the rainfall conditions during the last two months before harvest (**Table 8**).

Table 7. Fresh root yield (t/ha) of cassava planted in May, August, November and February and harvested at either 12 or 14 months at Sri Racha Research Station, 1986.

	Age at harvest (months)			Rainfall (mm)
Planting time	12	14	Yield increase	during the 2 months between harvests
May	27.88	36.45	8.57	272
September	29.39	40.73	11.34	619
November	30.18	30.34	0.16	0
February	16.26	18.51	2.25	22
Mean	25.93	31.51	5.58	-

Source: *Rojanaridhipichet et al., 1986.*

Table 8. Starch content (%) of four cassava varieties planted in May and harvested at monthly intervals at Sri Racha Research Station in 1990/1994. Numbers in parenthesis indicate the age (MAP) at harvest.

	Month at harvest								
Variety	Sept (4)	Oct (5)	Nov (6)	Dec (7)	Jan (8)	Feb (9)	Mar (10)	Apr (11)	May (12)
Rayong 1	9.4	16.7	19.4	19.4	19.8	22.2	14.7	10.6	12.0
Sriracha 1	12.5	18.0	21.5	22.0	23.7	23.0	18.4	15.8	19.1
Kasetsart 50	8.8	16.8	22.5	24.5	24.0	24.8	19.0	16.0	18.5
Rayong 60	10.6	14.0	18.2	19.9	17.2	21.3	13.1	9.2	10.2
Average	**10.3**	**16.4**	**20.4**	**21.4**	**21.2**	**22.8**	**16.3**	**12.9**	**14.9**

Source: *Vichukit et al., 1994.*

3. Land Preparation

On small farms, land preparation was usually done with animal traction at the beginning of the rainy season. On large farms, and presently on nearly all farms, land preparation is done by tractor; the land is plowed as soon as possible after the harvest of the previous crop. A major problem is the lack of tractors, which often results in delayed planting of cassava (Sinthuprama and Tiraporn, 1984). Several land preparation trials have been conducted at Rayong Field Crops Research Center since 1981. The preliminary studies in 1981, indicated that land prepared with the application of post-emergent herbicides but without any tillage gave a similar yield to that obtained with the traditionally prepared land, which includes one plowing by tractor followed by animal ridging (**Table 9**). The minimum tillage concept may be introduced to protect the soil from erosion and to reduce costs of cassava production.

Table 9. Effect of land preparation on the yield of cassava, Rayong 1, at Rayong Field Crops Research Center, 1981.

Treatments	Fresh root yield (t/ha)
No tillage; paraquat+hoeing	33.0
No tillage; paraquat+animal ridging	37.1
Animal plowing 2 times	36.2
Animal plowing 3 times	35.5
Plowing with 3 disc+animal ridging	34.7
Plowing with 3 disc+7 disc	31.6
Plowing with 3 disc+disc harrow	34.9
Plowing with 7 disc+animal ridging	35.2
Plowing with 7 disc 2 times	33.8
Plowing with 7 disc+disc harrow	35.4
Disc harrowing 2 times	34.4
Subsoiling+7 disc	35.8

Source: *Field Crops Research Institute, Annual Report 1982.*

During 1986-1987, trials with various land preparation treatments were also conducted, with the objective to determine the methods of land preparation which could result in high cassava yields and minimum production costs. In 1986 there were six treatments of land preparation, while in 1987 there were two additional treatments, shown in **Table 10**. No-tillage resulted in the same cassava yield as when land was prepared by tractor. However, during both years this treatment resulted in higher production costs per tonne of cassava produced, due to the higher cost of hand weedings. Land preparation with one pass of a tractor with a 7-disc harrow was found to result in the lowest cost per tonne of cassava produced in both years. This practice could be introduced to those areas where weeds are not a serious problem.

4. Plant Spacing and Population

Cassava is traditionally planted at various spacings with both row width and hill spacing ranging from 60 to 120 cm. The first cassava spacing studies were conducted in 1967-1969 at Rayong Field Crops Research Center, to find out the appropriate plant

Table 10. Effect of land preparation on cassava yield, gross income and cost of production, at Rayong Field Crops Research Center in 1986/87 and 1987/88.

Land preparation treatments	1986/87				1987/88			
	Root yield (t/ha)	Gross income (US$/ha)[1]	Cost of production (US$/ha)	Cost of production (US$/t)	Root yield (t/ha)	Gross income (US$/ha)[1]	Cost of production (US$/ha)	Cost of production (US$/t)
No tillage; (paraquat+hoeing)	16.31	489	377	23.1	16.38 ab	490	351	21.5
3 disc plow, once	12.94	388	371	28.7	18.06 ab	542	341	18.9
7 disc harrow, once	19.37	581	396	20.4	19.44 a	584	327	16.8
3 disc+7 disc	18.56	557	419	22.6	19.56 a	586	377	19.3
3 disc, twice+7 disc	18.81	565	446	23.7	-	-	-	-
Bullocks, twice	16.69	501	402	25.1	14.44 bc	432	442	30.6
7 disc harrow, twice (in planting strip only)	-	-	-	-	10.44 cd	311	316	30.3
7 disc harrow, twice (planting strip+ridging)	-	-	-	-	9.66 d	289	314	32.5
7 disc+subsoiler	-	-	-	-	16.59 ab	498	327	19.7
F-test	NS[2]				**[3]			

[1]Price of cassava fresh root in 1986 and 1987 = 30 US$/tonne
[2]Not significantly different.
[3]Mean separation within a column: DMRT, 0.01
Source: *Tongglum et al., 1990.*

spacing and optimum population of cassava to produce high yields. The results (**Table 11**) indicate that there were no significant differences in yield among spacings ranging from 60x60 cm (27,777 plants/ha) to 120x120 cm (6,944 plants/ha). A wider spacing facilitated inter-cultivation; planting cassava at 1x1 m was recommended (Charoenrath, 1983).

Cassava spacing studies for Rayong 1 were repeated for another two years as component research for the introduction of the cropping system. The results are shown in **Table 12**. When the cassava population was maintained at 10,000 plants/ha, but arranged in various spacings (100x100, 150x66, 200x50 and 300x33 cm) this did not significantly affect the yield.

Research on the spacing of two new cultivars, Rayong 2 and Rayong 3, were also conducted during 1983-1985 at different locations in order to define the best spacings for these new cultivars (**Table 13**). The different yield responses were due to different edafo-climatic conditions at each location. However, the results indicate that both Rayong 2 and Rayong 3 could be planted at populations ranging from 10,000-15,000 plants/ha; plant arrangement may not be very important (Tongglum *et al.*, 1987).

5. Planting Methods

Cassava was traditionally planted in various methods; horizontal planting prevailed, but vertical and inclined planting were also done. Various trials were conducted to evaluate these planting methods and to determine which would result in the highest yield. The results of experiments conducted in 1977 and 1978 (**Table 14**) indicate that root yields were not different for cassava planted on ridges, on the flat, or on the flat followed by earthing-up at 30 days after planting. Horizontal planting gave a lower yield than vertical planting, mainly due to a lower survival rate in the former. Vertical and inclined planting did not result in significant differences in yield. Depth of planting (5, 10 and 15 cm) had no significant effect when planting was done either vertical or inclined (Sinthuprama and Tiraporn, 1984).

Table 11. Fresh root yield of Rayong 1 planted at different spacings at Rayong Field Crops Research Center, 1967-1969.

Spacings (cm)	Number of Plants/ha	Fresh root yield (t/ha)			
		1967	1968	1969	Mean
60 x 60	27,777	20.00	30.94	28.88	28.89
60 x 80	20,833	22.37	30.56	29.94	27.63
60 x 100	16,666	21.63	30.63	29.94	27.38
60 x 120	13,888	21.25	32.44	28.88	27.50
80 x 100	12,500	21.13	34.19	29.00	28.06
80 x 120	10,416	21.38	30.94	30.88	27.75
100 x 100	10,000	22.44	36.50	29.25	29.38
100 x 120	8,333	19.75	34.19	28.69	27.50
120 x 120	6,944	19.25	29.63	27.69	25.50
					NS[1)]

No significant interaction between year and spacing.
[1)]NS = Not significantly different.
Source: *Charoenrath, 1983.*

Table 12. Effect of plant spacings on yield of Rayong 1 (combined analysis for five locations[1)], 1979-1980).

Spacing (cm)	#Plants/ha	Root yield (t/ha)
100 x 100	10,000	29.87
150 x 66.7	10,000	27.06
200 x 50	10,000	26.25
300 x 33.3	10,000	25.06
		NS

[1)]Rayong, Loei, Sakon Nakon, Supanburi and Khon Kaen.
No significant interaction between location and spacing.
Source: *Tongglum et al., 1987.*

Table 13. Effect of plant population and spacing on yield (t/ha) of Rayong 2 and Rayong 3 in different locations, 1985.

#Plants /ha	Spacing (cm)	Rayong 2 cultivar Location Rayong	Rayong 2 Khon Kaen	Rayong 2 Banmai Samrong	Rayong 2 Mean	Rayong 3 cultivar Location Rayong	Rayong 3 Khon Kaen	Rayong 3 Banmai Samrong	Rayong 3 Mean
10,000	100x100	14.0	19.9	18.4	17.4	17.7	20.1	15.2	17.7
10,000	125x80	22.8	19.0	12.3	18.1	15.3	18.1	15.1	16.1
12,500	100x80	16.9	15.6	17.4	16.7	20.8	14.2	16.1	17.1
12,500	125x64	15.1	21.5	19.4	18.7	20.3	13.8	12.6	15.6
15,000	90x74	17.4	19.1	23.9	20.1	17.7	12.6	13.5	14.6
15,000	100x66	19.8	18.5	26.2	21.5	19.3	12.3	17.5	16.3
17,500	76x75	20.3	14.6	23.5	19.5	22.0	9.9	16.5	16.2
17,500	100x57	16.5	14.7	20.1	17.1	16.7	11.7	19.9	16.1

LSD (0.05) for spacing of Rayong 2 x location =7.23
LSD (0.05) for spacing of Rayong 3 x location =7.18
Source: *Tongglum et al., 1987.*

Table 14. Fresh root yield (t/ha) of Rayong 1 in different methods, positions and depths of planting at Rayong Field Crops Research Center, 1977-1978.

Treatments	Depth of planting (cm) 5	10	15	Mean
Method of planting				
-Ridge	27.75	29.44	28.62	28.62 a
-Flat	30.75	30.44	28.75	29.94 a
-Flat+earthing up	30.56	29.19	27.75	29.19 a
Planting position				
-Vertical	30.87	31.13	30.31	30.75 a
-Inclined	30.62	30.87	29.00	30.19 a
-Horizontal	27.56	27.00	25.81	26.81 b
Mean	29.69 a	29.68 a	28.37 a	

No interaction between methods, positions and depths of planting.
Mean separation: DMRT, 0.01
Source: *Tongglum et al., 1987.*

Farmers are harvesting and planting cassava more and more during the dry season when root starch content is highest and plenty of labor is available. The germination of stakes planted in the dry season is often poor due to low soil moisture content; planting deeper or vertically may improve this situation. Planting on ridges is often desirable in the wet season, but may not be necessary or desirable in the dry season. Two separate experiments were conducted during three consecutive years in the rainy and dry seasons at Rayong Field Crops Research Center in 1987-1989. The results, summarized in **Table 15**, show that in the rainy season (May-Aug) planting cassava stakes in a vertical or inclined position, with 20 cm stake length and at 5-10 cm depth, resulted in significantly better yields than horizontal planting. Ridging had no significant effect on yield. In the dry season (Nov) planting cassava stakes in the vertical or inclined position also resulted in much higher yields than horizontal planting, and the use of 25 cm stakes planted at 15 cm depth resulted in significantly higher yields than planting 20 cm stakes or planting at shallow depths. Ridging was again not necessary. Planting on ridges may be more advantageous where the planting area is located on slopes or in low lying areas, in order to prevent soil erosion or flooding, respectively (Tongglum *et al*., 1990).

Table 15. Effect of stake position and planting method on cassava yield, planted in both the rainy and dry season at Rayong Field Crops Research Center (Average of 3 years, 1987-1989).

Treatments	Rainy season (May-August) Plants survived ('000/ha)	Plants harvested ('000/ha)	Root yield (t/ha)	Starch content (%)	Early dry season (November) Plants survived ('000/ha)	Plants harvested ('000/ha)	Root yield (t/ha)	Starch content (%)
Method of planting								
-Ridge	14.57 a	13.96 a	14.98 a	16.64 a	10.69 b	11.76 b	14.69 a	18.63 a
-No ridge	14.43 a	13.96 a	13.47 a	16.66 a	12.09 a	12.99 a	14.96 a	18.65 a
F-test	NS[3]	NS	NS	NS	**	**	NS	NS
Stake position								
-Vertical	14.87 a	14.51 a	16.04 a	17.03 a	13.04 a	13.97 a	17.74 a	19.04 a
-Inclined	14.89 a	14.47 a	15.46 a	17.14 a	11.99 b	13.04 b	16.40 b	18.68 a
-Horizontal	13.74 b	12.91 b	11.08 b	15.85 b	9.31 c	10.09 c	10.32 c	18.17 b
F-test	**[1]	**	**	**	**	**	**	**
Stake length (cm)								
-20	14.55 a	13.97 a	14.52 a	16.67 a	10.58 b	11.49 b	14.53 a	18.51 a
-25	14.41 a	13.95 a	13.54 b	16.69 a	13.02 a	14.14 a	15.41 a	18.87 a
F-test	NS	NS	*[2]	NS	**	**	NS	NS
Planting depth (cm)								
-5-10	14.43 a	13.72 b	13.90 a	16.61 a	9.74 b	10.56 b	13.14 b	18.21 b
-15	14.56 a	14.15 a	14.43 a	16.73 a	12.71 a	13.83 a	16.17 a	18.97 a
F-test	NS	**	NS	NS	**	**	**	**

No interaction between methods and treatments in all characters
[1]and [2]: Mean within a column separated by DMRT at 0.01 and 0.05 %, respectively
[3]NS = not significantly different.
Source: *Tongglum et al., 1990.*

6. Stake Size and Storage

Using cassava stems after the harvest for the next crop's planting has become a more serious problem because cassava is now preferably harvested in the dry season. After the harvest, cassava stems are collected and left in the field where they are exposed to the sun for a period of time; this causes the stems to dry up. When there is some rain, farmers start to plant but with poor cuttings the germination and plant survival is low. This problem markedly effects cassava production and also causes poor establishment of cassava, which finally results in low yields, particularly in areas where cassava planting and harvesting is done in the dry season.

Research on cassava stake size and stem part were first conducted in 1974-1976 at Rayong Field Crops Research Center, in order to determine the best length of cutting and the best part of the stem from which to cut stakes which would result in the highest plant survival rate. The results (**Table 16**) reported by Chankam (1994) indicate that the highest plant survival rate was obtained from stakes of 15-20 cm length, which resulted in a plant survival rate ranging from 83.7 to 95.0%. Cuttings taken from the middle and lower parts of the stem gave higher plant survival rate, ranging from 73.7 to 92.8%, than those taken from the upper part of the stem. **Table 17** shows that the number of buds depends on the length of the stem. The number of cuttings obtained depends on the cutting length, and the longer cuttings would result in a higher plant survival rate than the shorter ones. Again, the cuttings taken from the middle and lower parts of the stem resulted in higher plant survival rates than those taken from the upper part of the stem. These results also indicate that the best age of stems used as planting material is about 10-12 months.

During 1976-1993 several studies were conducted on the effect of time and method of stem storage on plant survival of Rayong 1, Rayong 3, Rayong 60, Rayong 90 and Rayong 5. Results for Rayong 1, shown in **Table 18**, indicate that the survival rate of stakes taken from stems stored up to 30 days in the field was higher than 80%. Storage of stems under shade tends to be a better method than storage in full sun (Sinthuprama and Tiraporn, 1984).

Further studies were conducted separately with Rayong 1, Rayong 3 and Rayong 60 cultivars in 1989/1990, as well as with Rayong 90 and Rayong 5 cultivars in 1991/1993. The portion of the stems still available for cutting stakes, as well as the plant survival rate were quantified. The results of both experiments (**Table 19**) indicate that stems of all cultivars stored under shade resulted in a greater proportion of the stem available for use as planting material and better plant survival. It was found that stems of Rayong 1, Rayong 60, Rayong 5 and Rayong 3 could be stored up to 30 days, with a plant survival rate of

Table 16. Effect of stake length and part of stem from which stakes are cut on plant survival of Rayong 1 at 30 days after planting at Rayong Field Crops Research Center, 1974-1976.

Treatments	Survival (%)
Stake length (cm)	
5	59.93
10	72.73
15	83.67
20	95.00
Part of stem	
Upper	49.87
Middle	73.67
Lower	92.80

Source: *Tongglum et al., 1987.*

Table 17. Effect of stem age, stake length and part of stem from which stakes are cut on survival of Rayong 1 at Rayong Field Crops Research Center, 1974 -1976.

	Stem age (months)				
	4	6	8	10	12
Stem length (cm)	153	181	201	266	282
# Buds/stem	62	69	93	113	137
Stake length (cm)					Survival (%)
5					48.6
10					77.5
15					88.8
Part of stem					
Upper					58.7
Middle					92.1
Lower					98.6

Source: *Chankam, 1994.*

Table 18. Plants survival (%) from stakes stored under different conditions and for various periods at Rayong Field Crops Research Center, 1976-1978.

Storage time	Storage method		
(days)	Under shade	In sun	Covered with leaves
0	95.6	95.3	96.5
15	93.5	93.4	91.6
30	83.4	84.3	87.9
45	80.0	55.9	58.4
60	57.5	48.9	50.0
75	49.2	31.9	43.1
90	44.9	28.9	35.9
105	43.2	21.0	22.1

Source: *Sinthuprama et al., 1984.*

about 80%; longer stem storage resulted in lower plant survival rate in all cultivars. Since Rayong 3 is characterized by a branching plant type, the storability of Rayong 3's branches to be used as planting material was also studied. It was found that the primary branches of Rayong 3 could be stored for only 15 days; storage beyond 15 days decreased both the portion of available stem and plant survival (Chankam, 1994). A similar trend was observed in Rayong 90, the stored stems of which had a lower proportion available as planting material, and plant survival percentage decreased markedly when stems were stored beyond 15 days.

Table 19. Effect of storage time and method on available part (%) and plant survival (%) of Rayong 1, Rayong 3, Rayong 60 and Rayong 90 at 30 days after planting at Rayong Field Crops Research Center, 1989/90 and 1991-1993.

Storage time (days)	Storage method											
	1989/90								1991-1993			
	In sun				Under shade				In sun		Under shade	
	Rayong 1	Rayong 3 A	Rayong 3 B	Rayong 60	Rayong 1	Rayong 3 A	Rayong 3 B	Rayong 60	Rayong 90	Rayong 5	Rayong 90	Rayong 5
	Available part (%)											
15	94	88	84	93	94	84	84	93	75	77	64	69
30	94	87	73	90	93	79	74	91	61	69	61	68
45	78	57	43	76	84	65	46	83	57	64	54	62
60	76	56	0	73	76	57	0	76	47	60	52	58
	Plant survival (%)											
15	83	66	31	78	86	59	26	80	76	85	77	95
30	97	88	46	82	94	83	50	80	75	79	66	90
45	91	68	20	93	97	70	44	88	57	65	63	70
60	64	14	0	47	64	0	0	50	45	64	50	67

A= main stem; B= branch of Rayong 3

Source: *Chankam, 1994; Rayong Field Crops Research Center, Annual Report 1993.*

In 1981/1982, various cassava cultural practices were tested in five farmers' fields, using a package of technology at two levels: 1) high technology which included the use of selected cuttings from the middle and lower parts of the stem, cut at 10-12 months, treated with both fungicide (Captan 600 gm/100 liters of water) and insecticide (Omethoated 100 cc/100 liters of water) to prevent damage of cuttings, ridging and application of chemical fertilizer 15-15-15, applied at 312 kg/ha; and 2) low technology, which included the use of selected cuttings as indicated above but without fungicide or insecticide treatment, planted on the flat without any fertilizer application; these two levels of technology were compared to the traditional practices used by farmers. The results (**Table 20**) indicate that with the high technology yields were 51% higher than with the traditional practices, while with low technology (only selected planting material), the yield was 16% higher than with the traditional practices.

Table 20. Effect of cassava cultural practices on yield and economic returns in farmers' field trials conducted in Rayong province in 1981/82 and in 1986/87.

	Average of five farmers' fields 81/82		Average of three farmers' fields 86/87				
Treatments	Root yield (t/ha)	Yield increase (%)	Root yield (t/ha)	Gross income (US$/ha)	Production costs (US$/ha)	Net income (US$/ha)	Unit cost (US$/t)
High technology	29.00	51	22.56	704.25	524.75	179.50	23.26
Low technology	22.19	16	14.50	453.25	298.00	155.25	20.55
Farmers' practice	19.13	-	11.50	358.75	249.00	109.75	21.65

Source: *Tongglum, 1991.*

These field tests were repeated in 1986/87 on three farmers' fields to further quantify the yield and the costs of cassava production. The results showed the same trends as those obtained in 1981/82. The farmers' practice resulted in the lowest cost of production, but this also resulted in the lowest net income. The results indicate that farmers can prevent considerable yield losses by practicing simple selection of planting material (Tongglum, 1991).

7. Root Storage

Tiraporn and Narintaraporn (1983) studied the effect of cassava root storage duration on root deterioration. The results, shown in **Table 21**, indicate that after harvest, roots can be stored for up to only two days. Longer storage caused a significant decrease in starch content and increase in root deterioration. Therefore, it is recommended that cassava growers and factories dealing with cassava prevent root damage by either selling or processing their roots within 2-4 days after harvest.

8. Weed Control

Cassava yields can be markedly reduced by competition from weeds. It has been reported that yields may be reduced 25-50% if weeds are not controlled, particularly at the early growth stage (Tirawatsakul, 1983). Traditionally weed control was done by animal and hand labor, which accounted for 40% of total labor used in cassava production (Sinthuprama and Tiraporn, 1984). Due to the high cost and lack of labor, several experiments on weed control were conducted during 1987-1991 with the objective of minimizing the number of times and cost of weed control in cassava. The results, shown in **Table 22**, indicate that the pre-emergence herbicide Metholachlor, applied at a rate of 1.56 kg ai/ha, could control 90% of the weeds during the first three months after planting, and this treatment resulted in a high yield at the lowest production cost. Tongglum *et al.* (1992) also studied the effect of frequency of weeding on the yields of two recommended varieties, Rayong 3 and Rayong 60. The results show that two times of hand weeding, at 1 and 2 months after planting, gave the best results for both varieties (**Table 23**). The results also indicate that weeding costs varied according to the planting season, the cost being much higher when cassava was planted in the early rainy season than in the dry season.

During 1993-1995, additional experiments on weed control for cassava were conducted at Khon Kaen Field Crops Research Center in the northeast of Thailand. Rayong 1, Rayong 60 and Rayong 90 cultivars were planted in both the early and late rainy seasons. Plots were weeded for either 0, 2, 3 or 4 months as compared to a typical "farmer" practice of manual weeding only at 2 MAP and without fertilizer application. Results shown in **Table 24** indicate that weed control is extremely important during the first two months after planting, but weed control beyond 2 MAP did not significantly increase yield any further. The highest yields were obtained when plots were maintained weed-free for 3 MAP. Thus, when cassava is planted in either the early or late rainy season, these three cassava cultivars need to be free of weeds for about 2-3 months after planting to produce high yields.

CASSAVA-BASED CROPPING SYSTEMS

1. Intercropping Systems

Studies on land use efficiency and restoration of soil fertility through intercropping have been conducted since 1970, using peanut, mungbean and soybean as the intercrops. The most promising intercropping systems appeared to be the combination of cassava and peanut or cassava and mungbean (Sinthuprama *et al.*, 1983).

Table 21. Effect of root storage duration on root starch content and deterioration at Rayong Field Crops Research Center, 1976-1978.

Storage duration (days)	Starch content (%)	Deterioration (%)
0	23.84 a[1)]	0 d[1)]
2	23.01 a	0.61 d
4	20.08 b	8.25 c
6	10.89 c	27.00 b
8	7.12 d	40.12 a

[1)] Mean within each column separated by DMRT at 0.01% level.

Source: *Tiraporn et al., 1983.*

Table 22. Effect of various chemical weed control methods in cassava (Rayong 1) on yield and economic benefits at Rayong Field Crops Research Center, Rayong, Thailand, in 1987/1988.

Treatment	Root yield (t/ha)	Gross income (US$/ha)	Weeding cost (US$/ha)	Net income[1] (US$/ha)
1. Metolachlor (1.56 kg a.i./ha); PE[2]	26.82 a[3]	955	230	725
2. Oxyfluorfen (1.56 kg a.i./ha); PE	21.26 b	757	234	523
3. Metolachlor (1.56 kg a.i./ha); PE-B +Paraquat (0.50 kg a.i./ha); ST	25.76 ab	917	234	683
4. Metolachlor (1.56 kg a.i./ha); PE +once bullock cultivation +Fluazifop-buty1(0.38 kg a.i./ha); PE	25.66 ab	914	268	646
5. Metolachlor (1.56 kg a.i./ha); PE +Fluazifop-buty1(0.38 kg a.i./ha); ST	27.00 a	961	258	703
6. Twice bullock cultivation +Paraquat (0.50 kg a.i./ha); ST	26.84 a	956	237	719
F-test	**	-	-	-

[1] Root price = US$ 35.6/tonne
[2] PE = Pre-emergence
PE-B = Pre-emergence, band spraying
ST = Spot treatment
Herbicide application rates are in kg active ingredient/ha.
[3] Mean within a column separated by DMRT at 0.01% level.
Source: *Tirawatsakul et al., 1988.*

Table 23. Cassava fresh root yield and weeding costs as effected by the frequency of hand weeding when cassava cutivars Rayong 3 and Rayong 60 were planted at Rayong Field Crops Research Center in the beginning of the rainy and dry seasons of 1991.

Treatment	Rainy season		Dry season	
	Root yield (t/ha)	Weeding cost (US$/ha)	Root yield (t/ha)	Weeding cost (US$/ha)
Varieties				
-Rayong 3	21.44 b	111	22.88 b	57
-Rayong 60	28.00 a	94	30.81 a	53
F-test	*[1]	-	*	-
Weeding times				
-No weeding	4.81 b	0	23.63	0
-1&2 months	26.69 a	77	24.88	9
-1, 2& 3 months	29.00 a	85	25.38	14
-1, 2, 3 &6 months	27.94 a	127	26.06	57
-1, 2, 3, 6 & 9 months	31.44 a	118	29.56	104
-As necessary	28.81 a	106	31.56	90
F-test	**[2]	-	NS[3]	-

[1] and [2] Mean within a column separated by DMRT at 0.05 and 0.01%, respectively.
[3] NS = not significant
Source: *Tongglum et al., 1992.*

Table 24. Effect of weed control on the yields (t/ha) of three cassava varieties planted in the arly (ER) and late (LR) rainy seasons at Khon Kaen, Thailand, in 1993/94 and 1994/95.

	1993/94		1994/95		Average 2 years		Average 2 seasons
	ER	LR	ER	LR	ER	LR	
Cultivars (C)							
-Rayong 1	28.33	19.53	10.86	17.23	20.97	18.38	19.67
-Rayong 60	23.33	27.68	15.11	14.59	19.22	21.13	20.18
-Rayong 90	25.03	21.88	11.33	12.25	18.18	17.06	17.62
F-test (C)	NS	*	*	NS	NS	*	NS
Weed-free period (W)							
-0 month (check)	2.61	13.48	4.49	5.63	5.83	9.56	7.69
-2 months	31.98	26.43	16.71	15.52	24.34	20.98	22.66
-3 months	34.71	26.03	13.84	19.20	24.28	22.61	23.44
-4 months	31.47	24.96	13.73	17.54	22.59	21.25	21.93
-farmers' practice[1)]	27.07	24.25	13.39	15.54	20.23	19.89	20.06
LSD (0.05) for W	6.73	7.38	4.97	5.82	5.51	4.70	3.56
F-test (W)	**	**	**	**	**	**	**
F-test (CxW)	NS	NS	**	NS	NS	NS	NS

[1)]Farmers' practice = manual weed control at 2 months with no fertilizer applied.
Source: *Khon Kaen Field Crops Research Center, Annual Report 1995.*

From 1976 to 1978, in order to improve the system, cassava was intercropped with each species of legume, planted in 1, 2 or 3 rows between cassava plants spaced at 1x1 m. The results indicate that increasing the number of rows of the intercrops reduced cassava yields. Two rows of intercrops was considered the best system (Charoenrath, 1983).

During 1982-1983, research on the effect of using a wider row spacing of cassava in combination with different patterns of intercropping indicate that root yields were reduced by the presence of the legumes and *vice versa*, but the Land Equivalent Ratios (LER) were always above 1.00, indicating that the intercropping system had a greater total productivity than cassava monocropping. The highest LER values were obtained when cassava was planted at a spacing of 125x80 cm, with two rows of either peanut or mungbean planted between cassava rows at a spacing of 20x10 cm (Tongglum *et al*., 1987).

In 1988-1989, a study on the spatial arrangement of cassava intercropped with mungbean, peanut and soybean was conducted to determine the optimum spacing for intercropped cassava, which would produce high yields of both the intercrops and cassava. Intercrops were arranged in four patterns with either 2 or 3 rows of legumes planted between cassava rows (spaced at 180 cm), while the intercrop rows were planted at either 45 or 60 cm from the cassava rows. All four intercropping patterns maintained the same legume population of 200,000 plants/ha as in legume monoculture, while both intercropped and monoculture cassava had a population of 10,000 plants/ha. The results indicate that intercropping cassava with any of the three grain legumes produced a higher gross income than cassava grown in monoculture, while intercropping with peanut produced the highest gross income. Keeping the intercrops 60 cm from the cassava rows resulted in higher cassava yields and gross incomes than when intercrops were grown at 45 cm from the cassava rows (Tongglum *et al*., 1990).

Long-term cassava intercropping experiments have been conducted at Rayong Field Crops Research Center, Thailand, since 1975, to study the effect of the intercrops on soil nutrient depletion in continuously planted cassava. Short-duration crops such as sweet corn, mungbean, peanut and soybean were intercropped yearly with cassava, and each five years cassava was planted as a monocrop without fertilization. The results indicate that the yields of both cassava and the intercrops fluctuated due to different competitive effects with different climatic conditions each year. After the first five years the yield of monocropped cassava was not significantly affected by the previous intercropping treatments. It was concluded that the intercropped legumes had no long-lasting effect on soil productivity (Tongglum *et al*., 1987). The experiment was continued for two more 5-year periods (1981-1987 and 1988-1993). Similar fluctuating yields of cassava and intercropped legumes were obtained during these second and third 5-year periods (**Tables 25** and **26**). After six years of the second cassava intercropping period, the yield of monocropped cassava (in the 7th year) without fertilizer application was significantly higher after continuous intercropping of cassava with soybean. These results seems to indicate a positive effect of the intercropped soybean, which might result in an increase in long-term cassava productivity. In the third cycle, after five more years of intercropping cassava, the yield of the cassava monocrop during the sixth year was not significantly affected by any of the previous intercropping treatments. Nevertheless, soil analysis of the long-term cassava intercropping experiment (**Figure 2**) shows an increasing trend in soil organic matter with the intercropped cassava treatments. Composite soil samples were taken at the beginning of the trial, and their analysis indicate an initial organic matter content of 1.01%. After the harvest of the first and second year, the intercropped treatments had higher organic matter contents than the monocropped cassava, especially those intercropped with soybean and peanut. Organic matter contents fluctuated depending on the climatic conditions each year, which affected the crops' growth. From the 12th to the 24th year of the trial, soil analysis results indicate a long-term positive effect on soil organic matter content, which increased by intercropping cassava with peanut and soybean. Cassava intercropping may take some time to show an increase in soil organic matter by the incorporation of the residues of the intercrops; this may contribute to improved soil fertility. Since the trial is a long-term study, the result still needs further confirmation with additional soil analyses and yield data of the cassava monocrop planted at the end of another intercropping cycle.

The results of long-term experiments on cassava intercropping with short-duration crops during 1975-1979, 1981-1986, 1988-1992 and 1994-1998 are summarized as the average for 21 years, in order to quantify the effect of intercropping cassava as compared to monocropped cassava. The results, shown in **Table 27**, indicate that all intercrops reduced cassava yields, ranging from 5 to 13%, as compared to monocropped cassava. Intercropping with sweet corn had the least effect on cassava yield. However, intercropping cassava with soybean, mungbean, peanut and sweet corn increased gross income 33, 35, 72 and 158%, respectively.

Table 25. Yield (t/ha) of cassava (C) and intercrop (INT) species in a long-term cassava intercropping trial conducted at Rayong Field Crops Research Centera, 1981-1987.

Intercropping patterns	Year												
	1981		1982		1983		1984		1985		1986		1987
	C	INT	C	INT	C	INT	C	INT	C	INT	C	INT	C
Cassava monoculture	29.2	-	15.2	-	5.9	-	25.1	-	17.4	-	19.9	-	22.5 bc[3)]
Cassava+sweet corn[1)]	31.3	27.2	19.2	18.8	9.9	17.8	26.3	9.7	14.5	0[2)]	21.9	13.9	25.7 ab
Cassava+mungbean	24.4	0.88	14.6	0.76	7.6	0.78	21.3	0.66	10.8	0	17.9	0.09	21.6 c
Cassava+peanut	23.5	1.35	13.4	1.28	8.9	1.24	21.2	0.92	11.8	0	21.4	0.31	24.6 abc
Cassava+soybean	29.1	0.63	14.1	1.52	8.9	0.58	18.7	0.93	11.9	0	17.4	0.63	26.8 a
F-test													*

[1)]Sweet corn yield in '000 cobs/ha.
[2)]Drought in 1985 caused complete intercrop yield loss
[3)]Means in a column separated by DMRT at 0.05%
Source: *Rayong Field Crops Research Center, Annual Report 1998.*

Table 26. Yield (t/ha) of cassava (C) and intercrop (INT) species in a long-term cassava intercropping trial conducted at Rayong Field Crops Research Center, 1988-1993.

Intercropping patterns	Year										
	1988		1989		1990		1991		1992		1993
	C	INT	C	INT	C	INT	C	INT	C	INT	C
Cassava monoculture	9.9	-	11.8	-	15.3	-	18.1	-	27.9	-	22.8
Cassava+sweet corn[1)]	10.2	9.8	13.4	12.7	14.9	0[2)]	15.6	15.3	30.7	20.1	26.2
Cassava+mungbean	9.1	0.33	13.6	0.16	13.4	0.19	17.5	0.55	32.9	0.23	26.4
Cassava+peanut	7.3	0.22	13.4	0.93	11.8	0.41	13.2	1.42	24.9	1.94	28.3
Cassava+soybean	5.9	0.33	12.3	0.56	10.4	0	12.0	0.47	27.2	0	27.2
F-test											NS

[1)]Sweet corn yield in '000 cobs/ha.
[2)]Drought in 1990 and 1992 caused complete yield loss of some intercrops
NS = not significantly different.
Source: *Rayong Field Crops Research Center, Annual Report 1998.*

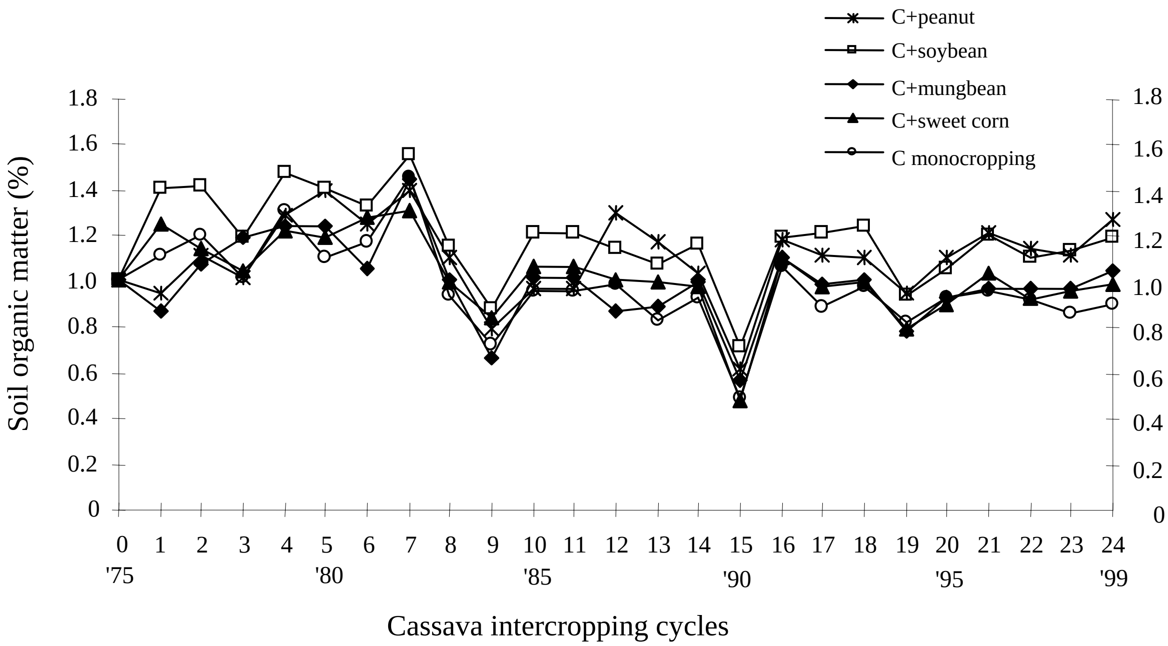


Figure 2. Percent organic matter as affected by different cassava intercropping patterns during 24 consecutive crops grown at Rayong Field Crops Research Center, Rayong, Thailand, from 1975 to 1999.
Source : *Rayong Field Crops Research Center, Annual Report 1999.*

Intercropping is a very intensive crop management system. Therefore, the system should be introduced to either small cassava growers who own their land and/or in areas located on slopes where adequate labor is still available.

CASSAVA SOIL CONSERVATION AND FERTILITY MAINTENANCE

1. Cultural Practices for Erosion Control

Cassava in Thailand is normally planted on flat or undulating land (0-10% slope) having soils with sandy loam and/or loamy sand texture. The rather wide spacing used as well as the slow growth during the first three months after planting results in the soil being exposed to the direct impact of raindrops, causing high soil loss due to erosion and a decrease in yield.

In 1988/89, the effect of soil and crop management on cassava yield and soil loss due to erosion was studied on 5% slope at Pluak Daeng in Rayong province, Thailand. **Table 28**, shows the effect of various land preparation and intercropping systems on the loss of soil and soil fertility. The results indicate that intercropping cassava with peanut, mungbean and soybean was very effective in reducing soil loss, with an average soil loss of 25.7 t/ha/year, as compared to 53.2 t/ha/year for the conventional monocropped cassava; this logically meant a much lower loss of soil fertility.

Table 27. Cassava (C) and intercrops (INT) species yield (t/ha) and gross income (US$/ha) in a long-term intercropping trial conducted at Rayong Field Crops Research Center during 1975-1979, 1981-1986, 1988-1992 and 1994-1998. Date are average values of 21 experiments.

Intercropping patterns	Yield (t/ha)		Relative cassava yield (%)	Gross income (US$/ha)		Total gross income	Relative gross income (%)
	C	INT		C	INT		
Cassava monoculture	20.15	-	100	55.16	-	55.16	100
Cassava + sweet corn[1)]	19.92	20.20	99	54.52	87.52	142.05	258
Cassava + mungbean	19.18	0.59	95	52.48	22.23	74.70	135
Cassava + peanut	17.96	1.08	89	49.15	45.50	94.65	172
Cassava + soybean	17.50	0.76	87	47.88	25.65	73.53	133

[1)]Sweet corn yield in '000 cobs/ha.

Price of crops :

Price of crops :	sweet corn	2.63 US$/100 cobs
	mungbean dry grain	236.84 US$/tonne
	peanut dry pods	263.16 US$/tonne
	soybean dry grain	210.53 US$/tonne
	cassava fresh roots	17.10 US$/tonne

Source: *Rayong Field Crops Research Center, Annual Report 1998.*

Table 28. Effect of various cassava intercropping systems on dry soil and soil fertility loss as compared to cassava monocropping using various land preparation practices on loamy sand with 5% slope at Pluak Daeng, Rayong, in 1988/89.

Treatment	Dry soil loss (t/ha)	Fertility loss (kg/ha)[1)]		
		OM	P	K
Intercropping systems (with fertilizers)				
-Cassava + peanut	28.63	241	0.69	1.75
-Cassava + mungbean	23.81	200	0.56	1.44
-Cassava + soybean	24.69	208	0.56	1.50
Average	**25.71**	**216**	**0.60**	**1.56**
Cassava monoculture				
-7 disc+7 disc, without fertilizers	69.81	586	1.63	4.31
-3 disc+7 disc, with fertilizers	34.94	293	0.81	2.13
-7 disc+7 disc, with fertilizers	47.81	402	1.13	2.94
-7 disc+7 disc, up/down ridges, with fertilizers	60.44	508	1.44	3.69
Average	**53.25**	**447**	**1.25**	**3.27**

[1)]loss of organic matter (OM), available P and exchangeable K based on analyses of soil sediments in the same experiment with on average 0.84% OM, 23.4 ppm available P and 61.3 ppm exchangeable K

Source: *Tongglum et al., 1994.*

Experiments were also conducted in cassava farmers' fields in Rayong province during 1994 to 1996 to determine the most appropriate cultural practices for erosion control which will reduce soil loss and maintain a high cassava yield. The results of two years of experiments, shown in **Table 29**, indicate that planting on contour ridges at closer spacing of 0.8x0.8 m, and with application of 312 kg/ha of 15-15-15 chemical fertilizers, gave the best results, reducing soil erosion and increasing cassava root yields.

Table 29. Effect of various cultural practices on cassava yield and on soil erosion in on-farm trials conducted in four locations of Rayong province, Thailand, in 1994/95 and 1995/96. Data are average values of four locations in each year.

	1994/95				1995/96			
Treatment	Plants harvested /ha	Root yield (t/ha)	Starch content (%)	Total dry soil loss (t/ha)	Plants harvested /ha	Root yield (t/ha)	Starch content (%)	Total dry soil loss (t/ha)
1x1m, no ridges, no fertilizers	8,331 b	11.81 b	17.20	23.56	9,363 c	11.50 c	17.70	18.50 ab
1x0.6m, no ridges+fertilizers[1)]	14,088 a	14.56 ab	16.65	38.63	15,481 a	18.56 ab	17.73	26.75 a
1x0.6m, contour ridges+fert.	14,106 a	17.75 a	16.88	17.94	15,750 a	21.75 a	19.35	8.56 b
1x0.6m, no ridges, no fert.	14,631 a	11.75 b	19.25	24.75	15,269 a	13.00 bc	20.05	15.31 ab
0.8x0.8m, contour ridges+fert.	14,438 a	18.75 a	18.38	20.50	14,869 ab	22.75 a	20.30	10.25 b
Farmers' practices	14,306 a	15.38 ab	17.20	23.81	13,656 b	19.75 a	18.05	10.69 b
F-test	**[2)]	**	NS[3)]	-	**	**	NS	**
CV(%)	6.86	14.68	10.77	-	4.63	15.42	7.80	39.99

[1)]+fertilizers = 312.50 kg/ha of 15-15-15 compound fertilizers

[2)] Mean within each colomn separated by DMRT at 0.01%

[3)] NS = not significantly different

Source: *Tongglum et al., 1996; Rayong Field Crops Research Center, Annual Reports 1995 and 1996.*

2. Long-term Effect of Fertilizer Application

Sittibusaya *et al.* (1987) reported that during 1954-1980, many fertilizer trials were conducted on farmers' fields; it was found that if no fertilizers were applied to cassava, soil productivity steadily declined causing a decrease in root yields in three major cassava soils, i.e. Korat, Sattahip and Huaipong soil series. The decline in yields could be attributed mainly to the fact that cassava growers seldom fertilize the land sufficiently and to the methods of cultivation used, which caused severe soil erosion and nutrient loss. Much research has been conducted to try to solve this problem.

During 1975-1999 three experiments on the long-term effect of fertilizer application in cassava were conducted at Khon Kaen and Rayong Field Crops Research Centers and at Banmai Samrong Field Crops Research Station; these represent the major cassava growing areas in Thailand. The results of 23 years of continuous cassava cropping at Khon Kaen, and 24 years at Banmai Samrong and Rayong, shown in **Figures 3, 4** and **5**, respectively, indicate a clear response of cassava to annual fertilizer applications in all three locations. Without fertilizer application cassava yields declined over time, especially in Khon Kaen. The omission of K reduced cassava yields more than the omission of either P or N, while the annual incorporation of cassava tops after harvest resulted in a marked increase in cassava yields, especially in the absence of chemical fertilizers. The combined application of complete chemical fertilizers with municipal compost tended to result in the highest cassava yields. Based on these results, cassava growers have been recommended to apply chemical fertilizers that are high in K and N, and low in P, such as compound fertilizers in the ratio of 2:1:2 or 2:1:3.

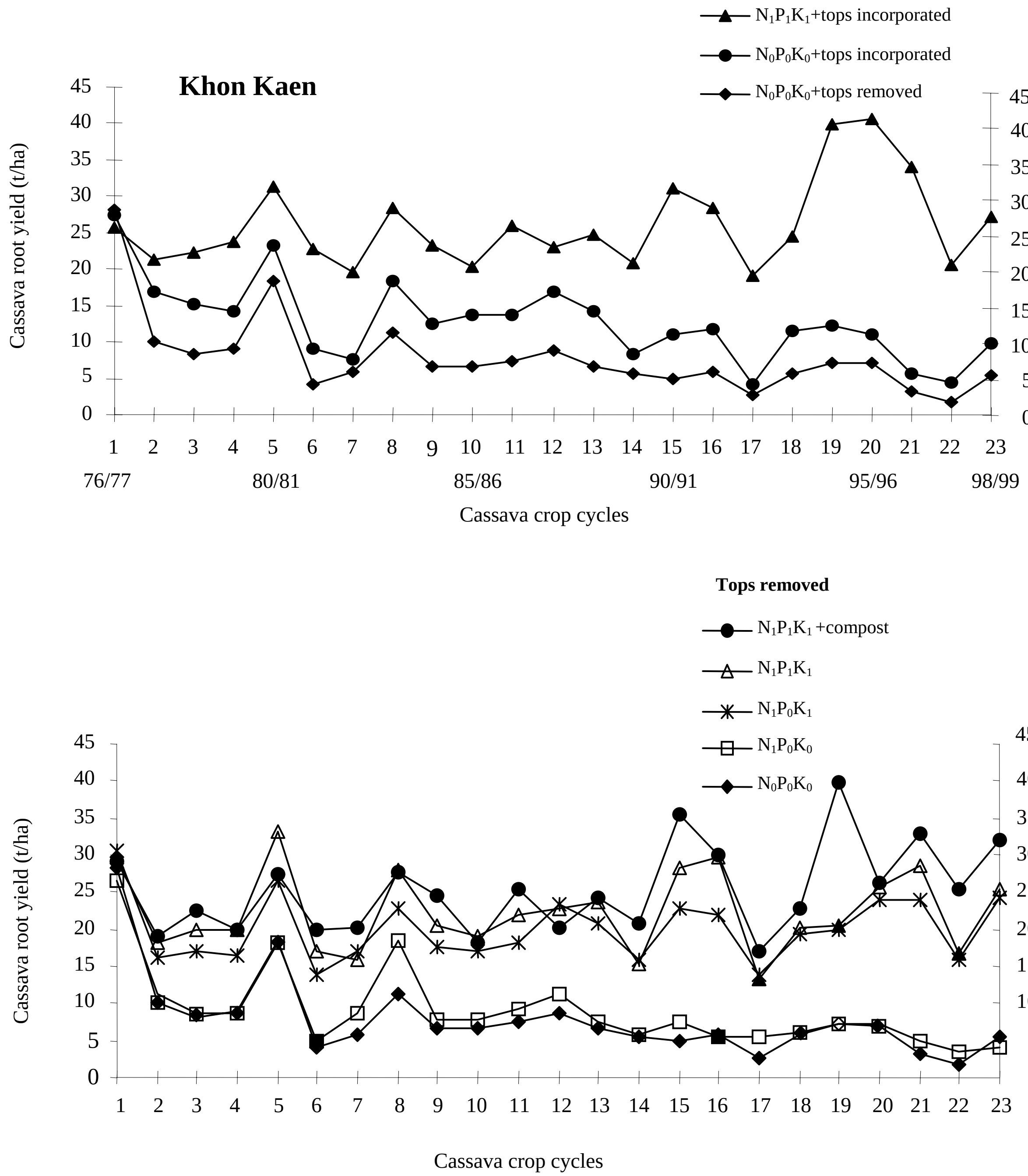
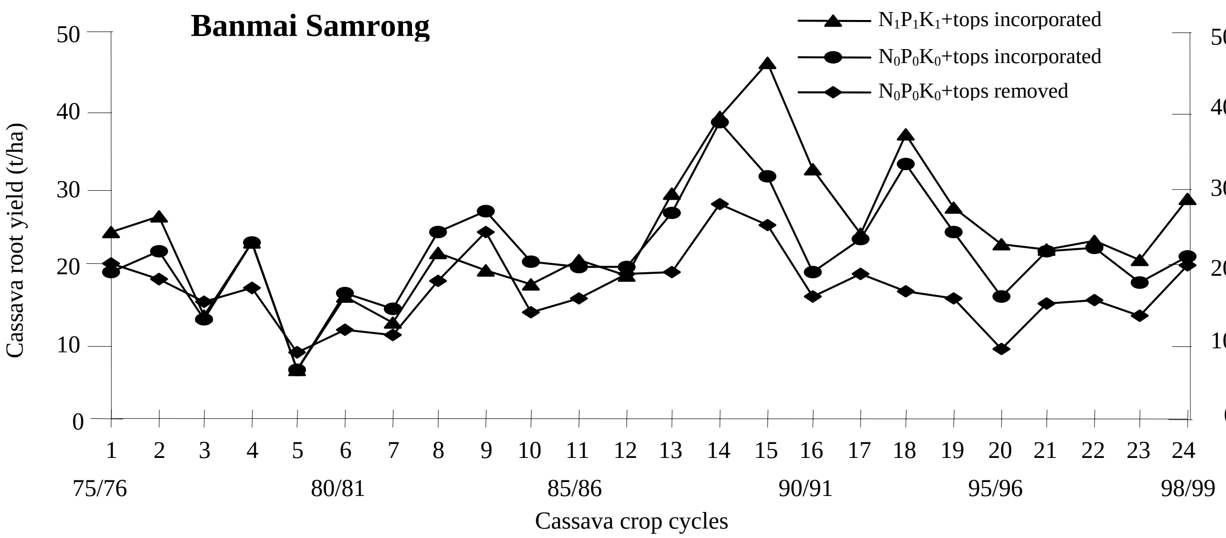


Figure 3. Effect of annual fertilizer application and crop residue management on cassava yields during 23 consecutive crops grown in Khon Kaen, Thailand.
Source : *Chumpol Nakviroj and Kobkiet Paisancharoen, Soils Division, DOA, Bangkok.*



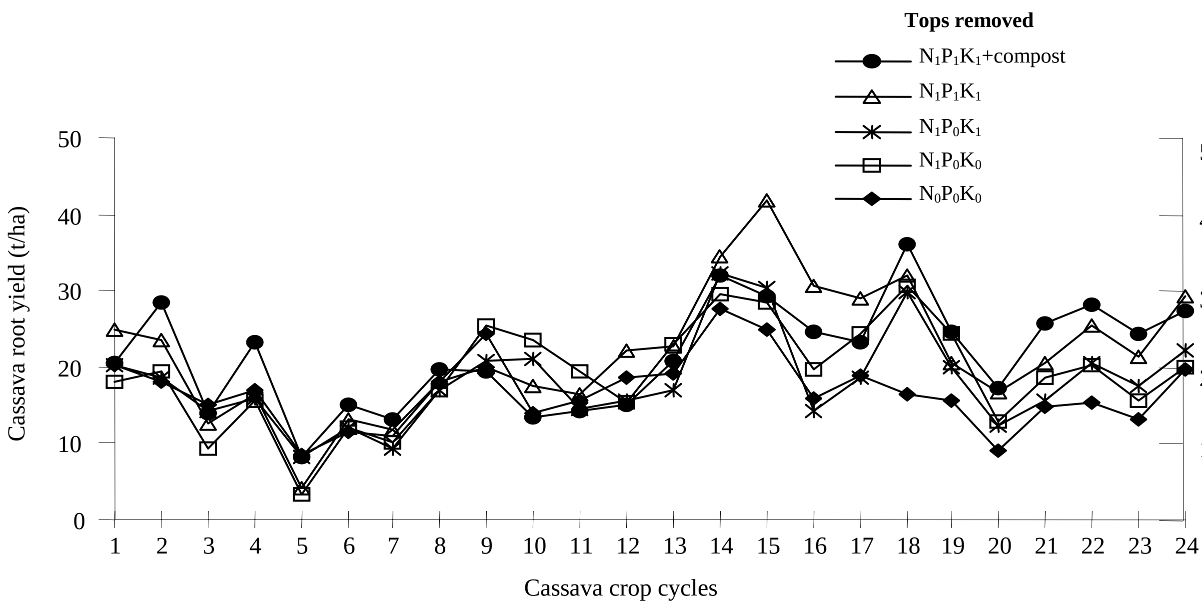


Figure 4. Effect of annual fertilizer application and crop residue management on cassava yields during 24 consecutive crops grown,in Banmai Samrong, Nakorn Ratchasima,Thailand.
***Source:** Chumpol Nakviroj and Kobkiet Paisancharoen Soils Division,DOA,Bangkok.*

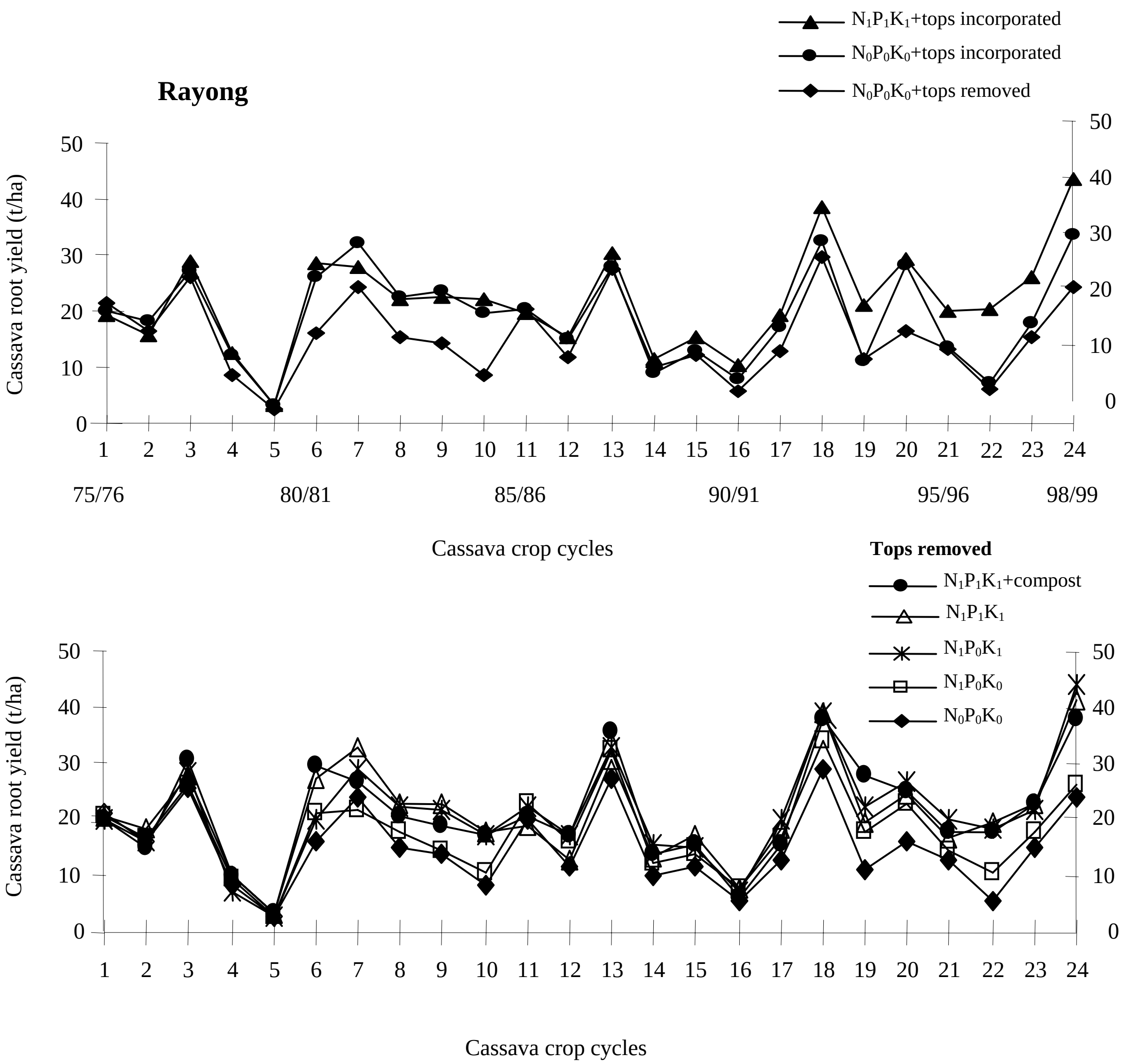


Figure 5. Effect of annual fertilizer application and crop residue management on cassava yields during 24 consecutive crops grown in Rayong, Thailand.
***Source :** Chumpol Nakviroj and Kobkiet Paisancharoen, Soils Division, DOA, Bangkok*

3. Soil Management

Research on the long-term effect of various soil management practices on cassava production has been conducted at Khon Kaen Field Crops Research Center from 1980 to 1994. The objective of the trial was to determine the most appropriate soil management system to maintain soil fertility and sustain high cassava yields. Rayong 1 was used as the test cultivar. The results, shown in **Table 30**, indicate that cassava rotated with peanut-pigeon pea, and with either chemical fertilizer alone or in combination with soil amendments, produced the highest cassava yields in the 19th year. These results should be complemented with soil analysis data to confirm the effect on soil fertility. Nevertheless, the results indicate that with suitable soil/crop management the long-term productivity of cassava can be sustained.

These results have led to better recommendation to cassava growers who plant cassava in areas located on either unfertile soil and/or on undulating land, and they are now more aware of the need for soil conservation and fertility maintenance.

Table 30. Long-term effect of various soil management treatments on the yield (t/ha) of cassava grown at Khon Kaen, Thailand from 1980 to 1999.

Treatments	Soil management				Average
	Check[1)]	Fertilizer[2)]	Soil amendment[3)]	Fertilizer+ soil amendment	
1st Year (1980)					
Continuous cassava monocropping	30.13	32.38	20.38	26.63	27.38
Cassava rotated with peanut-pigeon pea[4)]	27.88	26.81	18.63	22.88	24.05
Cassava intercropped with peanut[5)]	18.81	27.00	27.31	28.81	25.48
Average of 1st year	**25.61**	**28.73**	**22.11**	**26.11**	**25.64**
19th Year (1999)					
Continuous cassava monocropping	13.38	39.13	29.81	38.31	30.13
Cassava rotated with peanut-pigeon pea[4)]	15.00	42.88	33.50	38.44	32.44
Cassava intercropped with peanut[5)]	12.50	21.06	17.63	18.63	17.44
Average of 19th year	**13.63**	**34.38**	**27.00**	**31.81**	**26.69**
Relative to 1st year (%)	53.22	119.67	122.12	121.83	104.60

[1)] No fertilzers or soil amendments

[2)] Applied 50-50-50 kg/ha of N-P_2O_5-K_2O for cassava or 18.75-56.25-37.50 kg/ha of N-P_2O_5-K_2O for peanut in crop rotation treatment

[3)] Applied 1250 kg/ha of lime and rock phosphate (3% P_2O_5) with 18.75 t/ha of compost in 1st, 5th, 9th, 13th, 17th and 19th year (1980, 1984, 1988, 1992, 1996 and 1999).

[4)] Crop rotation by planting cassava and peanut-pigeon pea in alternate years; after harvest of the sequentionally planted legumes, the residues were incorporated into the soil before the following year's planting of cassava.

[5)] two rows of peanut were intercropped between cassava rows. After harvest of peanut the residue was used as mulch.

Source: *Chairoj Wongviwatchai, Khon Kaen Field Crops Research Center, Khon Kaen, Thailand.*

ADOPTION OF IMPROVED CULTURAL PRACTICES

During the past 35 years the Dept. of Agriculture and Kasetsart University have done intensive research on cassava breeding and agronomy with the objective of developing higher yielding varieties and cultural practices that would increase yield and protect the environment. Starting in the mid 1980s new varieties were released periodically together with information on recommended practices. In 1993 the area planted to a new variety, Rayong 3, reached 100,000 ha (Klakhaeng *et al*., 1995). With the active participation of the Dept. of Agric. Extension in varietal release sinds the early 1990s the area under new varieties and the number of farmers adopting improved cultural practices increased markedly. Data from the Dept of Agric. Extension (DOAE) revealed that in 1997 already 660,000 ha of cassava (63% of the total cassava area) were planted to newly released varieties.

Since 1994 both DOA and DOAE have been actively involved in the Nippon Foundation-supported Farmer Participatory Research (FPR) project, which involves the conducting of research by cassava farmers with the help of officials from both departments, not only on soil conservation but also on varieties, intercropping and fertilization practices.

In 1993, the recently founded Thai Tapioca Development Institute (TTDI) established a new 260 ha "Center for Cost Reduction in Cassava Production" in Huay Bong village of Nakhon Ratchasima province, with the initial objective of producing and distributing planting material of newly released varieties, and training of cassava farmers in improved cultural practices (Rojanaridpiched *et al*., 1998). From 1995 to 1999 a total of 23,413 cassava farmers had participated in 2-3 day training courses at TTDI. These courses covered all production aspects, from cassava varietal characteristics to fertilization and soil conservation. Many farmers also received planting material of new varieties. In 1999 a questionnaire was sent out by TTDI to 800 leaders of farmers groups in 32 provinces that had passed through these training courses. A total of 527 questionnaires were returned. **Table 31** summarizes the results. It is clear that many recommended practices have now been adopted, at least by the more progressive cassava farmers, including the planting of new varieties (79%), the application of chemical fertilizers (about 200 kg/ha of 15-15-15) and some organic or green manures, while about 31% of farmers used chemical weed control. Most (67%) of cassava was planted in the early dry season, and cassava was harvested on average at 10 MAP, producing a yield of 23.4 t/ha, about 50% higher than the average national cassava yield. In addition, in 2000 a total of 70 km of contour hedgerows of vetiver grass had been planted to control erosion by farmers in the FPR pilot sites. Thus, with active participation from many government departments, a non-governmental organization (TTDI) and farmers groups, the improved cassava production technologies have been widely disseminated and are now being adopted by many cassava farmers in Thailand, leading to a slow but steady increase in cassava yields, produced at highly competitive prices (**Table 32**). Unfortunately, due to the current (1999/2000) low price of cassava, this still does not produce much income for cassava farmers. But it leaves the Thai cassava farmer with at least the prospect of being able to compete in the future with other starch and animal feed raw materials on the world market.

Table 31. Agronomic practices used for cassava production in four regions of Thailand in 1999/2000, according to questionnaires returned by 527 farmers in 29 provinces.

	Northeast	Central	East	North	Whole country
1. Planting time (%)					
-early rainy season	65	65	40	80	67
-late rainy season	35	35	60	20	33
2. Harvest time					
-early rainy season planting	Dec-May	Dec-June	Dec-March	Jan-May	Dec-May
-most harvest	March	March	Jan	March	March
-late rainy season planting	Sept-Nov	July-Dec	Aug-Nov	Sept-Dec	Aug-Dec
-most harvest	Oct	Nov	Nov	Nov	Nov
3. Age at harvest (months after planting)	10.0	10.6	10.5	9.6	10.0
4. Use of new varieties (%)	79	73	91	78	79
5. Perceived use of chemical fertilizers (%)					
-most farmers use	79	44	57	77	76
-some farmers use	15	52	43	18	18
-very few farmers use	6	4	0	5	6
6. Rate of fertilizer application (kg/ha)	206	137	175	200	201
7. Type of chemical fertilizers					
-most used	15-15-15	15-15-15	15-15-15	15-15-15	15-15-15
-also used	16-8-8, 13-13-21 16-16-8, 46-0-0	16-20-0, 21-0-0 15-7-18, 13-13-21		16-20-0, 46-0-0 15-7-18, 13-13-21	16-8-8 15-7-18
8. Perceived use of organic fertilizers	some farmers	some farmers	some farmers	some farmers	some farmers
9. Type of organic fertilizers	chicken, buffalo green manure sugarcane residue	manures		manures, green manures, ami-ami	chicken manure green manures
10. Weeding (%)					
-hand labor	41	38	0	22	38
-hand labor + mechanical	32	15	29	31	31
-chemical	27	46	71	47	31
11. Average yield (t/ha)	23.3	22.7	25.0	24.3	23.4
12. Average starch content (%)	25.0	24.2	23.8	26.0	25.1
13. Sell (%)					
-fresh roots	94	91	83	69	91
-dry chips	6	9	17	31	9
14. Sell to (%)					
-drying floor	47	59	55	59	49
-local factory	53	41	45	41	51
15. Price (baht/kg)					
-fresh roots	0.66	0.64	0.65	0.62	0.65
-dry chips	1.41	1.85	1.50	1.51	1.45
Note: No. of farmers returning questionnaire	423	33	6	65	527

Source: *Adapted from TTDI, 2000.*

Table 32. Cassava production costs, gross and net income in four regions of Thailand in 1999/2000.

	Region[1]				Whole country
	Northeast	Central	East	North	
A. Production costs (baht/ha)					
1. land preparation	1,806	2,081	1,763	1469	1,781
2. planting	1,144	875	825	925	1,097
3. weeding	1,962	1,675	1,581	1,738	1,912
4. chem. fert. and application	1,806	1,281	2,125	1,450	1,733
5. other fertilizers	1,444	650	1,469	875	1,324
6. harvest	3,069	3,150	3,887	3,075	3,084
7. transport of harvest	2,625	2,344	2,856	2,575	2,604
Total variable costs	*13,856*	*12,056*	*14,506*	*12,107*	*13,535*
8. land rent	1,756	2,381	1,562	1,887	1,809
Total costs	15,612	14,437	16,068	13,994	15,344
B. Yield (t/ha)	23.29	22.67	25.00	24.30	23.40
C. Cost per tonne (baht)	670	637	643	576	656
(US$)[2]	18.12	17.21	17.37	15.56	17.72
D. Price fresh roots (baht/t)	660	640	650	620	654
E. Gross income (baht/ha)	15,371	14,509	16,250	15,066	15,304
F. Net income (baht/ha)	-241	72	182	1,072	-40

[1] Northeast: Nong Khay, Nakhon Phanom, Roy Et, Sri Saket, Mukdahaan, Khon Kaen, Chayaphum, Nakhon Ratchasima, Kalasin, Nong Bua Lamphu, Sakon Nakhon, Udon Thanii, Mahaasarakham, Buriram, Yasothon, Amnaat Charoen, Loey; Central: Suphanburii, Chainaat, Kanchanaburii, Uthay Thanii, Lopburii, Ratchaburi; East: Prachinburii, Sra Kaew; North: Pitsanulook, Utradit, Nakhon Sawan, Kamphaeng Phet

[2] in 1999/2000: 1 US$ - 37 baht

***Source:** Adapted from TTDI, 2000.*

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CASSAVA AGRONOMY RESEARCH AND ADOPTION OF IMPROVED PRACTICES IN INDONESIA – MAJOR ACHIEVEMENTS DURING THE PAST 20 YEARS

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ABSTRACT

In Indonesia, annual growth rates for cassava production and yield from 1961 to 2000 were 0.81% and 1.35%, respectively. However, the harvested area decreased at an average annual rate of 0.61%. The average yield of about 12 tonnes of fresh roots/ha is much below the potential yield of 20 to 40 t/ha obtained in experiments, indicating that cassava yields could be further increased by the adoption of improved practices.

Soil preparation using minimum tillage reduced erosion effectively and had no significant effect on root yield compared to that of complete tillage, but the control of weeds was much more difficult. Therefore, most cassava farmers prepare the soil using complete tillage. The quality of planting material used influences the final population and yield. Cuttings of 15-25 cm length planted vertically is used by most farmers even though no significant differences in sprouting capacity and root yield were observed compared to shorter cuttings of 2 to 3 nodes. It means that reducing the stake length from 25 cm to 2 nodes is a way to get more high-quality cuttings when planting material is limited. Maintaining only two stems per plant, as farmers do, produced good planting material and high root yields. Cassava planting time is affected by the cropping system, soil type and water availability. Planting cassava on medium to light textured soils could be done from the beginning to the end of the rainy season without any significant effect on root yield when plants were harvested at 8 to 12 months, since water availability of 35 to 60 mm/10 days could be maintained during the first five months.

Intercropping of cassava can result in a decrease in root yield, but this is generally compensated by the yield of the interplanted crops; therefore, intercropping cassava did not affect total crop value. Most farmers plant intercropped cassava in the early rainy season, whereas monoculture cassava is planted from the early rainy season to the early dry season, especially in areas surrounding cassava factories and near big cities. Plant spacing of cassava was determined by soil fertility, plant type, cropping system and expected yield. The optimum plant population for monoculture cassava using non- or late-branching varieties on poor and better soils are 12,000-14,000 and 10,000 plants/ha, respectively. The best plant population of branching varieties under monoculture on both poor and better soils is 10,000 plants/ha. For monoculture, farmers often use a plant spacing of 100-125 cm between rows and 75-100 cm in the row, while for intercropped cassava they plant at 200-300 cm between rows and 50-75 cm in the row. Intercropping systems of cassava with upland rice and other secondary food crops increased LER to 1.59, increased net income 15%, reduced soil erosion 20% and resulted in a B/C ratio of about 2.80. Therefore, an intercropping system of cassava + maize + upland rice or grain legumes followed by grain legumes is often practiced by farmers which have limited land and capital.

The soil fertility of cassava production areas is rather low; therefore, annual fertilization to increase soil fertility and crop productivity is generally needed. A recommended fertilization to produce 25-35 t/ha of fresh roots for monocropped cassava is 60 kg N+40 P_2O_5+60 K_2O/ha, while that for intercropping systems to produce 20-30 t/ha fresh roots, 2 t/ha dry grain of maize and rice as well as 1 t/ha of legumes is 180 kg N + 90 P_2O_5 + 180 K_2O/ha. When fertilizers were not applied

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annually, cassava yields of 25 t/ha during the first year decreased to 5 t/ha in the 8th year. Applying organic matter annually or every two years could maintain root yields of 20 t/ha, improve both soil fertility and physical conditions and increase fertilizer use efficiency. Annual fertilization of cassava is practiced by most farmers surrounding cassava factories and near big cities who grow cassava commercially, while most other farmers apply a combination of small amounts of inorganic fertilizers and farm-yard manure (FYM).

INTRODUCTION

The main goal of agricultural development in Indonesia is to increase crop production for food, feed, industrial purposes and export, and to increase farmers' income. Rice is the food crop of highest priority in the country since rice is the main staple food.

The annual growth rate in rice production during the past ten years was 1.19%, while that of rice yield was 0.94%. It means that the increase in rice production was achieved both through increasing planted area as well as yield. Increasing the rice-planting area is not easy because about 10% of the lowlands have been used for the development of non-agricultural sectors (CBS, 1998; Rusastra and Budi, 1997).

The importation of 5.8 million tonnes of rice in 1998 indicate that rice production was lower than demand; therefore, food diversification by the utilization of both maize and cassava as a substitute and supplement is the only option to maintain national food security.

The importation of about 600,000 tonnes of maize indicate that the national production of maize is also lower than domestic demand; as a consequence, food diversification depends mostly on cassava.

The annual growth rates for cassava production, harvested area and yield during the past 40 years are 0.81, -0.61 and 1.35%, respectively (FAOSTAT, 2001); thus, a significant increase in yield achieved over the years resulted in an increasing trend in production in spite of a decreasing trend in harvested area. Cassava production and harvested area fluctuated significantly, while yield tended to be more constant, indicating that annual production is mainly a function of the harvested area (Nasir Saleh *et al*., 2001). Increasing the harvested area to increase production is difficult since more than 60% of cassava production areas are located in Java, which is dominated by subsistence farmers with very small land holdings. Therefore, increasing cassava yields, or increasing the planted area in the outer islands, are the only ways to increase national cassava production.

The use of cassava for food, feed, industrial purposes and export accounts for 71, 2, 14 and 12%, respectively, of total cassava production (FAOSTAT, 2001). The national average cassava yield is 12 t/ha, but ranges from 18 to 30 t/ha for farmers that have adopted recommended technologies (Wargiono *et al*., 1995); this indicates that cassava production can be increased significantly through the development of a more intensive production system. Yield is one of the main factors determining farmers' income, so agronomy research to increase cassava yields is very important.

Cassava production areas are generally located in the uplands and are mainly dominated by soils that are low in nutrients and organic matter and susceptible to erosion while crop production is dependent on rainfall. Soil types are mainly Alfisols, Ultisols, Entisols and Inceptisols (Howeler, 1992). Cassava farmers are generally smallholders with limited labor and capital. Therefore, cassava agronomy research that aims to develop technology components that will maximize the utilization of land, labor and capital without affecting the environment is needed to support more sustainable cropping systems. Farmer traditions and socio-economic conditions are also important factors determining the adoption of technologies that will increase cassava yields.

Commercial cassava farmers tend to be more progressive and more willing and more able to adopt new technologies. However, most cassava farmers in Indonesia are subsistence farmers who are not well informed about improved technologies or are not able to adopt these technologies due to lack of technical assistance and capital.

The farmers' situation and needs (**Table 1**) are important considerations in selecting technologies for improving cassava production practices. Intercropping cassava with maize, upland rice and grain legumes are suitable cropping systems; the planting of high-yielding varieties and the use of low inputs are adoptable practices for subsistence farmers because they:

Table 1. Characteristics of cassava subsistence farmers in Central Java and Lampung provinces of Indonesia.

Items	Characteristics		Notes
	Java	Lampung	
1. Land holding			
-Lowland	0.13 ha	0.17	
-Upland	0.6 ha	0.95	60-90% in uplands
2. Family labor	2-3 persons	3-4 persons	
3. Capital	limited	limited	
4. Skill	low	low	
5. Use of fertilizers (low-medium)			
-N	90%	50%	
-N+P	70%	50%	
-N+P+K	4%	40-60%	
-FYM	80%	80%	
6. Use of new recommended clones	20-80%	60-80%	varies among regions
7. Reason for planting cassava			
-Staple food	23%	50%	
-Increase income	13%	75%	
-Low risk cropping system	5%	12%	
-Low investment	9%	20%	
-Traditional system	40%	33%	
8. Way to increase productivity			
-Use fertilizer	90%	80%	subsidies/credit
-Intercropping	89%	50%	
9. Cassava yield			
-Monoculture	11-18 t/ha	17-32 t/ha	
-Intercropping	4-15 t/ha	6-17 t/ha	
10. Adoption of technologies	partial	partial	

Source: *Bagyo, 1990; Wargiono et al., 1995.*

- reduce labor (compared to growing the crop in monoculture)

- control erosion more effectively
- increase income
- distribute income during the year (23-39% at 4, 5-21% at 8 and 45-65% at 10-12 months after planting) (Wargiono *et al*., 1995)
- maintain soil fertility (by reducing erosion and returning intercrop residues to the soil)
- increase land use efficiency (Leihner, 1983)
- reduce N fertilization (when intercropped with grain legumes)
- increase fertilizer use efficiency (Fujita and Budu, 1994)
- enhance the stability of the cropping system (by reducing risks), and
- improve the farmers' well-being (Guritno, 1989).

The objective of commercial farmers is to grow cassava in order to increase income. Therefore, they don't necessarily adopt technologies to maximize yield if the increase in production is not in balance with demand for the product. Cassava grown in monoculture with optimum inputs, as practiced by commercial farmers, can produce fresh root yields of 30 t/ha (Wargiono *et al*., 1995).

Stimulating farmers to adopt new technologies of improved varieties and cultural practices is a way to increase cassava production in order to meet the demand for food, feed, industrial purposes and export, and to increase farmers' income.

AGRONOMY RESEARCH RESULTS

Selected technology components to increase yields and income in each agro-ecological zone are: land preparation, erosion control, planting material, plant growth management through plant population and spacing, planting time, weed control, cropping systems and fertilization.

1. Land preparation

The objective of land preparation is to improve the soil structure, reduce weeds without enhancing soil degradation. Good soil preparation aims to maintain or enhance the circulation of soil O_2 and CO_2 so as to optimize plant growth.

Land preparation by twice plowing or one plowing followed by ridging in the dry season or in the early rainy season when available water is less than 75% of field capacity is recommended (Hudoyo, 1991). Disk plowing of soils that are susceptible to erosion increased soil losses significantly (Suparno *et al*., 1990) (**Table 2**); therefore, a single plowing followed by ridging along the contour is advised to reduce erosion.

Strip tillage controlled erosion effectively and reduced by more than 50% the cost of soil preparation without decreasing root yields significantly when weeds were controlled effectively (Wargiono, 1990) (**Table 2**); however, this is not practiced by farmers because it makes controlling weeds more difficult. Therefore, complete tillage of soils susceptible to erosion should be followed by the adoption of erosion control practices, such as contour ridging, hedgerows, mulching, fertilization and intercropping.

2. Erosion control

Soil erosion is often the main cause of soil degradation and is affected by climate, topography, vegetation and type of soil as well as by human activities (Suwardjo and Sinukaban, 1986). **Table 3** shows that under the climatic and soil conditions of Lampung, Sumatra, cassava grown in monoculture, either with or without fertilizers, caused more serious erosion than two successive crops of maize, peanut, soybean or one crop of rice followed by soybean. Among the various crops, peanut caused the least erosion. Fertilizer application reduced the amount of soil loss in all crops by enhancing rapid canopy formation. Cassava production areas are dominated by soils susceptible to erosion, but most subsistence farmers are not concerned about controlling erosion. Therefore, the development of simple technology components to control erosion, which can be adopted by both subsistence and commercial cassava farmers, is urgently needed.

Table 2. The effect of soil preparation on cassava yields and soil loss due to erosion in Lampung in 1990.

Soil preparation	Cassava yield (t/ha)	Dry soil loss (t/ha)
1. Rome harrow; disk plow followed by contour ridging	25.4 a	89.7 ab
2. Rome harrow; disk plow followed by up-down ridging	25.9 a	88.5 ab
3. Rome harrow; disk plow followed by diagonal ridging	23.8 a	107.8 a
4. Rome harrow; contour ridging	23.5 a	66.8 b
5. Rome harrow; up-down ridging	25.2 a	68.1 b
6. Rome harrow	19.0 b	30.8 c
1. Full tillage (twice hoeing of whole area)	14.3 a	10.3
2. Strip tillage (twice hoeing in 40 cm strips in cassava row	15.0 a	7.6

Source: *Suparno et al., 1990; Wargiono, 1990.*

Table 3. Effect of various crop and cropping systems on dry soil losses due to erosion and on net income during an 8 month cropping cycle on 5% slope in Tamanbogo, Lampung, Indonesia. Data are average values for two years (1994-1996).

	Dry soil loss (t/ha)	Net income ('000 Rp/ha)
Without fertilizers		
Cassava	41.92	322
Rice-soybean	26.29	570
Maize-maize	30.64	159
With fertilizers		
Cassava	29.06	804
Rice-soybean	24.31	1477
Maize-maize	24.98	892
Peanut-peanut	17.92	2488
Soybean-soybean	27.61	2031
Cassava+maize+rice-soybean	19.60	1301

[1] Net income = total crop value minus fertilizer costs.

Source: *Howeler, 1998.*

The adoption of erosion control technology components practiced by farmers depend on their capability to produce sufficient food, feed or cash income. Technology components that are adopted by most farmers include intercropping, ridging and planting hedgerows with elephant grass. These technology components are able to improve soil physical conditions and soil fertility, increase income, and/or produce biomass for animal feeding (Wargiono *et al*., 1995); therefore, these cropping systems are sustainable. **Figure 1** shows that for the first 1-2 years hedgerows reduced cassava yields, but that after 3-4 years of cropping hedgerows of leguminous tree species, like *Leucaena leucocephala, Gliricidia sepium* or *Flemingia macrocarpum*, resulted in higher yields and less erosion than hedgerows of elephant grass or no hedgerows. Thus, farmers may have to weigh short-term benefits against long-term sustainability.

The capability of crops to minimize erosion depends on the crop's canopy diameter to cover the soil surface, which is affected by soil fertility, cropping system and plant spacing. The greater the canopy diameter and the closer the plant spacing the more the soil is protected from the direct impact of falling raindrops, and the lower the erosion. Therefore, fertilizer application, intercropping with maize, rice and peanut (**Table 4**), and the planting of contour hedgerows (**Figure 1**) are effective erosion control measures. Planting upland rice, maize or peanut with adequate fertilization resulted in 10 and 20% less soil loss than planting cassava, whereas fertilizer application of cassava reduced soil erosion 12% compared to the unfertilized crop (**Table 4**). Even though fertilizer application is very effective in controling erosion and may increase gross return from 40 to more than 400%, most farmers do not apply fertilizers at optimum rates due to limited capital. Therefore, intercropping cassava with peanut (source of biological N fixation) and the application of low to medium rates of fertilizers is an improved practice that is more easily adopted by subsistence farmers. The planting of contour hedgerows of leguminous tree species such as *Gliricidia sepium* or *Leucaena leucocephela* is another practice that is being adopted by some farmers. The capacity of this system to reduce erosion tends to increase over time as the cassava growth rate is increased due to an improvement in soil fertility and soil physical conditions as a result of the addition of hedgerow prunings (Wargiono *et al*., 1998). These hedgerows produce biomass for either feed or mulch and are thus more easily adopted by poor farmers.

3. Planting material

The planting of high-yielding varieties is a technology component that is easily adopted by farmers, as it is cheaper than other technology components for increasing cassava yields. But, only about 20% of subsistence farmers grow new recommended varieties (Bagyo, 1990). The bulkiness of planting material is a serious limitation in the dissemination of new recommended varieties, because the cost of both production and transport of planting material is much higher than that of grain crops. This problem can be partially overcome by the use of planting stakes with only 1-3 nodes (Cock *et al*., 1978).

The quality of planting material influences the final plant population and thus yield (Lozano *et al*., 1977). Sprouting capacity (or germination) depends on the source as well as on the length and size of stem cuttings. Young cassava stems (top parts) have a high water content and dehydrate rapidly when cut for use as planting material; so, the sprouting capacity of stakes produced from young stems is lower than those from older stems (from bottom to middle parts). The sprouting capacity of older stems was not significantly different for stakes ranging from 1.5 to 4.0 cm in diameter (**Table 5**); therefore, farmers are advised to use the middle or lower parts of the stems as planting material.

In case the number of available stakes is limited, stakes of 2-3 nodes could be either planted directly in the field or be transplanted after 7-10 days in the nursery where stakes are placed on wet paper towels to stimulate the growth of roots and sprouts (Wargiono *et al*., 1992).

Table 4. Effect of intercropping systems, cassava plant spacing and fertilizer application on total crop value, net income and dry soil loss due to erosion when cassava was grown on 5% slope in Tamanbogo, Lampung, Indonesia. Data are average values for four cropping cycles (1987-1991).

Treatments[1)]	Total crop value (‘000 Rp/ha)	Net income[2)] (‘000 Rp/ha)	Dry soil loss (t/ha)
A. Without fertilizers			
1. Cassava monoculture (1.0 x 1.0 m)[3)]	744.1	744.1	24.80
2. C+M+R-P (2.0 x 0.5 m)	968.7	938.7	19.02
3. C+M+R-P (2.73 x 0.6 x 0.6 m)[4)]	1,025.6	955.6	20.14
Average	912.8	879.5	21.32
B. With fertilizers[5)]			
4. Cassava monoculture (1.0 x 1.0m)	1,042.6	939.1	21.79
5. C+M+R-P (2.0 x 0.5 m)	1,417.1	1,179.4	18.30
6. C+M+R-P (2.73 x 0.6 x 0.6 m)	1,464.1	1,226.4	19.97
Average	1,307.9	1,115.0	20.02
7. R-C (1.0 x 1.0 m)	494.7[6)]	307.6	17.90
8. M-C (1.0 x 1.0 m)	658.9[6)]	471.8	19.47
9. P-C (1.0 x 1.0 m)	816.1[6)]	661.9	19.02

[1)] C = cassava, M = maize, R = upland rice, P = peanut.
C+M+R-P indicates cassava intercropped with maize within the row, upland rice between rows, which, after harvest is followed by peanut.
R-C indicates monoculture upland rice followed by monoculture cassava.
[2)] Net income = total crop value minus fertilizer costs.
[3)] Planting distance for cassava.
[4)] Cassava planted in double rows, with 0.6 m between rows and 2.73 m between adjacent double rows (3.33 m between centers of double rows).
[5)] Fertilizers: 90-30-90 for cassava/maize; 60-40-60 for rice; 30-30-30 for peanut.
In first year rice and peanut received fertilizers in T_2 and T_3, but not in subsequent years.
[6)] Low total crop value due to very low yields of the cassava relay crop.

4. Plant growth management

Biomass production depends on the crop growth rate (CGR), while CGR depends on the net assimilation rate (NAR), as well as the leaf area index (LAI). The CGR can be increased either through a greater LAI or greater NAR, but when shading occurs as a result of increasing the leaf area index the light interception decreases resulting in a decrease in NAR (Hozyo *et al*., 1984). An optimum LAI of 3.5 could be obtained by the use of an optimum plant population and by controlling the number of shoots as well as the number of leaves per plant (Hozyo *et al*., 1984).

Higher root yields were obtained with two stems/plant compared to either one or three stems/plant (**Table 6**); with two stems the leaf blades overlapped only slightly resulting in an optimum capacity to intercept sunlight. The obtaining of an optimum LAI through plant population arrangement is affected by soil fertility as well as the branching habit of the variety (Wargiono, 1990). When the LAI is higher than 3.5, removing the lower (older) leaves by no more than 25% of the total number of leaves is a way to reduce the LAI and this may result in an increase in yield; the removed leaves can be used as animal feed (Sugito, 1990).

Technology components to obtain high CGR through LAI management are:

- maintaining two stems or shoots/plant (Wargiono and Sumaryano, 1981)
- removing the lower leaves by no more than 25% of the total number of leaves per plant when the LAI is higher than 3.5 (Sugito, 1990)
- using a population of 10,000 plants/ha of branching varieties on both poor and fertile soils; using a population of 12,000 to 14,000 plants/ha of non-branching varieties on poor soil and 10.000 plants/ha on fertile soils (Wargiono, 1990)
- using a plant spacing for monoculture of 100 x 100 cm, 125 x 80 cm or 100 x 80 cm; and 125-300 cm between rows and 50-80 cm in the row for intercropping systems (Wargiono, 1990).

5. Planting time

The maximum crop growth rate (CGR) occurs at about 5-6 months after planting (MAP) (Hozyo *et al*., 1984). As cassava growth depends greatly on water availability, crop productivity is affected mainly by water availability during the first six months as well as during the last two months, just before harvest. Most farmers avoid stand failure by planting cassava at the beginning of the rainy season and harvesting in the dry season; this leads to an excess of cassava roots at that time, resulting in a decrease in price of cassava and thus a decrease in farmers' income. However, the farmer's flexibility is limited as the root starch content will decrease if the harvest is delayed to more than 10 months for early harvestable clones, and to more than 12 months for medium and late harvestable clones, especially when the harvest takes place at the start of the rainy season.

The best way to solve this problem is to move the harvest time by changing the planting time according to the rainfall distribution or soil water availability. The yield of cassava is highly correlated with soil moisture during the first six months; high yields can be obtained when the rainfall is more than 35 mm/10 days and is well distributed up to harvest time (Wargiono, 1991). **Table 7** shows that moving the planting and harvesting time has a significant effect on yield but can improve the year-round supply of cassava roots produced, and result in higher prices paid to the farmer. **Table 8** shows that the yield

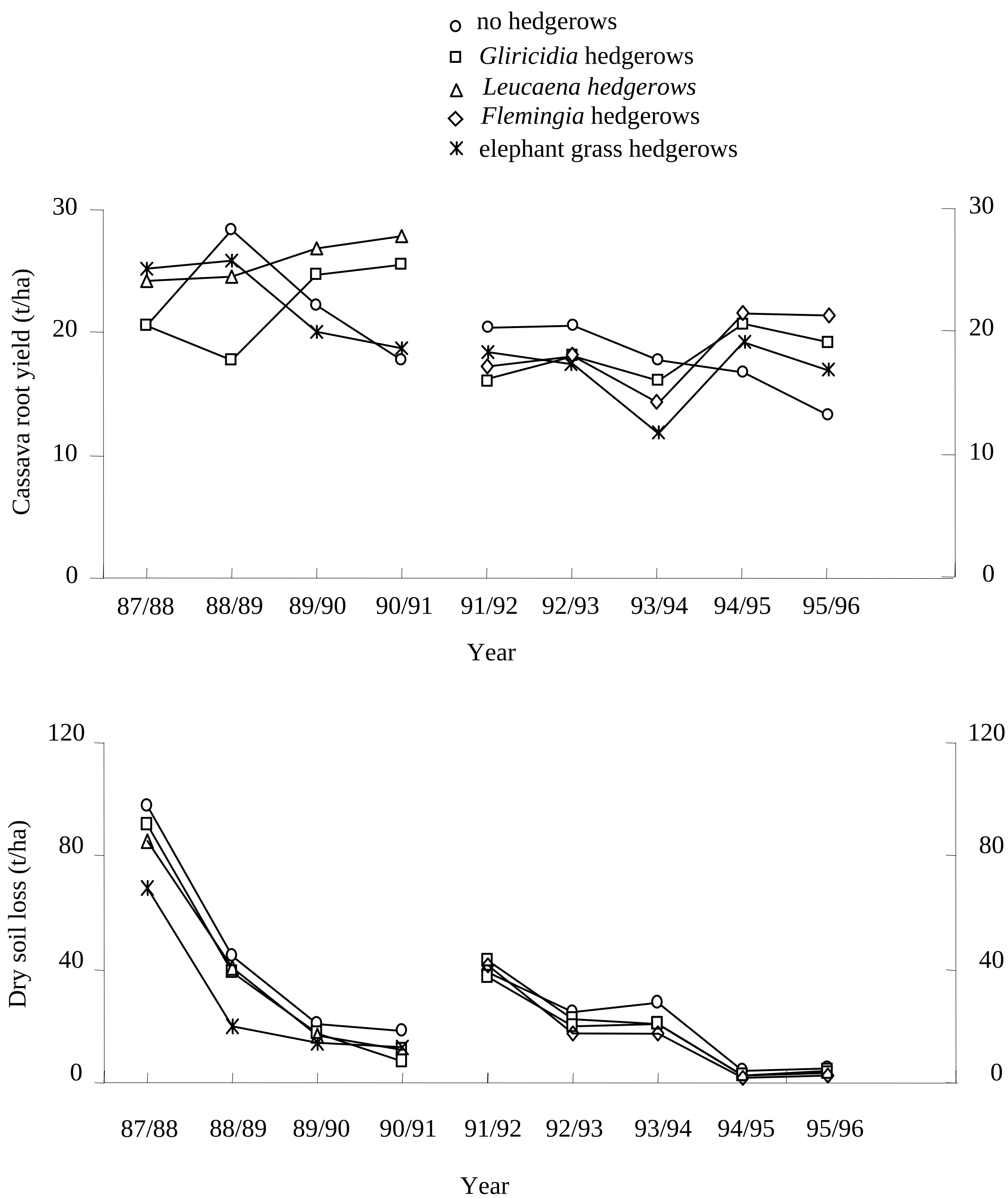

Figure 1. Effect of various types of contour hedgerows on cassava yield and soil loss due to erosion when cassava and maize were intercropped during nine consecutive years on 8% slope in Jatikerto, Malang, Indonesia, from 1987 to 1996.
Source: *W.H. Utomo, personal communication.*

of intercropped cassava decreased with a delay in planting time as the competition from interplanted crops (planted in Dec) increased, resulting in a CGR of cassava during the first two months that was lower than that of the interplanted crops. This decrease in cassava yield was partially compensated for by an increase in the yield of the interplanted crops; however, it was also influenced by the type of soil. Delaying the planting of cassava in intercropping systems in soils that become hard in the dry season (Alfisols in Yogyakarta) is not recommended as the decrease in cassava yield was not compensated by an increase in yield of interplanted crops (**Table 8**). Delaying planting time in lighter soils (Utisols) in Lampung did not significantly affect the total crop value, because the decrease in cassava yield was mostly compensated by an increase in the yields of interplanted crops; therefore, this technology component could be adopted by farmers.

Table 5. Effect of source of planting material and size of stakes on germination and cassava yield in Bogor, West Java, in 1980 and 1989.

Source/size	Germination (%)	Fresh root yield	No of planting stakes produced (# stakes/plant)
***Bogor, 1980*[1)]**			
Stakes diameter (10-12 nodes)		(t/ha)	
1.5-2.0 cm	97-100	26.6	
2.1-2.6 cm	97-100	22.2	
2.7-3.0 cm	97-100	22.5	
3.1-3.5 cm	97-100	25.3	
3.6-4.0 cm	97-100	23.6	
***Bogor, 1989*[2)]**			
Young stem (top part)		(kg/plant)	
one node	10.0 a	1.53 a	6.2 a
two nodes	33.3 b	2.81 ab	8.1 a
three nodes	30.0 b	3.47 ab	9.2 a
Older stem (lower part)			
one node	66.7 c	3.08 ab	11.8 ab
two nodes	96.7 d	3.21 ab	12.6 abc
three nodes	96.6 d	3.92 b	18.2 bc
10-12 nodes	100.0 d	3.85 b	20.3 c

Source: [1)] *Wargiono and Sumaryono, 1981; Wargiono, 1990.*
[2)] *Wargiono et al., 1992.*

6. Weed Control

The growth rate of cassava during the first two months is lower than that of weeds, so weed control is as important as other management practices, such as choice of varieties, stand establishment and fertilizer application. In fact, without adequate weed control the use of other improved cultural practices will generally lead to disappointing yields. Effective weed control is the first step towards reducing competition from weeds for light, water and nutrients, thereby improving cassava yields in the uplands.

Weed control is traditionally done by hand weeding. The number of weedings necessary for cassava varies considerably, depending on the weed population, soil fertility, rainfall, cropping system and the response of particular varieties to competition from weeds. The fact that hand weeding can double root yields compared to that of unweeded plots indicates that effective weed control is a very necessary cultural practice (Bangun, 1990).

The use of herbicides by farmers is increasing in areas with limited available labor; the kind of herbicides used depends on the predominant weed species. Weed populations can also be reduced by increasing the diameter of the cassava canopy so as to increase the plant's light interception through fertilizer application, optimum plant population, and by intercropping or mulching. **Table 9** shows that hand weeding 2 to 3 times increased the root yield 43% compared to the control, whereas using herbicides increased the yield 62 to 100% (Bangun, 1990).

Table 6. Effect of stem number and the removal of leaves on cassava fresh root yield in Bogor, West Java in 1980, and in Malang, East Java in 1988.

Stem number/leaves removed per plant	Cassava fresh root yield (t/ha)
Bogor, West Java[1]	
Number of stems/plant	
-One stem	15.08
-Two stems	20.39
-Three stems	17.95
Malang, East Java[2]	
Leaves removed	
-0%	48.44
-25%	51.07
-50%	49.33
-75%	47.30

Source: [1]*Wargiono and Sumaryono, 1981.*
[2]*Sugito, 1990.*

Table 7. Effect of planting time and age at harvest on cassava yields when planted in monoculture in Lampung in 1988. Data are average values for three varieties.

Planting time (month)	Fresh root yield (t/ha) 6 MAP	8 MAP	10 MAP
February	17.2 a	30.7 a	34.6 a
March	17.7 a	27.4 ab	21.2 b
April	15.0 a	24.5 ab	27.0 ab
May	14.6 a	25.2 ab	26.4 ab
June	16.2 a	18.4 b	19.4 c

Source: *Wargiono, 1990, 1991.*

Table 8. Effect of time of planting cassava relative to that of intercropped rice on the yields of cassava and the intercrops when cassava was intercropped with rice followed by mungbean in Yogyaharta, and rice followed by soybean in Lampung in 1991/92.

Planting time of cassava[1)]	Yield (t/ha)				Total crop value[2)]
	Cassava	Rice	Mungbean	Soybean	('000 Rp/ha)
A. Yokyakarta					
December	18.46	1.98	0.25	-	1483.4
January	11.07	2.17	0.42	-	1405.3
February	8.03	2.37	0.47	-	1383.7
March	4.74	2.37	0.55	-	1332.1
B. Lampung					
December	39.78 a	1.68	-	0.28	2235.2
January	37.74 a	2.11	-	0.34	2309.1
February	28.95 b	2.17	-	0.36	1988.5
March	21.29 c	2.18	-	0.44	1748.6

[1)]Rice intercrop planted in Dec 91 in all treatments; mungbean or soybean planted in April 92 for all treatments; cassava harvested at 8 MAP (Aug-Nov '92)

[2)]Prices:cassava: Rp 40/kg fresh roots
rice: 250/kg dry grain
mungbean: 1000/kg dry grain
soybean: 800/kg dry grain

Source: *Wargiono et al., 1997.*

Table 9. Effect of methods of weed control on cassava fresh root yields in two experiments conducted in Lampung in 1985 and in 1989.

Weed control method	Root yield (t/ha)
1. Lampung, 1985[1)]	
Control (no weeding)	6.0
Hand weeding at 30, 60, 90 DAP	25.3
Gesapax 80 WP: 1.5 k/ha at 1 DAP	9.3
Laso 4l/ha at 4 DAP	6.4
2. Lampung, 1989[2)]	
Control (no weeding)	11.0 b
Hand weeding at 30 and 60 DAP	15.7 ab
Paraquat 1.25 l/ha at 30 DAP	17.8 ab
Paraquat 2.50 l/ha at 30 DAP	17.4 ab
Paraquat 3.75 l/ha at 30 DAP	18.8 ab
Paraquat+Diuron: 1.25 l/ha at 30 DAP	17.8 ab
Paraquat+Diuron: 2.50 l/ha at 35 DAP	17.4 ab
Paraquat+Diuron: 3.75 l/ha at 30 DAP	21.9 a

Source: *[1)]Wargiono and Bangun, 1986.*
[2)]Bangun, 1990.

7. Cropping System

In Indonesia cassava is planted in monoculture only around urban areas and starch factory plantations, as well as in non-productive land, which cannot be planted with other food crops. Most farmers, however, plant cassava intercropped with other food crops, since this will enable them to increase their land use efficiency and income, improve the soil's physical and chemical conditions and reduce erosion (Guritno, 1989; Wargiono, 1993; Wargiono *et al*., 1998). Intercropping systems practiced by farmers yielded 10% and 20% higher gross income under experimental conditions as compared to the monoculture system, with a B/C ratio of more than 2.0; this indicates that intercropping cassava is a feasible and adoptable system for resource poor farmers (Bagyo, 1990; Wargiono, 1993). Therefore, more than 80% of farmers in the main cassava production areas have adopted intercropping systems to increase their incomes (Bagyo, 1990).

Sustainable upland cropping systems can be achieved by choosing suitable varieties and management practices that increase nutrient use efficiency without degradation of the environment.

Adira 1 is a cassava variety which is suitable for intercropping systems as it is characterized by a non-branching or late branching plant type, high starch content, high leaf area index (which could be maintained during 42 weeks) and a high CGR (Hozyo *et al*., 1984; Wargiono, 1991).

The optimum cassava plant population for cassava intercropped with other food crops is 10,000 plants/ha, and the optimum total level of fertilizer application maybe as high as 180 kg N, 90 P_2O_5 and 180 K_2O/ha (Leihner, 1983; Wargiono *et al*., 1995; 1998). The problem is that farmers generally lack capital to buy fertilizers.

N obtained through biological nitrogen fixation (BNF) of the intercropped legumes is an important resource for cassava intercropped with legumes, especially when N-fertilizer or soil-N are limited. It has been reported that interplanted legumes reduced the loss of soil-N by about 50% and fixed 24 kg N/ha (Fujita and Budu, 1994). For that reason, cassava intercropped with maize or upland rice and maize followed by peanut at optimum plant population and fertilization yielded a high Land Equivalent Ratio (LER) and gross income (**Table 10**).

Intercropping cassava with other food crops generally increases LER and total crop value, it reduces both nutrient loss and erosion and it minimizes the risk of crop failure; this indicates that the adoption of this technology component would considerably improve the sustainability of the cropping system, optimize the use of land, water and sunlight, and increase farmers' income.

8. Fertilization

Cassava growth is often inhibited and leaves may show deficiency symptoms when the contents of available nutrients in the soil are below the critical level. Wargiono *et al*.,(1997) reported critical levels of 3.3 to 5.2 ppm for available P and 0.13 to 0.19 me/100 g for exchangeable K. When this is the case, crop growth can be improved by adding nutrients to the soil. The crop’s ability to absorb soil nutrients is affected by the type of soil and the fertilizer applied, the responsiveness of the variety, the crop's general condition, the cropping system and the availability of other nutrients (Howeler, 1981; Wargiono, 1988; Widjaya *et al*., 1990).

Table 10. Land use efficiency and total crop value with different intercropping systems of cassava in CIAT, Cali, Colombia (1979) and in Bogor, W. Java, Indonesia (1991).

Cropping system[1)]	Cassava[2)] planting time	Cassava population ('000/ha)	Fertilization[3)]	Land Equivalent Ratio
Colombia[4)]				
C+Cp	-3	10	F	1.5
C+Cp	0	10	F	1.8
C+Cp	+3	10	F	1.4
Bogor[5)]				
C+P-Mb	0	10	UF	1.9
C+P-Mb	0	10	F	2.1
C+R+M-P	0	10	UF	1.6
C+R+M-P	0	10	F	2.1

[1)]C=cassava; Cp=cowpea; M=maize, P=peanut; Mb=mungbean
[2)]-and +: months before and after intercrop planting, respectively; 0:planted at the same time
[3)]F=fertilized; UF=unfertilized
Source: *[4)]Leihner, 1983; [5)]Wargiono, 1991.*

The amounts of nutrients removed by cassava roots are generally rather low compared to those removed by other crops (Howeler, 2001), but can be relatively high when yields are high or when stems and leaves are also removed (Wichmann, 1992; Howeler, 2001). For that reason, soil fertility will decrease with time if cassava is planted continuously without any addition of nutrients to the soil. Potassium is the nutrient removed by cassava in greatest quantities, so the amount of K added to the soil should be higher than those of other nutrients. However, if K is added to the soil in very large amounts this may decrease Mg and Ca uptake and *vice versa*, due to antagonism among these three cations; therefore, if inorganic NPK fertilizers are applied continuously this may reduce the available Ca and Mg in the soil (Nayar *et al*., 1995). Addition of organic manure or compost and application of balanced NPK fertilizers minimized this antagonistic effect among the cations (Nayar *et al*., 1995) and resulted in a significant increase in yield (**Table 11**). Application of farm-yard manure (FYM) is practiced by most farmers, but that of balanced NPK fertilizers is not yet widely practiced. Adoption of this technology component is a way to increase cassava production and farmers' income (Bagyo, 1990, and Wargiono, 1993).

The amounts of nutrients removed by food crops intercropped with cassava is relatively high, but part of these nutrients (46% of N, 33% of K, 85% of Ca, and 73% of Mg) may be returned to the soil with the crop residues (Wichmann, 1992). Therefore, harvesting and removing all plant parts will increase the soil fertility decline over time if no fertilizers are applied. Fertilizer application and reincorporation of crop residues of both cassava and interplanted crops can maintain the fertility status of the soil. If the level of soil K is low this could be improved by returning the residue of interplanted rice, since 93% of K absorbed by rice is concentrated in the straw (Wichmann, 1992).

Table 11. Effect of application of organic matter and inorganic NPK fertilizers on the Total crop value in two different cropping systems in Lampung, 1993.

Treatment	Total crop value (‘000 Rp/ha)	
	Monoculture	Intercropping
Without organic matter		
-Without NPK	480	525
-With NPK	653	702
With organic matter		
-Without NPK	778	1,008
-With NPK	1,037	1,253

Source: *Wargiono, 1986.*

Application of organic matter in each growing season also improved the soil physical conditions, such as bulk density, infiltration rate and aggregate stability (Wargiono *et al*., 1995). Reincorporation of crop residues is, therefore, a technology component that will help maintain soil fertility and increase fertilizer use efficiency.

For soils that are low in P and K, the application of a balanced NPK fertilizer is an effective way to increase cassava yields and farmers' income. Intermediate levels of application, such as 90 kg N, 25 P_2O_5 and 60 K_2O/ha for cassava grown in monoculture (Wargiono *et al*., 1998) and higher rates, such as 90-120 kg N, 50 P_2O and 90-120 K_2O/ha for cassava grown in intercropping systems will tend to maintain stable yields of both cassava and interplanted crops (**Figure 2**), provide the highest gross and net income (**Figure 3**), and can generally maintain soil fertility (**Figure 4**). The B/C ratio of this technology component is usually above 2.0, and is, therefore, a feasible and adoptable practice.

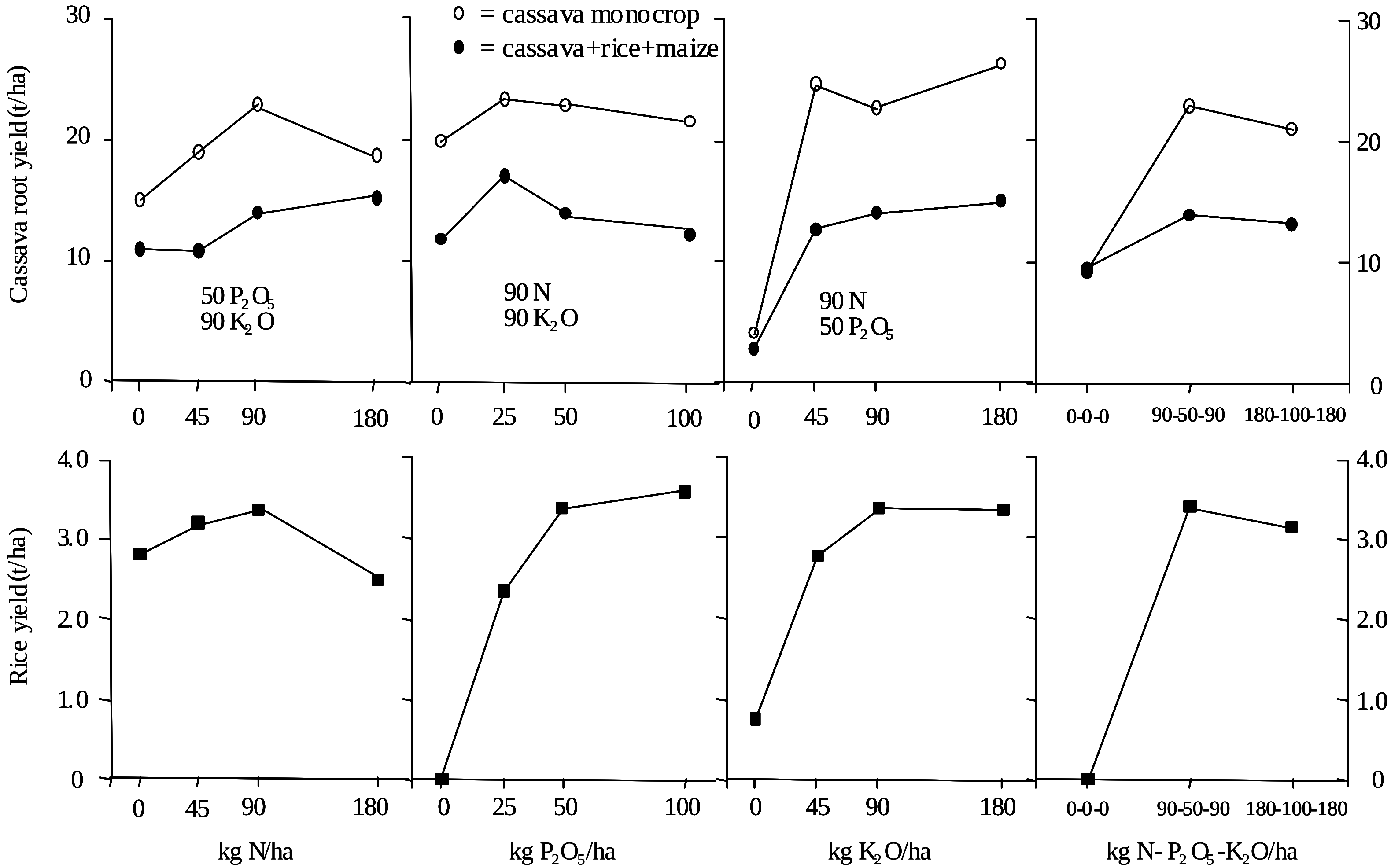

Figure 2. Effect of annual applications of various levels of N, P and K on the yields of cassava (both monocropped and intercropped with rice and maize) and upland rice during the 9th consecutive cropping cycle in Tamanbogo, Lampung, Indonesia, in 1999/2000. Note: maize yields were zero.

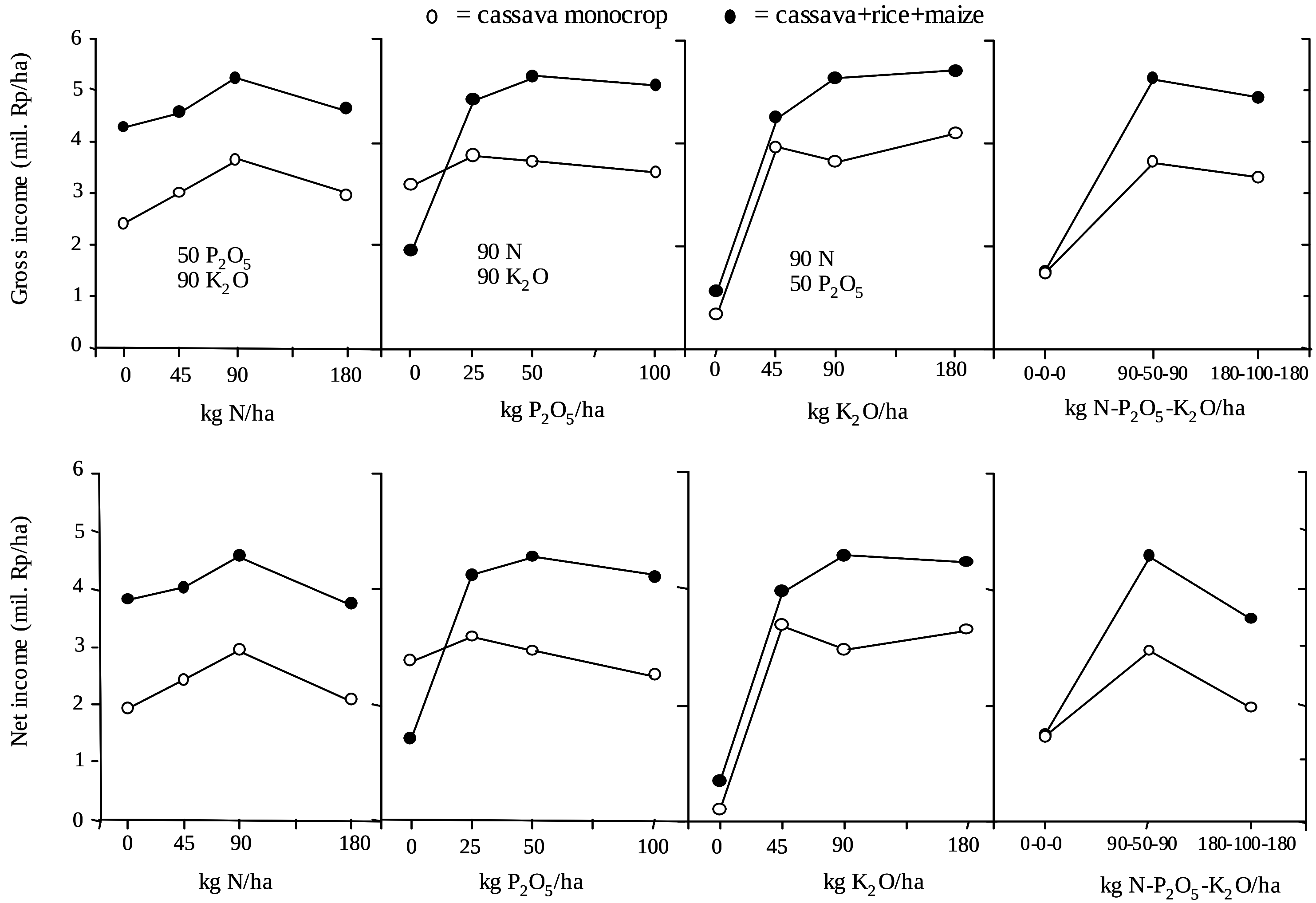

Figure 3. Effect of annual applications of various levels of N, P and K on the gross and net incomes obtained when cassava was monocropped or intercropped with rice and maize during the 9th consecutive cropping cycle in Tamanbogo, Lampung, Indonesia, in 1999/2000. Note: maize yields were zero.

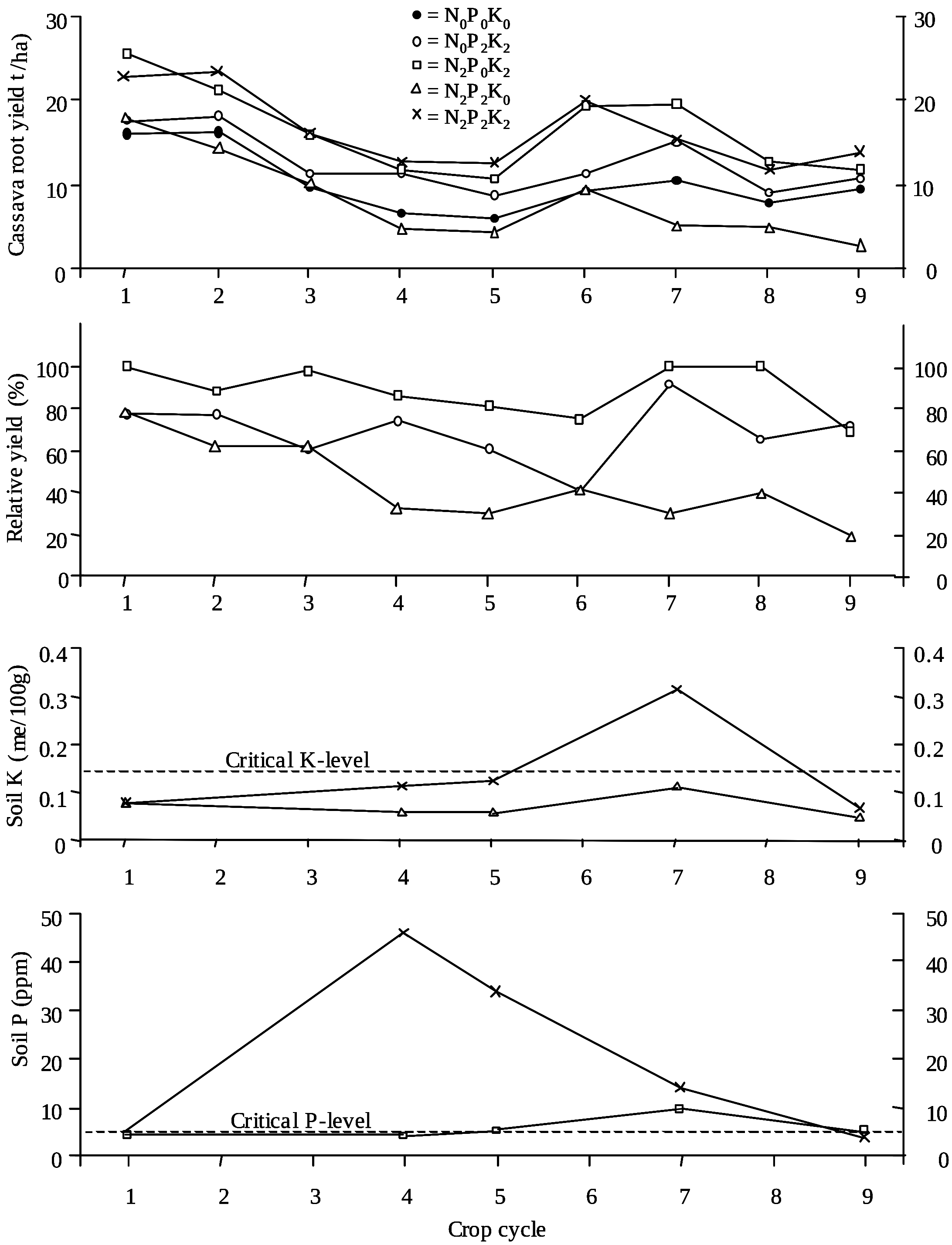

Figure 4. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during nine years of continuous cropping (cassava intercropped with upland rice and maize) in Tamanbogo, Lampung, Indonesia.

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CASSAVA AGRONOMY RESEARCH AND ADOPTION OF IMPROVED PRACTICES IN INDIA - MAJOR ACHIEVEMENTS DURING THE PAST 30 YEARS

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ABSTRACT

Over the past 25-30 years, cassava agronomy research in India has made tremendous progress. In the recent past there has been a steady increase in the cultivation of cassava in non-traditional areas, despite the fact that cereals form the major crop and staple food of the country. There has been a marked increase in the number of cassava-based industries in states like Tamil Nadu and Andhra Pradesh, which is responsible for the expansion of the area under cassava in those states. Compared to 1980/81 the cassava area in Andhra Pradesh increased by 40% and in Tamil Nadu by 34%. In the state of Kerala, where cassava is traditionally grown for food, the cassava area decreased considerably (46%) due to farmers' preference for more remunerative plantation crops like rubber and coconut. A shift in the traditional cropping pattern, however, could also be noted in Kerala where rice in the lowlands is now being replaced by cassava, as the latter produces more income than the former. The yield of cassava has been almost static in the range of 19 to 23 t/ ha in Kerala, about 7 to 10 t/ha in Andhra Pradesh, and 36-37 t/ha in Tamil Nadu, which has the highest yield in the world.

Extensive research on cassava's nutritional requirements, agro-techniques, cropping systems and a long-term fertilizer trial have been conducted during the past three decades. Under rainfed conditions the best time of planting was found to be April-May; however, under irrigated conditions, it can be planted during any part of the year. Pit followed by mound has been identified as the best method for planting cassava stakes, using a spacing of 90x90 cm. Removing all but two healthy shoots on opposite sides of the stem has been found to increase yields. Investigations on the use of cassava plants as an alternate source for rearing eri silk worms revealed that the cassava root yield was adversely affected by this practice. Irrigating the crop at 25 per cent available soil moisture depletion level during the growth period could double the root yield. Supplementary irrigation at IW/CPE ratio=1.0 increased the root yield by 90 per cent over the rainfed crop.

Continuous application of NPK fertilizers did not significantly effect soil pH, but the available nutrient status of the soil was considerably enhanced, while the build-up of P was excessively high. An appreciable increase in the soil pH (4.7 to 6.1) was noticed in the treatment that received continuous applications of wood ash. Organic carbon content of the soil was found to increase in the plots that received farm-yard manure (FYM). When chemical fertilizers were applied regularly, the Cu and Zn status of the soil declined, but these deficiencies were not observed in plots that received FYM in addition to NPK. It was further revealed that the N and K requirement of the crop was in the ratio of 1:1. Liming at a rate of 2 t CaO/ha was found to be effective in increasing root yields in very acid soils. Application of sulfur resulted in an increase in starch and a decrease in the HCN content of roots. Significant responses to soil application of the micronutrients Zn, B and Mo were also observed.

Cropping systems research has shown that short-duration (seven months) cassava varieties can be grown successfully in a rice-based cropping system. Cowpea and groundnut were found quite remunerative as intercrops in cassava. Incorporation of cowpea as green manure *in situ* at time of planting cassava was found to be as effective as the application of FYM; in addition, it also reduced the N requirement by 50%.

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Cassava stems stored vertically gave better sprouting on planting as compared to those stored horizontally. Cassava stems of 7-11 months age and having a diameter of 2-4 cm were ideal as planting material. In non-traditional areas where rainfall is limited to 4-5 months per year, planting of cassava stakes in nursery beds at very close spacing, followed by transplanting at 20 DAP, was found to be quite effective in ensuring uniform establishment of the crop while also enhancing the eradication of cassava mosaic disease.

When cassava was grown on slopes, planting on staggered mounds reduced soil loss due to erosion by 40-50%. When cassava was grown in a multitier cropping system, its association with banana or coconut was found to be beneficial; however, when grown with eucalyptus or leucaena, the root yields were reduced by 60-80%.

Pruning the crop at eight months and thereafter retaining the crop for another eight months resulted in a two-fold increase in yield over the normal harvest.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) had been introduced into India by Portuguese merchants in the 17th century, and has since become a popular root crop. It is commonly known as tapioca in India. The crop has historical and sentimental value in Kerala state, which is indebted to her erstwhile ruler, King Visakham Thirunal, who was responsible for introducing the crop in India. Furthermore, this crop has saved many lives during an acute famine that gripped the state in the early part of the 20th century. The popularity of the crop later spread to neighboring states; however, not as a food crop but as a crop of industrial significance.

CLIMATE AND SOIL

In India, cassava cultivation is confined mainly to the southern states, which have a sub-tropical climate. Kerala receives a mean annual rainfall of about 3000 mm (**Figure 1**), well distributed over a period of 7-8 months, extending from April to November.

Nearly 60% of the annual precipitation is received during the southwest monsoon (May to Aug), and the rest during the northeast monsoon (Sept to Nov) (**Figure 2**). In the cassava-growing belt of Tamil Nadu, however, the annual rainfall on average is about 800-900 mm only. A major portion of this rainfall is received during the northeast monsoon.

Cassava is mainly grown on laterite soil (Ultisols) in Kerala, apart from forest soil (Mollisols) and red soil (Alfisols). In Tamil Nadu, the major soil groups under cassava are red soil (Alfisols) and black soil (Vertisols). In Andhra Pradesh, cultivation is mainly confined to the alluvial (Entisols) and red soils (Alfisols).

RESEARCH ACCOMPLISHMENTS

Extensive research has been done on cassava agronomy in India over the past three decades, mainly by the Central Tuber Crops Research Institute (CTCRI), located at Trivandrum in the major cassava-growing state of Kerala. The other leading institutions where cassava research is being carried out are the Kerala Agricultural University (KAU) and the Tamil Nadu Agricultural University (TNAU), Coimbatore. A brief review of the major research achievements is given below:

1. Planting

1.1 Time of planting

Cassava is mostly cultivated as a rainfed crop; however, if irrigated, it can be grown throughout the year. As a rainfed crop, the best time to plant cassava in Kerala is from April to May, with the onset of pre-monsoon showers. The next best season is from Aug to Sept, with the onset of the northeast monsoon. The effect of time of planting on root yield is presented in **Figure 2** (CTCRI, 1980).

1.2 Land preparation and planting

The physical conditions of the soil influence plant growth and development, and hence proper tillage is necessary for realizing the full yield potential of the crop. A study on the effect of deep and shallow tillage – either by tractor-plowing or by manual labor – did not show any significant difference in yield. One to three earthings up during weeding at monthly intervals, starting from 30 days after planting, significantly increased root yield as compared to the treatment where no earthing up was carried out (**Table 1**). Maximum root yield was obtained with three earthings up, but considering the cost involved, two earthings up at the second and third month stages of the crop were found to be more economical (Mandal and Mohankumar, 1973).

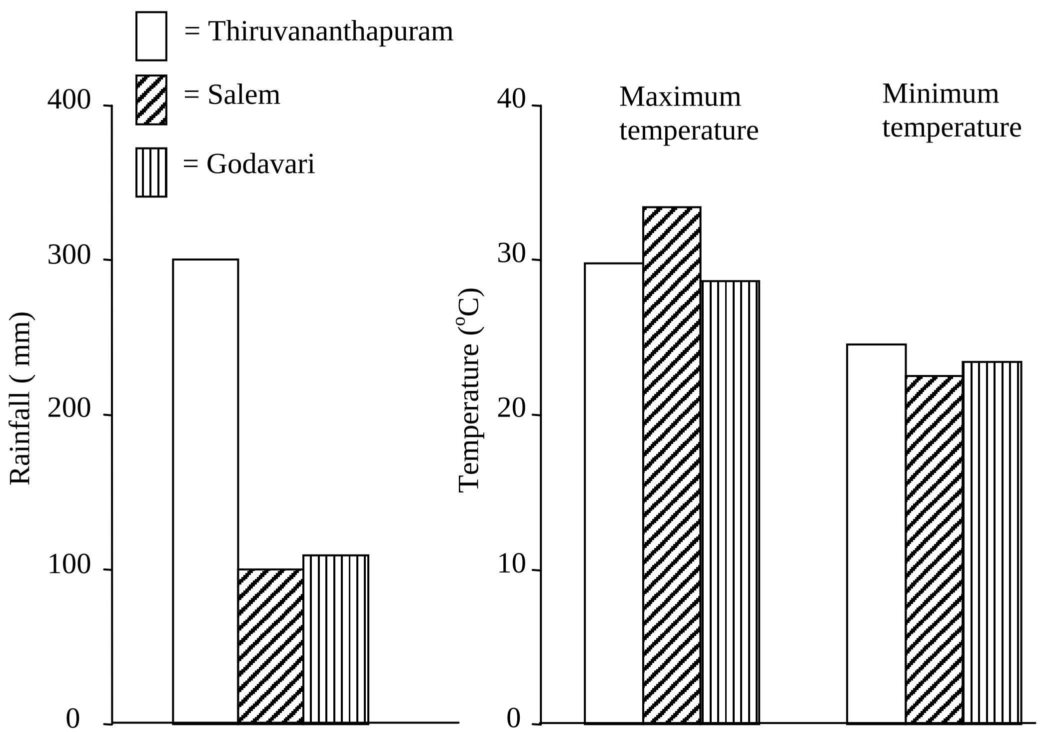

Figure 1 . Climatic characteristics of major cassava-growing states in India, i.e. Thiruvananthapuram in Kerala, Salem in Tamil Nadu and Godavari in Andhra Pradesh.

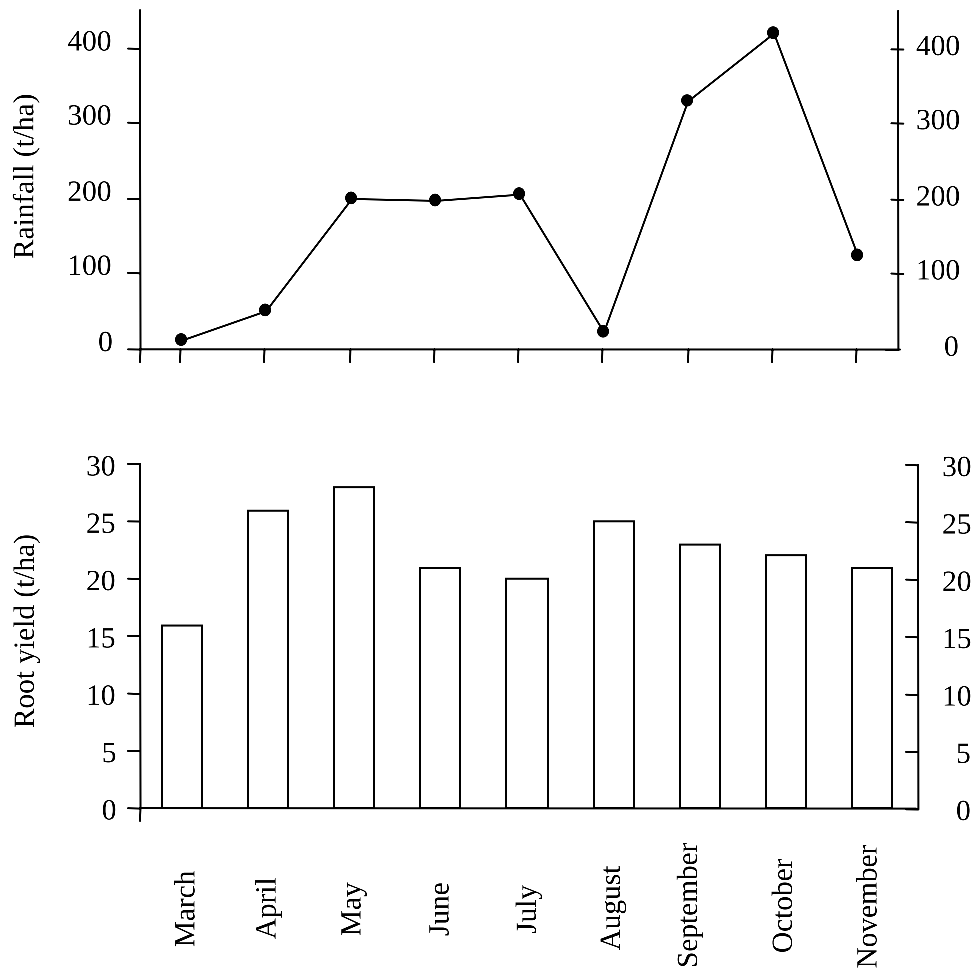

Figure 2. Effect of time of planting and rainfall on cassava root yield at CTCRI, Thiruvananthapuram, Kerala, India.

1.3 Method of planting

Different methods of land preparation, such as pit followed by mound, flat, mound and ridge methods did not show any significant differences in yield, although pit followed by mound recorded the maximum root yield (CTCRI, 1971) (**Figure 3**).

When planting on slopy land, the staggered mound method was found to be the most effective in reducing runoff losses. Runoff plot studies conducted at CTCRI on slopy land (8-9% slope) indicate that planting cassava on staggered mounds reduced soil loss due to erosion by 24% as compared to planting on flat beds (Kabeerathumma *et al*., 1996).

Table 1. Effect of tillage on cassava root yield (t/ha) at CTCRI, Trivandrum, India, in 1973.

Plowing/ digging	Number of earthings up*				Mean
	0	1	2	3	
Tractor plowing					
Once	16.2	22.1	24.2	25.1	**21.9**
Twice	18.1	22.6	23.5	24.0	**22.1**
Digging					
Once	14.4	21.6	23.4	25.3	**21.2**
Twice	12.7	20.4	25.3	25.6	**21.0**
Mean	**15.3**	**21.7**	**24.1**	**25.0**	
CD (0.05)	Plowing: NS		Earthing up: 2.51		

*Includes weeding
NS : not significant
Source: *Mandal and Mohakumar, 1973.*

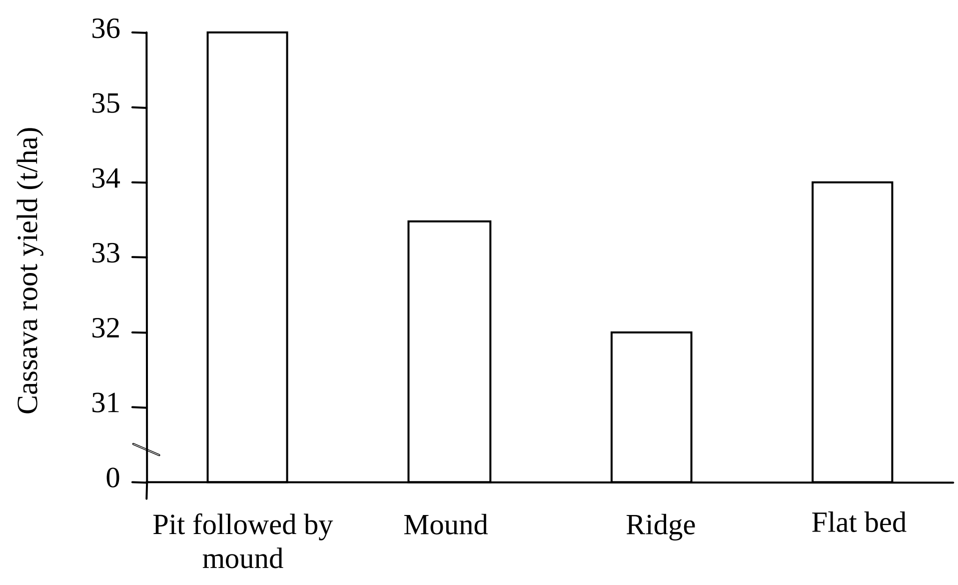

Figure 3. Effect of method of planting on cassava root yield at CTCRI, Thiruvananthapuram, Kerala, India.
Source: *CTCRI, 1971.*

1.4 Selection and preparation of planting materials

Disease-free planting material of 8-12 months' maturity with a stem girth of 2-3 cm has been found to be ideal for planting cassava (CTCRI, 1968). Stakes derived from the lower part of the stem had significantly higher survival rates than those from the immature top portion. It was observed that plant establishment was best when stakes were prepared by discarding one-third of the total length of the stem from the top end, and about 5 cm from the bottom end. Stakes with a smooth circular cut at its base resulted in uniform callus formation and root initiation. A stake length of 25-30 cm was found to be ideal for obtaining high root yield. A significant reduction in root yield was noticed when stakes of 10 cm length were used. Shallow planting facilitates the production of a large number of roots. When the soil is sufficiently loose and friable, stakes can be planted to a depth of 5-10 cm. Planting the stakes deeper resulted in swelling of the mother stem with consequent reduction in root size and yield.

1.5 Method of planting stakes

Different methods of planting the stakes, such as vertical, slanted (at a 45° angle) and horizontal, showed that vertical planting resulted in a more uniform distribution of callus tissue around the cut surface of the stake, which helped in the uniform bulking of roots all around the base of the plant (CTCRI, 1969; 1971).

1.6 Raising of young plants in the nursery

Planting of cassava stakes in traditional areas coincides with the onset of monsoon rains; however, in non-traditional areas where rainfall is very limited, nursery techniques have been developed for sprouting the stakes in the nursery first and then transplanting in the main field with the onset of rains. In the nursery, stakes are planted at a very close spacing of 4.5 x 4.5 cm under irrigated conditions during the first week of May (Mohankumar *et al*., 1998). The report further indicates that maximum root yields were obtained when 20-day old settlings were transplanted in the main field. The rooting media had no significant effect on root yields. High quality planting materials, free of disease, could be produced by this method.

1.7 Production of planting material

The rate of multiplication of planting material is only about ten times at harvest. A study undertaken to enhance the rate of multiplication revealed that spacings of 60x60 cm and 90x45 cm with one stake/hill were significantly superior to other treatments. Planting of two stakes/hill considerably reduced the number of high quality planting material under the different spacing (Mohankumar *et al*., 1980). Rapid multiplication of cassava stems by means of planting single-node cuttings was found to increase the multiplication rate to 647 stakes in one year (Kamalam *et al*., 1977).

1.8 Plant population

Experiments conducted to determine the effect of plant population and shoot number per plant for both branched and non-branched cultivars of cassava showed that a plant spacing of 90x90 cm for branched and a closer spacing of 75x75 cm for non-branched cultivars gave the highest yields (**Figure 4**).

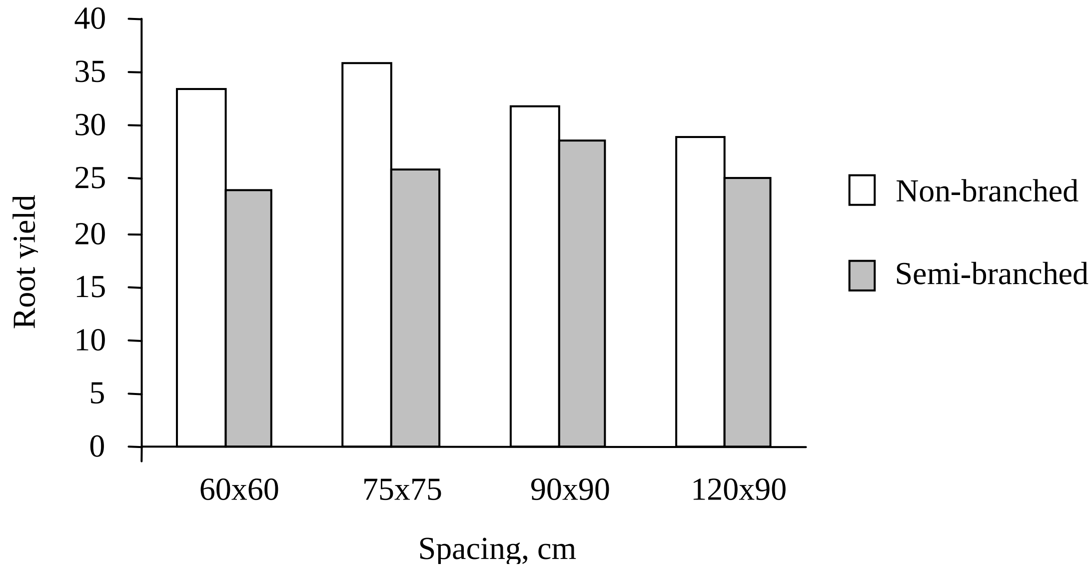

Figure 4. Effect of plant spacing on the root yields of a non-branched and semi-branched cassava variety at CTCRI, Trivandrum, India. in 1973. ***Source:*** *Mandal et al., 1973.*

Planting two stakes/hill for non-branched types produced better yields as compared to the normal practice of one plant/hill. However, despite an increase in root yield by this method, root size was considerably reduced, probably due to competition for light, nutrients and moisture.

1.9 Shoot number per hill

Under favorable conditions, the upper dominant buds produce sprouts. The sprouts emerging from the top buds are more vigorous than those emerging from the lower nodes of the same stake. Retaining two shoots at opposite sides was found to be better than retaining only one shoot. This practice helped in the production of a large number of uniformly sized roots all around the base of the plant (Mandal *et al.*, 1973). Thus, it was recommended that excess sprouts be removed at 10-15 days after sprouting, retaining only two sprouts per plant.

1.10 Gap filling

Establishment of stakes planted in the main field may turn out to be poor if low quality planting material is used or if weather conditions are adverse. Gap filling therefore becomes essential within a reasonable period of time for establishing a uniform crop stand, and to prevent economic loss. In an experiment conducted to identify the best time and method of gap filling, it was observed that using longer stakes of 40 cm at the 15^{th} day after planting can produce 50% higher yield compared to normal stakes (of 20 cm length) used for gap filling (CTCRI, 1983).

1.11 Storage of planting material

Stems for planting material when stored for 15 days resulted in the highest percentage of sprouting (96%) as compared to planting fresh stakes (90%). Viability of the stems declined when stored beyond 60 days, as shown by the lowered percentage of sprouting (<75%) when planted.

2. Age at harvest

A study on the optimum age at harvest in cassava indicated that root yields increased progressively with a delay in harvesting time from the sixth to the tenth month of the crop. Maximum root yield was obtained at the tenth month (Mohankumar *et al*., 1985).

3. Pruning

Field experiments conducted for the June planting suggested that by close pruning (30 cm from the ground) at the eighth month after planting, the pruned plants could establish a fresh canopy during the drought period. The crop can then be further retained for a period of eighth months (total duration of 16 months), with a doubling of yield as compared to the normal crop of ten months. The quality of the roots was not affected by such pruning of cassava (Ramanujam, 1987).

4. Cropping systems

4.1 Intercropping in cassava

In a comparative study to evaluate the performance of some vegetables as intercrops with cassava, French bean (*Phaseolus vulgaris*), variety Contender, was found to be a successful intercrop (Thomas *et al*., 1982). Similar results were reported by Prabhakar *et al*. (1982).

Canopy spread and light penetration studies conducted in cassava fields, in which the stakes were planted at a spacing of 90x90 cm, showed that cassava canopies meet between the 45th and 75th day after planting, and with advancing age there was substantial canopy overlap. One hundred percent light penetration through the canopy at the interspace of 45 cm between two rows of cassava was observed up to the 45th day after planting. Thereafter, light penetration reduced to 50, 36 and 26% at 75, 90 and 120 days after planting, respectively (Ashokan *et al*., 1985).

An array of crops with duration not exceeding four months have been tested under irrigated conditions at Coimbatore in Tamil Nadu, and results show that onion (*Allium cepa*) was the most suitable intercrop with cassava, because bulb formation and maturity were completed within 85 days. Neither growth nor root yield of cassava were affected by onion (Muthukrishnan and Thamburaj, 1978).

Earlier reports suggested that intercropping legumes like peanut and cowpea with cassava caused a yield reduction in the main crop. Manipulation of spatial arrangements is one of the means to mitigate such yield losses. Experiments conducted by Meera Bai *et al*. (1991) showed that the paired-row system of planting cassava was beneficial in realizing higher yields of the main as well as the intercrops, i.e. peanut and cowpea (**Table 2**). Higher net income was also realized from the paired-row intercropping system.

Under lowland conditions, vegetable cowpea followed by cassava was found to be a feasible alternative to the use of farmyard manure. The yield reduction under such conditions was only 12% when compared to the control, where there was no preceding crop

Table 2. Yield of cassava and intercrops under different intercropping systems at Kerala Agricultural University, Kerala, India. 1990-1993.

Treatment	Cassava root yield (t/ha)	Yield of 1st intercrop		Yield of 2nd intercrop	
		Peanut (kg/ha)	Cowpea (kg/ha)	Cowpea (kg/ha)	Black gram (kg/ha)
Cassava monoculture (square planting)	19.46	-	-	-	-
C+P	21.77	819	-	-	-
C+CP	19.84	-	2,577	-	-
Cassava monoculture (paired-rows)	19.68	-	-	-	-
C+P	22.21	929	-	-	-
C+CP	22.22	-	2,145	-	-
C+P-CP	22.34	938	-	25	-
C+P-BG	21.55	908	-	-	negligible
C+CP-CP	20.45	-	1,501	35	-
C+CP-BG	20.48	-	1,770	-	7

C = cassava, P = peanut, CP = cowpea, BG = black gram
Source: *Meera Bai et al., 1991.*

of vegetable cowpea (**Figure 5**). The vegetative matter produced by the seasonal crop was sufficient to provide enough organic matter to cassava; however, under upland conditions, the cassava crop that followed the vegetable cowpea had a yield reduction of 30%. The significant reduction in yield was due to moisture deficiency as a result of late planting and subsequent drought, affecting the crop at the root bulking stage. When cassava was planted in May, there was no serious moisture stress up to the time of harvest in December.

4.2 Cassava as an intercrop in coconut plantations

A study on the growth and development of some cassava genotypes under coconut shade indicates that internodal elongation, thin leaves and absence of branching were the principal effects of shading. Most of the photosynthates produced by shade-grown cassava were utilized for shoot growth, leaving little resources for root development (**Table 3**) (Ramanujam *et al*., 1984).

4.3 Cassava-based multiple cropping system

In a cassava-based multiple cropping experiment, involving pure stands of perennials (banana, leucaena, eucalyptus and coconut), cassava and seasonal intercrops (peanut or cowpea), it was observed that inclusion of cassava and intercrops improved wood recovery in eucalyptus (**Table 4**). However, cassava intercropping adversely affected the yield of banana and the forage yield of leucaena. The perennials, especially eucalyptus, were also found to cause a serious reduction in cassava root yield. Intercropping with banana, however, increased cassava yields. A cost/return analysis showed that the highest net return was obtained for the crop combination of cassava + french bean or cowpea. The next best combination was banana + cassava + french bean or cowpea (Ghosh *et al*., 1987).

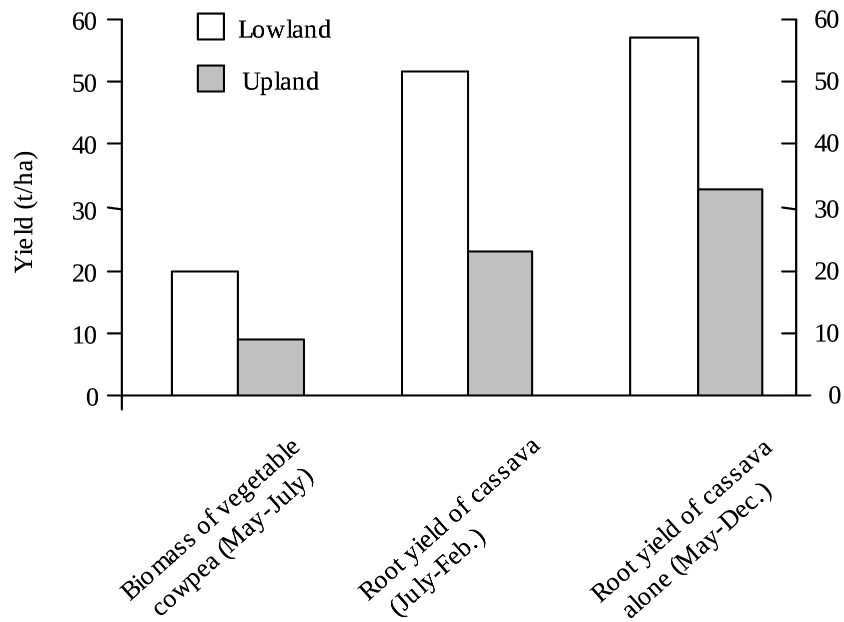

Figure 5. Biomass production of vegetable cowpea and cassava root yield (t/ha) of subsequently grown cassava as compared to the root yield of cassava grown without cowpea under upland and lowland conditions at CTCRI, Trivandrum, India, 1996.
Source: *Mohankumar and Nair, 1996.*

Table 3. Crop growth rate and yield of cassava genotypes under open conditions and under shade (in a coconut plantation) at CTCRI, Trivandrum, India. 1983-1985.

Clone	Crop growth rate ($g/m^2/day$)		Root yield (g/plant)		Yield reduction (%)
	Open	Shaded	Open	Shaded	
M-4	5.06	1.11	2,000	160	92
H-2304	6.40	2.61	2,500	506	79
H-1687	5.62	2.17	2,410	483	80
H-226	5.17	1.58	2,450	393	84
H-165	6.02	2.38	2,500	800	68
H-97	6.49	1.07	2,000	170	94

Source: *Ramanujam et al., 1984.*

Table 4. Wood yield of eucalyptus (t/ha) in various cassava-eucalyptus cropping Systems at CTCRI, Trivandrum, India. 1984-1987

Months after planting	Eucalyptus	Eucalyptus + cassava	Eucalyptus + cassava + peanut	Eucalyptus + cassava + cowpea
Side shoot removed at 18 months	0.52	0.36	0.40	0.33
Wood recovery at 33 months	30.11	28.05	40.40	43.53

Source: *Ghosh et al., 1987.*

In another study on root crop-based cropping systems for paddy fields in Kerala, cassava followed by rice was found to be an ideal crop sequence for obtaining maximum returns and for sustaining the fertility of the field (Mohankumar *et al*., 1985).

The root yield of cassava grown under the partial shade of coconut palms was poor (68%) compared to cassava grown in the open (**Table 5**). As shade was more or less uniform in the coconut garden, no significant differences in cassava root yield were observed from the various crop combinations (Ravindran, 1996).

Table 5. Root yield of cassava grown in various intercropping systems in a coconut garden, as compared to that of monoculture cassava grown in full sunlight at Kerala Agricultural University, Trivandrum, India. 1992-1994.

Cropping systems	Cassava root yield (t/ha)		
	1992-93	1993-94	Mean
Co+Ca	25.01	19.43	22.22
Co+Ca+Vcp	19.75	20.11	19.93
Co+Ca+EFY	29.79	31.56	30.67
Co+Ca+Ba	27.32	22.26	24.79
Co+Ca+Vcp+Ba	30.20	29.21	29.70
Mean	26.41	24.51	25.46
C.D. (0.05)	NS	NS	-
Standard error of mean	2.642	3.247	-
Cassava monoculture	35.38	30.23	32.80

Co=coconut, Ca=cassava, Vcp=vegetable cowpea, EFY=elephant foot yam, Ba=banana
Source: *Ravindran, 1996.*

5. Soil nutrient management

Substantial work has been done on soil nutrient/fertility management aspects of cassava for a sustainable and economic production of roots during the past two to three decades in India.

In order to formulate fertilizer recommendations for cassava on laterite soil, different promising clones were tested at different levels of organic manures and inorganic fertilizers. It was observed that application of 12.5 t/ha of farmyard manure (FYM) and 100 kg/ha of N, P_2O_5 and K_2O, respectively, produced the highest root yield (Mandal *et al*., 1973). Similar findings were reported by Pillai *et al*. (1985). Recent reports, however, suggests that the rate of phosphorus application can be reduced to 50 kg P_2O_5/ha (Kabeerathumma and Ravindran, 1996). This view has been endorsed by most of the recent findings.

Mohankumar and Nair (1996) reported that for the production of one tonne of total dry matter produced, cassava absorbed 6.45 kg N, 1.3 kg P and 8.62 kg K in the whole plant, whereas for a similar level of dry matter production, rice removed 6.6 kg N, 1.3 kg P and 8.62 kg K. This indicates that these two starch-producing crops behave almost identically with regard to total nutrient absorption per unit of dry product.

5.1 Effect of long-term cropping and fertilizer application on soil fertility

In order to study the effects of long-term cropping and fertilizer application to an acid Ultisol on the yield and quality of cassava and the consequent physico-chemical changes in the soil, an experiment has been conducted at CTCRI, Trivandrum for 13 years. Susan John *et al*. (1998) reported that in the 13th year the maximum root yield was obtained when N, P_2O_5 and K_2O were applied at 100 kg/ha each, along with 12.3 t/ha of FYM (**Table 6**). Root yields obtained with the FYM+NK and NPK treatments were, however, not significantly different from each other. Yield increases in these treatments were 400% more than the control (no fertilizer or manure). The lowest yield was recorded when P alone was applied. Ash and K alone as well as in combination increased the starch content and decreased the HCN content of roots, whereas FYM, N alone and FYM+N tended to increase the HCN content.

Table 6. Long-term effect of organic manures and fertilizers on root yield (t/ha) from 1978 to 1990 at CTCRI, Trivandrum, India.

Treatment[1]	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
N	12.5	18.9	11.7	7.6	13.8	3.4	7.2	7.1	3.8	5.3	7.1	3.3	3.6
P	11.2	9.3	6.3	5.1	8.1	5.2	2.3	0.9	4.2	3.0	4.7	1.5	1.3
K	17.0	15.5	10.0	10.4	9.2	12.0	16.9	5.9	8.9	9.4	10.9	2.3	3.4
NP	22.4	18.2	13.7	12.2	15.7	7.6	9.7	3.1	4.9	6.3	4.1	4.1	1.6
NK	17.2	23.0	18.0	15.6	16.3	15.7	29.8	13.1	16.4	19.7	25.7	12.0	9.4
PK	13.7	12.4	8.7	6.4	9.9	9.8	9.8	2.1	9.9	9.5	10.4	3.9	5.4
NPK	20.0	22.1	18.5	21.8	26.0	25.6	28.0	14.6	18.7	29.0	34.0	18.7	22.3
FYM+N	19.5	20.0	14.0	10.6	16.3	17.6	23.3	6.6	15.6	23.0	28.8	5.0	11.0
FYM+P	16.2	14.5	7.5	6.8	11.7	12.8	14.4	5.5	11.7	12.8	20.7	4.3	9.8
FYM+K	13.8	17.1	9.1	10.1	13.4	21.5	20.6	6.4	14.4	17.4	20.8	9.7	10.9
FYM+NP	19.0	21.7	13.4	12.1	24.3	22.8	19.6	5.0	17.5	24.0	25.3	4.4	17.6
FYM+NK	22.9	22.9	13.7	17.9	25.1	31.2	33.5	13.0	21.3	30.0	39.8	14.3	21.9
FYM+PK	15.9	16.7	9.7	12.1	12.6	16.8	17.1	8.6	12.7	14.1	22.1	6.6	9.8
FYM+NPK	23.7	31.9	19.1	21.2	28.9	28.7	42.4	16.6	22.7	34.3	46.5	21.3	29.0
FYM	11.6	9.7	6.9	4.6	10.9	12.8	17.2	2.9	10.3	9.3	25.1	3.0	11.6
Ash	nd	nd	7.2	12.1	12.1	18.3	11.1	5.1	9.6	18.1	32.7	3.1	5.3
Ash+FYM	nd	nd	8.5	12.3	8.0	15.8	22.1	9.4	12.2	20.3	16.6	8.7	12.3
Control	11.3	9.6	5.0	4.4	5.7	6.0	2.8	1.4	4.3	2.4	1.6	1.7	1.0
C.D. (0.05)	6.35	8.53	6.35	4.96	5.69	6.12	11.2	4.55	4.47	4.00	6.13	3.29	6.73

[1] N=100 kg N/ha; P=100 kg P_2O_5/ha; K=100 kg K_2O/ha; FYM=12.5 t farm-yard manure/ha; Ash=2.65 wood ash/ha; *nd=no data*

***Source:** Susan John et al., 1998.*

Combined application of FYM and NPK fertilizers increased the availability of N, P and K in the soil. Continuous application of ash was found to increase soil pH as well as the available K status in the soil, whereas FYM alone or in combination with inorganic fertilizers was found to increase the organic carbon status in the soil (**Table 7**). The build-up of P was very high (up to 280 kg/ha) when applied alone or in combination with FYM. A build-up of P even in non-treated plots was seen to be high, as the original soil was already high in P.

Table 7. Soil chemical characteristics at the end of the 13th cropping season in a long-term fertility trial studying the effects of applying organic manure and inorganic fertilizers at CTCRI, Trivandrum, India. 1990.

Treatment	pH	OC (%)	Ave. N	Ave. P	Ave. K	Ca	Mg	Zn	Cu
			------------(kg/ha)-----------			---(mg/100g)---		----(μg/g)----	
N	4.2	0.58	220.9	212.0	33.6	1.5	0.80	0.20	0.25
P	4.5	0.26	152.4	229.0	40.3	3.5	2.15	0.14	0.13
K	4.5	0.48	114.8	222.0	143.3	1.8	0.63	0.27	0.30
NP	4.4	0.39	144.8	296.8	48.2	2.3	1.57	0.24	0.37
NK	4.5	0.50	214.8	25.8	107.5	2.0	0.93	0.44	0.47
PK	4.5	0.41	227.7	282.0	183.7	3.0	2.14	0.57	0.32
NPK	4.5	0.60	234.8	263.0	96.3	2.0	0.90	0.30	0.24
FYM+N	4.4	0.91	315.1	112.0	53.8	2.5	2.10	0.68	0.34
FYM+P	4.5	0.83	304.2	330.0	60.5	4.8	4.13	0.78	0.40
FYM+K	4.6	0.75	277.6	64.4	164.6	3.2	5.43	0.75	0.45
FYM+NP	4.3	0.87	246.2	266.0	53.8	2.4	0.78	0.54	0.40
FYM+NK	4.4	0.91	249.1	61.6	105.8	2.0	2.13	0.68	0.45
FYM+PK	4.5	0.74	161.1	224.0	170.2	3.0	2.18	0.67	0.43
FYM+NPK	4.6	0.98	246.3	263.0	96.3	3.0	2.06	0.70	0.44
FYM	4.6	0.96	277.6	110.6	71.7	4.0	4.85	0.67	0.37
Ash	6.1	0.49	201.9	22.4	205.0	24.0	13.60	0.80	0.58
Ash+FYM	6.2	0.50	252.4	26.4	192.6	28.0	14.62	1.05	0.56
Control	4.3	0.23	201.9	22.5	41.4	1.6	0.98	0.22	0.16

FYM = farmyard manure, OC = organic carbon (%),
Ave. N, Ave. P and Ave. K are total N, available P and exchangeable K in kg/ha
Ca, Mg are exchangeable nutrients in mg/100 g
Zn, Cu are available nutrients in μg/g
Source: *Susan John et al., 1998.*

Continuous cropping of cassava with only chemical fertilizers decreased the levels of Ca, Mg, Zn and Cu in the soil and lowered the pH. The results clearly indicate the need for organic manure application to the soil along with inorganic fertilizers.

Planting cowpea as a green manure crop, and incorporating the plants before planting cassava, resulted in increased cassava yields (Sasidhar and Sadanandan, 1976). Prabhakar and Nair (1987) suggested that incorporation of cowpea as green manure *in situ* at the time of planting cassava could be as effective as the application of FYM; in addition, it also reduced the N requirement by 50%.

5.2 Substitution of KCl with sodium chloride

Studies conducted at the Kerala Agricultural University have shown that up to 50 per cent of the K requirement of cassava can be substituted by Na through the application of sodium chloride (NaCl), without any negative effect on yield (**Table 8**) (Sudharmai Devi, 1995; Mohankumar *et al*., 1998). Substitution of K by Na in varying levels also influenced the uptake of N at different stages of cassava growth (**Table 9**). Uptake of N showed an increasing trend in all the treatments up to six months after planting and thereafter a decline was noticed. At two and six months after planting, the treatment with 50 per cent substitution recorded the highest uptake of nitrogen.

Table 8. Effect of partial substitution of K[1) by Na application on the root yield of cassava at Kerala Agricultural University, Trivandrum, India. 1992-1994.

Treatment	Root yield (t/ha)		
	1992/93	1993/94	Mean
100% KCl	21.91	16.70	19.30
75% KCl + 25% NaCl	19.05	20.30	19.70
50% KCl + 50% NaCl	26.04	24.50	25.30
25% KCl + 75% NaCl	18.42	17.90	18.20
100% NaCl	11.43	15.30	13.40
50% wood ash + 50% NaCl	13.81	18.30	16.10
50% $KHCO_3$ + 50% $NaHCO_3$	16.19	17.80	17.00
C.D. (0.05)	7.87	6.55	3.44

[1)] Rate of K application was 100 kg K_2O/ha; no control treatment.
Source: *Sudharmai Devi, 1995..*

Table 9. Nitrogen uptake at different growth stages as affected by partial substitution of K[1)] by Na application in cassava at Kerala Agricultural University, Trivandrum, India. 1992-1994.

Treatments	Nitrogen uptake (kg/ha)				
	2 MAP[2)]	4 MAP	6 MAP	8 MAP	Harvest[3)]
100% KCl	17.08	33.90	70.36	59.73	60.94
75% KCl + 25% NaCl	11.13	48.89	58.81	54.60	45.74
50% KCl + 50% NaCl	18.85	42.30	102.42	49.65	37.01
25% KCl + 75% NaCl	14.95	37.39	69.25	50.53	34.93
100% NaCl	10.20	43.32	66.48	53.58	23.97
50% wood ash + 50% NaCl	8.86	57.10	89.36	54.04	30.50
50% $KHCO_3$ + 50% $NaHCO_3$	11.20	33.18	77.25	49.54	36.93
C.D. (0.05)	4.16	NS	22.39	NS	28.40

[1)] Rate of K application was 100 kg K_2O/ha; no control treatment.
[2)] MAP= months after planting.
[3)] At 10 MAP.
Source: *Sudharmai Devi, 1995.*

5.3 Response to N and K

A study on the response of two short-duration cassava varieties to application of N and K in a rice-based cropping system revealed that the application of N had a significant effect on root production (**Figure 6**). The highest yield was obtained at 75 kg N/ha, which was significantly superior to that at 50 kg N/ha. The former was, however, not significantly different from that at 100 kg N/ha. Application of K had a favorable effect on root yield. The highest yield was obtained with the application of 100 kg K_2O/ha, which was significantly higher than that at 50 or 75 kg K_2O/ha. The highest root yields of both varieties were obtained with 75 kg N and 100 kg K_2O/ha.

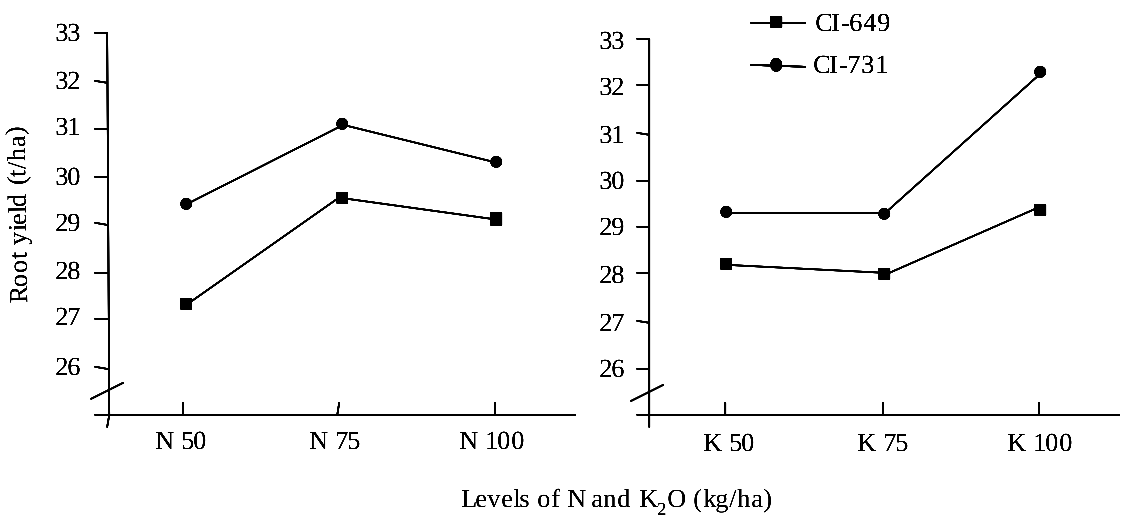

Figure 6. Effect of various rates of N and K application on the root yields (t/ha) of two short-duration lines of cassava grown in lowland soils at CTCRI, Trivandrum, India in 1991-1994.
***Source:** Mohankumar, 1996.*

5.4 Soil amelioration with lime and sulfur

Amending an acid soil with lime is a common practice for reducing acidity and thereby making available more soil nutrients, which in turn benefit the crop and increases root production. A study conducted at CTCRI with different levels of lime, ranging from 0 to 2,000 kg CaO/ha in addition to the recommended dose of 100 kg/ha each of N, P_2O_5 and K_2O, revealed that the root yield was raised by as much as 35.6% with the application of 2,000 kg CaO/ha as compared to that of the control (**Table 10**). In addition to increasing root yield, lime application also improved the quality of roots by increasing the starch content and decreasing the level of HCN.

Table 10. Cassava root yield and quality as affected by different levels of lime application at CTCRI, Trivandrum, India. 1981-1984.

Level of lime (kg CaO/ha)	Root yield (t/ha)	Starch content (%, dry wt. basis)	HCN content (ppm, fresh wt. basis)
0	18.76	86.5	54.8
500	22.19	88.4	46.1
1,000	23.54	88.4	50.1
1,500	22.66	89.3	46.2
2,000	26.00	88.4	40.8
C.D. (0.05)	3.35	-	-

Source: *Mohankumar and Nair, 1985.*

A positive response in root yield to sulfur application in acid laterite soil of low available S (6.62 ppm) was obtained by Mohankumar and Nair (1985). They reported that application of S at the rate of 50 kg/ha increased the starch and methionine content but decreased the cyanogen content of roots, while the root yield increased 3.94 t/ha over the no-S treatment.

5.4 Effect of slow-release nitrogen fertilizers on cassava

Nitrogen fertilizers, especially urea, are subject to various losses under tropical conditions. An investigation into the effect of slow-release nitrogen fertilizers and nitrogen inhibitors on cassava was conducted by Vinod and Nair (1992). The N sources were urea, urea super-granule, neem cake-coated urea and rubber-coated urea, each applied at the rate of 50, 75, 100, 125 and 150 kg N/ha. Urea super-granule and neem cake-coated urea produced apparently higher yields and quality attributes as compared to other treatments (**Table 11**).

Table 11. Effect of four sources of nitrogen on the yield and quality attributes of cassava, cv. Sree Visakham, grown at the College of Agriculture, Trivandrum, India. 1989-1991.

Source	No. of roots/plant	Root yield (t/ha)	HCN content (ppm, fresh wt. basis)	Total dry matter (t/ha)
Urea	5.1	19.95	47.4	10.52
Neem-coated urea	5.8	22.59	46.8	12.13
Urea super-granule	5.9	25.65	48.4	13.97
Rubber cake-coated urea	4.9	17.76	48.2	10.40
	0.27	1.44	1.1	0.24
SE	0.55	2.96	-	0.49
CD (0.05)				

Source: *Vinod and Nair, 1992.*

5.6 Response to micronutrients

Cassava responded significantly to soil application of Zn, Mo and B at 12.5, 1.0 and 10.0 kg/ha as zinc sulfate, ammonium molybdate and borax, respectively, along with 100 kg/ha each of N, P_2O_5 and K_2O. Yield increases over the control of 4.0, 2.8 and 3.1 t/ha were obtained by the application of Zn, Mo and B at the rates mentioned (**Table 12**).

Table 12. Root yield, starch and HCN contents of cassava as influenced by micro-nutrient applications at CTCRI, Trivandrum, India. 1979–1982.

Treatment	Rate (kg/ha)	Root yield (t/ha)	Starch content (%)	HCN content (ppm, fresh wt. basis)
Mn	25 (Manganese sulfate)	26.8	27.0	101.7
Zn	12.5 (Zinc sulfate)	29.4	29.6	90.3
Cu	12.5 (Copper sulfate)	26.9	27.2	99.2
B	10 (Borax)	28.5	28.1	96.8
Mo	1.0 (Ammonium molybdate)	28.2	29.5	115.9
Control		25.4	29.2	110.5
C.D. (0.05)		1.6	27.6	119.6

Source: *Nair and Mohankumar, 1980.*

5.5 Response to mycorrhizal inoculation

Studies on the effect of inoculation with mycorrhizal fungi (VAMF) on field-grown cassava clearly showed that inoculation with *Glomus microcarpum* var. *microcarpum* in the nursery prior to transplanting to the field, enhanced total dry matter and root yields (**Figure 7**); inoculation also increased the concentrations of micronutrients, such as Zn and Cu, in the leaves.

6. Water management

Cassava is a drought tolerant crop, but to realize its potential yield it is essential that adequate soil moisture is available. Moisture stress at the time of root bulking drastically reduces root yield. Irrigation is thus essential in drought-prone areas like Tamil Nadu, Andhra Pradesh and Orissa. In the State of Kerala, where cassava is traditionally grown as a rainfed crop, reasonably high yields are obtained due to the good distribution of rain.

A study conducted at CTCRI revealed that irrigating the crop at the 25% available soil moisture depletion level throughout the growing period could double the root yield as compared to the control (no irrigation) (CTCRI, 1983). Another report indicated that supplemental irrigation at IW/CPE ratio=1.0, increased the cassava yield by 90% over the the rainfed crop (**Table 13**). The report further indicates that in order to fully realize the production potential of the crop, irrigation at IW/CPE=1.0 along with a fertilizer application of NPK at 150:100:150 kg/ha would be required.

7. Package of Cultural Practices

A summary of the recommended cultural practices for cassava production in India is given in **Table 14.**

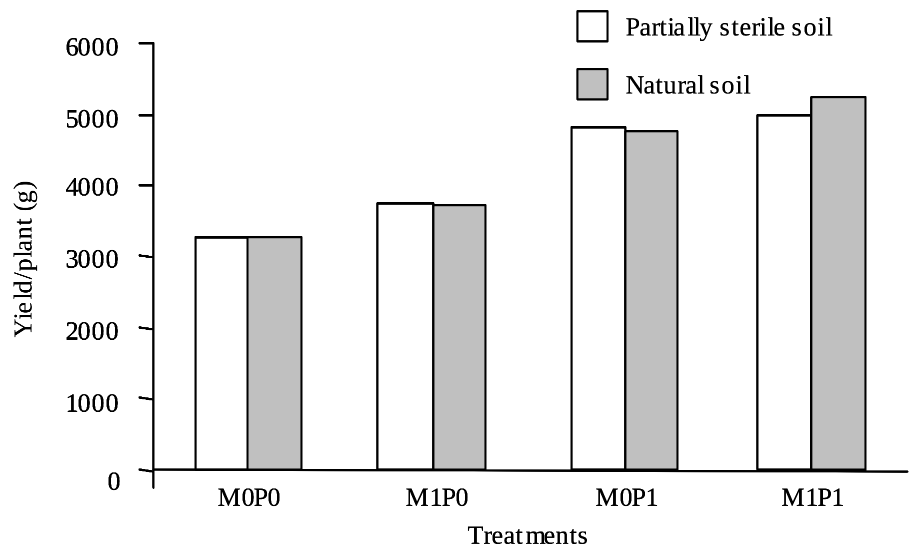

Figure 7. Influence of inoculation with mycorrhiza (M1) and application of P (P1) to nursery grown stakes on the yield of cassava grown in acid laterite soil at CTCRI, Trivandrum, India in 1996.
Source: *Potty, 1998.*

Table 13. Effect of various levels of supplemental irrigation and fertilizer application on root yield, and starch and HCN contents of cassava planted at CTCRI, Trivandrum, India. 1982-1985.

Treatments	Fresh root yield (t/ha)	Starch (% on dry wt. basis)	HCN (ppm on fresh wt. basis)
Levels of irrigation			
IW/CPE = 0 (rainfed)	20.8	72.7	55
IW/CPE = 0.25	24.5	72.9	41
IW/CPE = 0.50	30.8	74.5	41
IW/CPE = 0.75	34.8	75.2	33
IW/CPE = 1.0	39.7	75.0	22
C.D. (0.05)	4.8	-	-
Levels of NPK (kg/ha)			
50:100:50	23.3	75.9	37
100:100:100	28.9	75.2	37
150:100:150	33.4	71.1	39
200:100:200	34.9	74.0	46
C.D. (0.05)	2.6	-	-

[1)] Irrigation during drought periods (more than 7 days without rains); IW = irrigation water in mm, CPE = cumulative pan evaporation in mm. Fertilizers were applied 50% at planting and the rest at 45 days.
Source: *Nayar et al., 1985.*

Table 14. Recommended cultural practices adopted by cassava farmers in India

1. Cropping system:	Cultivated as monoculture in uplands and lowlands and also as an intercrop in plantation crops.
2. Variety:	M-4: Excellent as an edible variety H-97: High starch, good cooking quality H-165: Early (7 months) maturing, disease and pest resistant. H-226: Good cooking quality Sree Visakham: Good cooking quality, high yield Sree Sahya: High yield, drought resistant, high starch content Sree Prakash: Early maturing (6-7) months, good cooking quality Sree Rekha: A top cross hybrid line. Excellent cooking quality and high starch content Sree Prabha: A top cross hybrid line. Yellow flesh, high yield and high starch content Sree Harsha: A triploid variety. Very high starch and root yield Sree Jaya: Early maturing (6-7 months) Sree Vijaya: Early maturing (6-7 months), high root yield.
3. Planting time:	April/May or Sept/Oct.
4. Land preparation:	Two plowings followed by harrowing. Planting is done on mounds or on ridges of about 25-30 cm height.
5. Planting material:	Select and store disease-free cassava stems, 10-11 months old. For planting, cut the stems into stakes of 15-20 cm length.
6. Planting method:	Stakes planted vertically with buds facing up, 5 cm deep. Replant missing hills as early as possible.
7. Plant spacing:	90x90 cm for branching varieties and 75x75 cm for non-branching types. On sprouting, only two shoots are retained on either side.
8. Fertilization:	Farm-yard manure at 10-15 t/ha is applied at the time of land preparation. NPK recommended is 100 kg N, 50 kg P_2O_5 and 100 kg K_2O/ha. Half of N and K is applied at planting and the other half at 45-60 days after planting. Under lowland situation, FYM could be substituted with *in situ* planting of cowpea.
9. Weeding and hilling up:	At 45–60 days and 1-2 months later.
10. Intercropping:	Cassava could be intercropped with two rows of peanut or one row of cowpea.
11. Harvest:	Early maturing varieties are harvested at 6-7 months while the others at 9-10 months.
12. Storage of stems:	Stems are stored in vertical position under shade or in the open.

FUTURE THRUST

Future directions in agronomy research on cassava will focus on:

- The role of cassava in sequential and intercropping systems
- Development of an integrated nutrient management system for enhancing productivity of the crop and for sustaining soil fertility
- Irrigation requirements of cassava in low rainfall areas and nutrient management under such conditions
- Dynamics of applied nutrients in soil planted with cassava
- Physico-chemical transformations in the soil under long-term cassava cropping
- Chemical control of weeds
- Development of cassava models and simulation studies with these cassava models

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CASSAVA AGRONOMY RESEARCH AND ADOPTION OF IMPROVED PRACTICES IN CHINA – MAJOR ACHIEVEMENTS DURING THE PAST 20 YEARS

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ABSTRACT

During the past 20 years, cassava agronomy research in China placed major emphasis on fertility maintenance, erosion control, planting methods, time of planting and harvesting, etc. Long-term fertilization trials conducted at GSCRI, CATAS and the Upland Crops Research Institute (UCRI) in Guangzhou, Guangdong, indicate that N was the most important nutrient for increasing cassava root yields during the early cropping cycles of cassava, but that K, and in some cases P, also became increasingly important. Results of soil erosion control trials conducted in Hainan and Guangxi showed that contour ridging, intercropping with peanut or the planting of vetiver grass contour hedgerows were the most effective practices for reducing soil erosion when cassava was grown on slopes. Planting cassava stakes vertically resulted in more rapid sprouting than horizontal or inclined planting, but there was not much difference in root yield among several methods of planting. Research on time of planting and harvesting cassava conducted at CATAS indicate that when cassava was harvested at 8 months after planting, highest yields were obtained when cassava was planted during the spring (Feb-May). However, when cassava was harvested at 12 months, time of planting had no consistent effect on yield. Effect of time of fertilizer application on cassava yield conducted at CATAS showed that a basal fertilizer application at 30 days after planting resulted in highest yields; there were no significant differences between a single application at 30 days and split applications at 30 and 60 days, or at 30, 60 and 90 days.

INTRODUCTION

The earliest research on cassava cultivation in China was carried out at the Guangdong Agriculture and Sericulture Experimental Farm during 1914-1919, but systematic and intensive research on cassava cultivation was first conducted in 1958, with the objective of stimulating China's cassava production. Most of this early work was concentrated at the present Chinese Academy of Tropical Agricultural Sciences (CATAS) and was described in detail in an unpublished manuscript (in Chinese) by Prof. Wu Jian, completed in 1964. Experiments on land preparation, ridging, length of stakes, planting methods, planting density, harvesting time, NPK fertilization, systems of intercropping, etc, were conducted during 1958-1964 (Zhang Weite *et al*.,1998). Cassava agronomy research was practically suspended from 1965 to the early 1980s. During the 1980s, through cooperation with CIAT, cassava agronomy research in China entered a new stage of development; many trials were conducted in Hainan, Guangxi, Guangdong and Yunnan provinces. This paper summarizes the major results and adoption of improved practices during the past 20 years of research.

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RESEARCH RESULTS

1. Fertilization

A long-term fertility trial has been conducted at the Guangxi Subtropical Crops Research Institute (GSCRI) from 1989 to 1996 (**Figures 1** to **3**). The results indicate that there was a significant response to N throughout the period, but insignificant responses to K and P during the early cropping cycles. As of the third year, the response to K became increasingly important, and the response to P also increased. Application of N tended to increase the yield of stems; high rates of N led to excessive stem growth, while the yield of roots and the starch content tended to decrease. Different varieties showed a different response to fertilizers (**Figure 1**): SC205 was shown to be more responsive to fertilizer application than SC201; the root yield of SC205 increased markedly as the fertilizer rate increased. On the other hand, SC201 was more adapted to grow in poor soils. Similar results were obtained at CATAS in Hainan, where a long-term NPK trial has been conducted for eight years since 1992 (**Figures 4** and **5**). The results again showed the important effect of N for cassava, followed by K, while the response to P was generally not statistically significant. This is a result of the relatively high P status of the soil (Howeler, 1998). The variety SC205 was again more responsive to high applications of N, P and K than SC124 (**Figure 4**).

Table 1 shows the effect of various combinations of N, P and K on cassava yield in a trial conducted at CATAS from 1988 to 1990. Combined application of N, P and K was better than that of any single nutrient, and the application of N alone or NK were better than that of P or K alone or in combination (Zhang Weite *et al*., 1998).

Another trial on the effect of time-of-fertilizer-application conducted at CATAS in 1988 (**Table 2**) indicate that a basal fertilizer application at 30 days after planting resulted in higher yields than later applications. When the fertilizer application was postponed the yield and the number of roots per plant decreased; however, there were no significant differences between a single application and a split application using the same total amount of fertilizer (Zhang Weite *et al.*, 1998).

2. Planting Method

Table 3 shows the results of trials on planting methods conducted at GSCRI from 1990 to 1992 and at CATAS in 1994. Vertical planting resulted in more rapid sprouting and a higher percent germination than horizontal or inclined planting (Tian Yinong *et al*., 1995). Ridging resulted in a little lower percent germination than no ridging in GSCRI, but produced higher yields at CATAS. There was not much difference in root yield among several methods of planting, while inclined planting resulted in a slightly higher yield than horizontal or vertical planting (Tian Yinong *et al*., 1995).

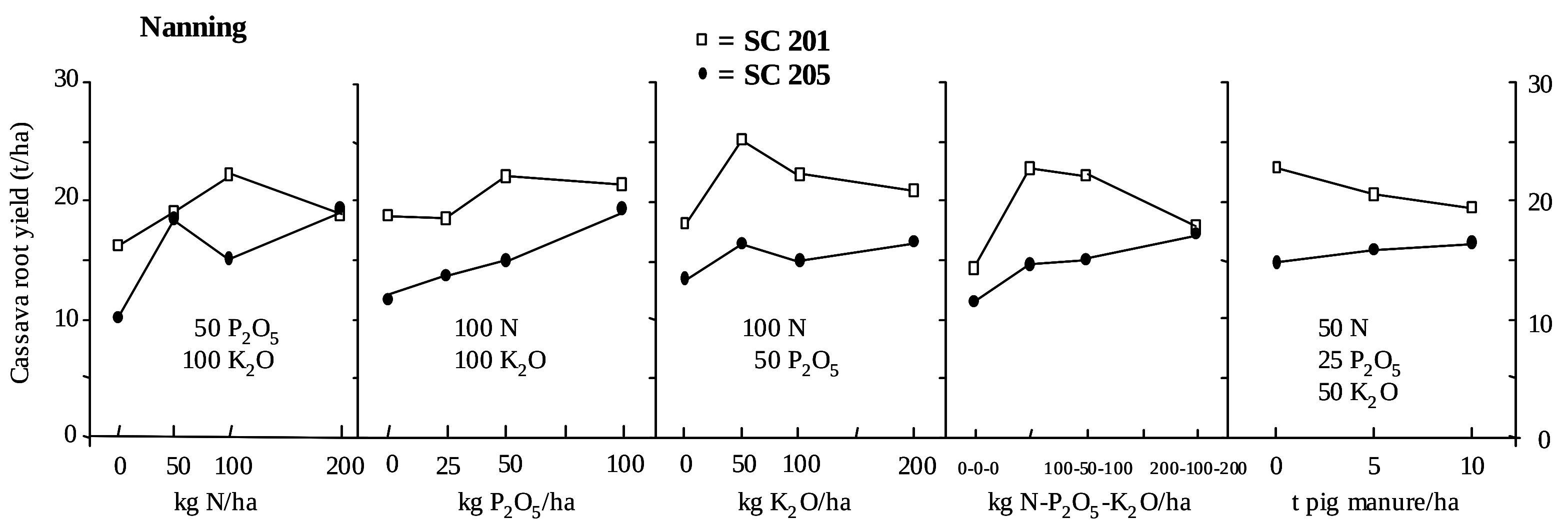

Figure 1. Effect of annual application of various levels of N, P and K as well as pig manure on the yield of two cassava cultivars grown in GSCRI in Nanning, Guangxi, China in 1996/97 (8th year).

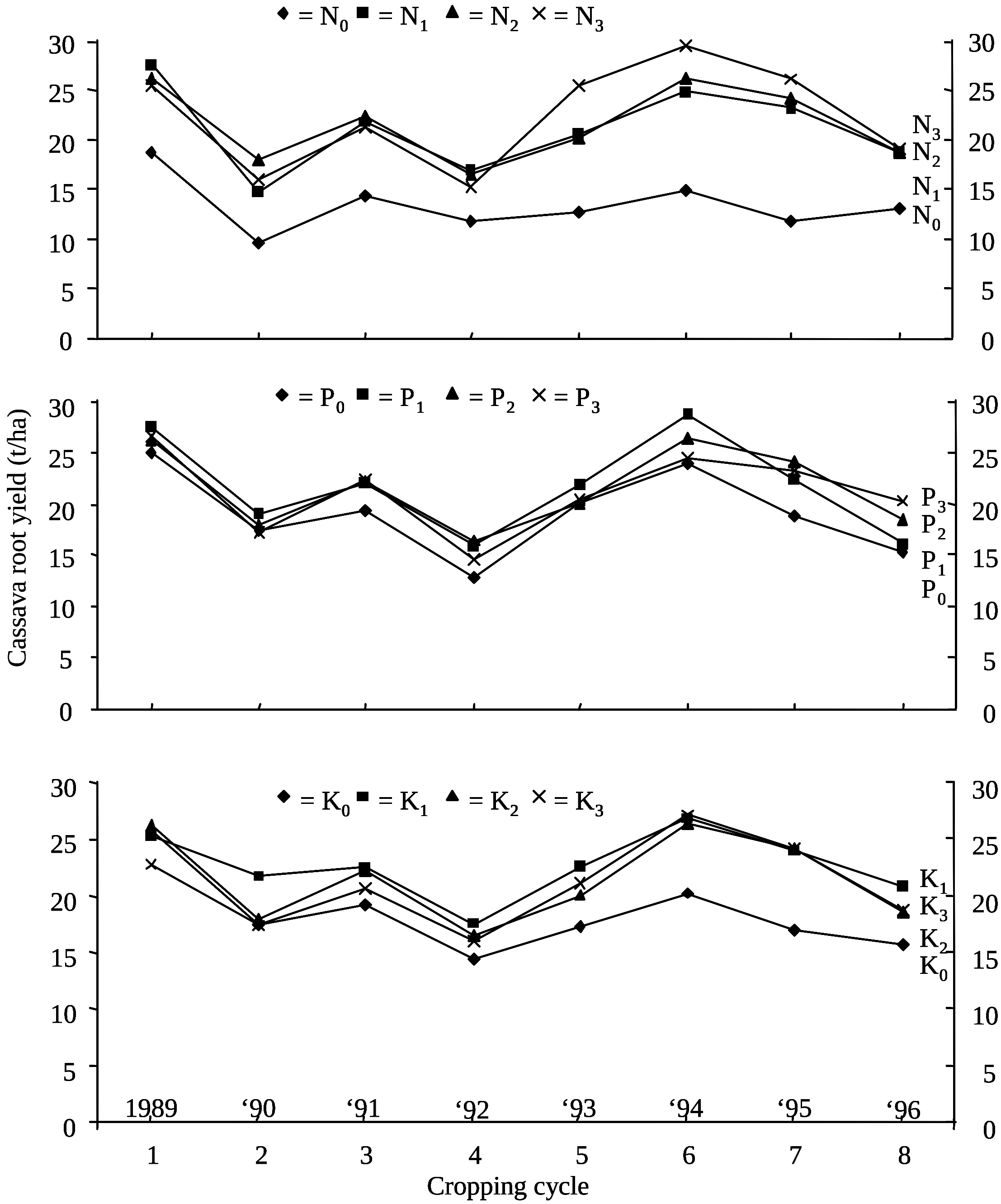

Figure 2. Effect of annual applications of four levels of N (top), P (middle) and K (bottom) on the average root yields of two cassava varieties grown during eight consecutive years at GSCRI in Nanning, Guangxi, China, from 1989 to 1996.

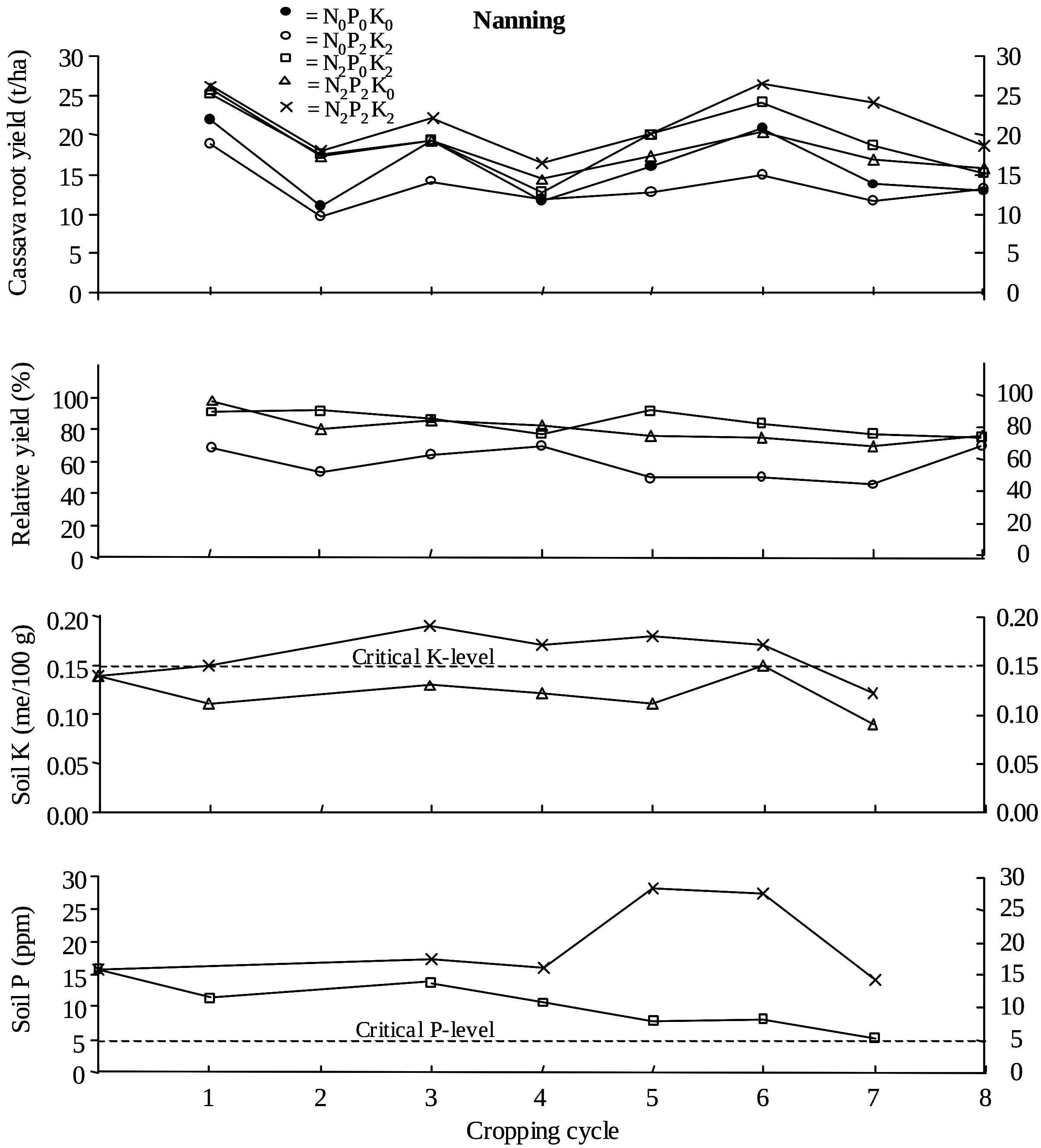

Figure 3. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during eight years of continuous cropping at GSCRI in Nanning, Guangxi, China. Data are average for two varieties.

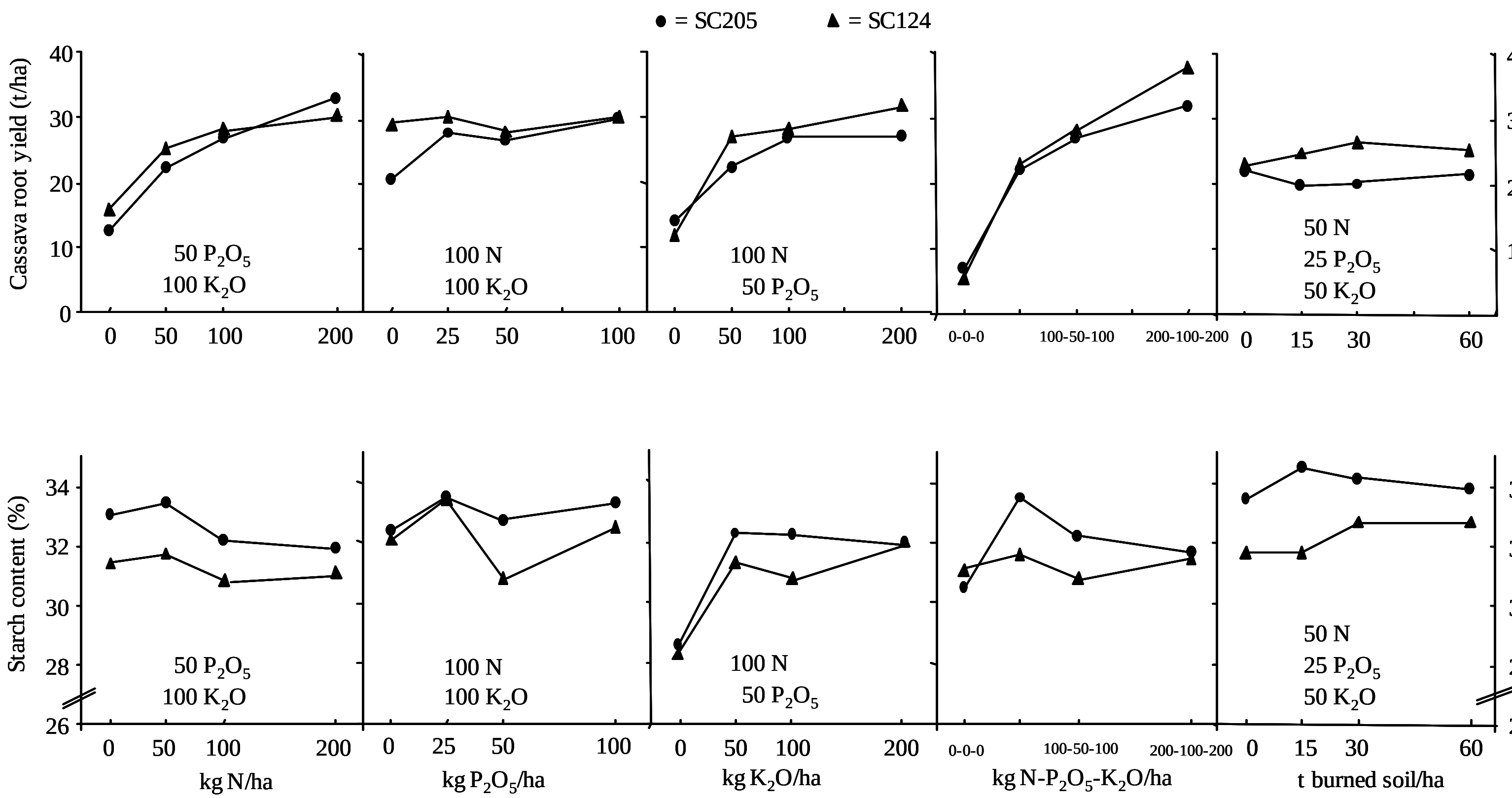

Figure 4. Effect of annual applications of various levels of N, P and K, as well as that of "burned soil" on cassava fresh root yield and starch content during the 8th consecutive cropping cycle at CATAS in Danzhou, Hainan, China, in 1999/2000.

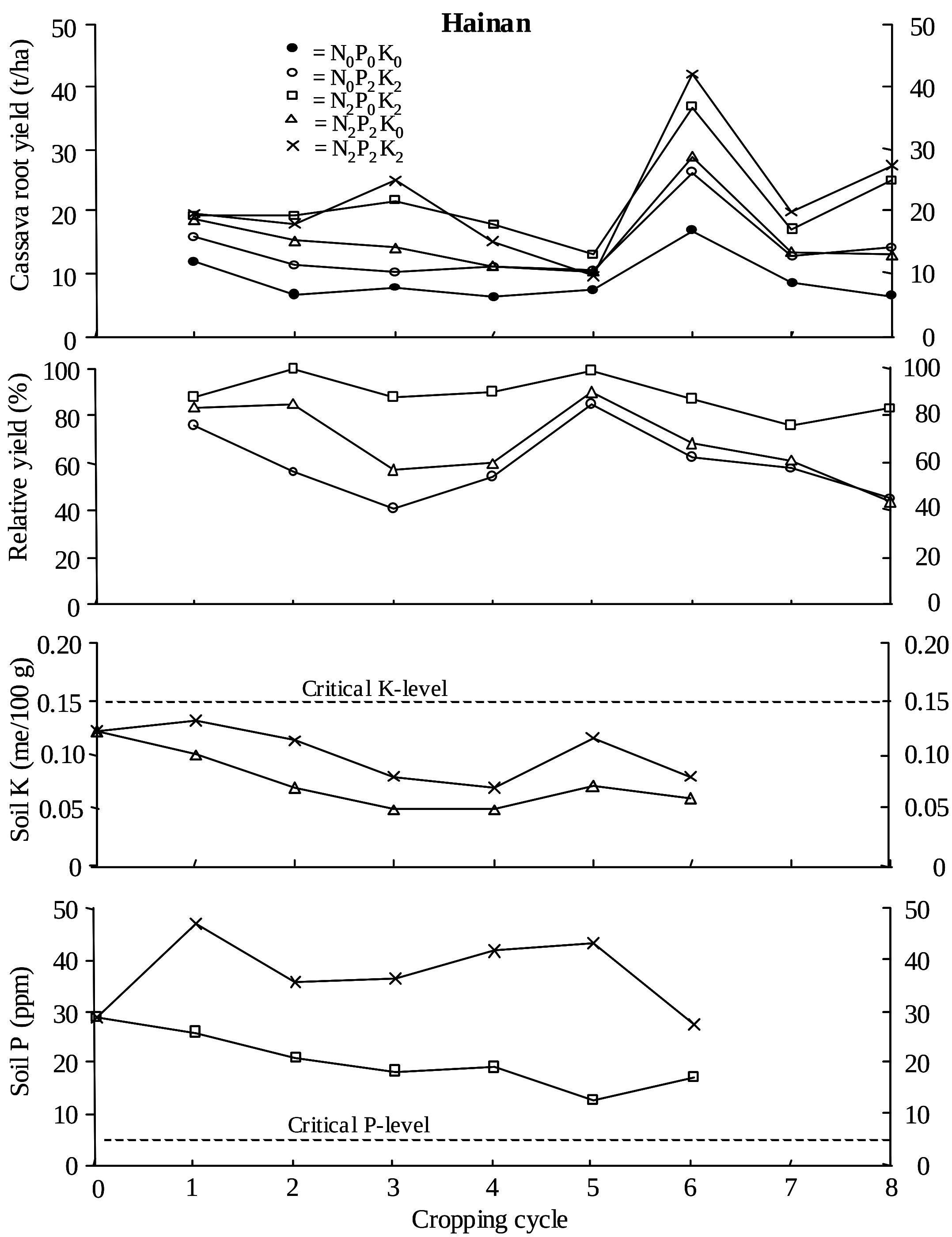

Figure 5. Effect of annual applications of N, P and K on cassava root yield, relative (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during eight years of continuous cropping at CATAS in Danzhou, Hainan China. Data are average for two varieties.

Table 1. Effect of N, P and K application, either singly or in combination, on the fresh root yield (t/ha) of cassava, SC205, planted in CATAS, Danzhou, Hainan, China from 1988 to 1990.

Treatments	1988	1989	1990	Average
Check	15.0	23.1	17.5	18.5
N	16.3	29.5	28.0	24.6
P	20.0	25.3	21.7	22.3
K	19.3	28.6	19.7	22.5
NP	16.8	27.7	22.8	22.4
NK	21.8	31.1	33.7	28.9
PK	22.7	28.5	22.7	24.6
NPK	24.8	34.7	30.2	29.9

Source: *Zhang Weite et al., 1998.*

Table 2. Effect of time of application of fertilizers on cassava root numbers and root yield at CATAS, Danzhou, Hainan, China, in 1988.

	Root numbers/plant	Root yield (t/ha)
Check without fertilizers	8.5	14.5
Fertilizers applied at:		
30 days after planting	11.8	27.2
60 days after planting	9.0	24.8
90 days after planting	8.5	24.2
120 days after planting	7.9	22.0
Fertilizers applied at:		
30 and 90 days	11.1	27.5
60 and 120 days	9.7	23.7
LSD (0.05)	2.3	4.9
(0.01)	3.1	7.5

Source: *Zhang Weite et al., 1998.*

3. Time of Planting and Harvesting

From 1990 to 1994 an experiment was conducted at CATAS in Hainan to determine the optimum time for planting and harvesting of cassava. In this trial, two cassava varieties were planted monthly and were harvested at either 8 or 12 months. The conclusion of this trial is that when cassava was harvested at 8 months the highest yields were obtained when cassava was planted from Feb to May. When cassava was harvested at 12 months, the highest yields were obtained when cassava was planted in May-June, but in two of the three years cassava yields were not greatly affected by the date of planting. The highest starch content was obtained by harvesting in Dec-March, irrespective of whether cassava was harvested at 8 or 12 months (Zhang Weite *et al*., 1998). Thus, it can be concluded that under the climatic conditions of Hainan island cassava should be planted in early spring and harvested in Dec-March, but that planting at almost any time of the year is feasible if plants are harvested after 12 months.

4. Erosion Control

Erosion control experiments have been conducted for many years in Hainan and Guangxi provinces, where the effect of soil and plant management practices on erosion have been studied intensively. With respect to soil management, the results have shown that plowing and disc harrowing increased yields compared with minimum or zero tillage, but that this also caused more soil erosion; planting cassava with zero tillage resulted in somewhat lower yields, but was quite effective in reducing erosion. Zero tillage but planting in hand-prepared planting holes (30x30 cm) resulted in good yields and good erosion control (**Table 4**). Plowing and disc harrowing followed by contour ridging not only increased yields but also reduced soil losses. Contour ridging was found to be an effective way to reduce erosion, while also increasing cassava yields (**Tables 4** to **6**).

With regard to crop management practices, fertilizer application, closer spacing, contour barriers of grasses like vetiver grass, or intercropping with early-maturing and short-stature crops, such as peanut, soybean, watermelon, and mungbean, were all found to be effective in reducing erosion. Among these various management practices, contour barriers of vetiver grass and intercropping with peanut were generally the most effective in reducing erosion, while they also increased cassava yields. The method of planting (vertical or horizontal) had no significant effect on erosion (**Tables 5** and **6**).

Table 3. Effect of stake planting position and ridging on cassava yield and germination at 1 month in GSCRI, Nanning, Guangxi, and in CATAS, Danzhou, Hainan, China. Data are the average for SC201 and SC205 in CSCRI, and for SC205 and SC124 at CATAS.

Planting Position		GSCRI (1990-1992) Germination[1] (%)	GSCRI (1990-1992) Root yield[2] (t/ha)	CATAS (1994) Root yield (t/ha)
Horizontal				
	-ridging	61.5	11.7	20.0
	-no ridging	67.4	10.9	18.6
Inclined				
	-ridging	66.4	13.0	25.3
	-no ridging	78.1	11.5	16.9
Vertical				
	-ridging	82.8	11.1	19.4
	-no ridging	85.8	11.2	18.5

[1)]Average of 1991 and 1992 (no data taken in 1990)
[2)]Average of 1990 and 1992 (no harvest in 1991 due to drought)
Source: *Zhang Weite et al., 1998.*

Table 4. Effect of land preparation on root yield and dry soil loss due to erosion when cassava was grown on 25% slope in CATAS, Hainan, China from 1989 to 1992.

	Root yield (t/ha)					Soil loss (t/ha)				
Treatment	1989	1990	1991	1992	Average	1989	1990	1991	1992	Average
Twice plowing, twice discing, contour ridging	26.3	34.6	17.0	22.8	25.2	71.1	117.0	186.9	79.3	113.6
Twice plowing, twice discing, no ridging	26.0	29.6	18.2	22.3	24.0	141.1	193.4	261.0	134.6	182.5
One time plowing, no ridging	21.3	30.5	19.1	18.6	22.4	91.0	104.8	167.5	119.8	120.8
Zero tillage, hand prep. of planting holes 30x30 cm	25.6	27.6	20.6	21.3	23.8	45.3	97.4	203.3	90.8	109.2
Zero tillage, direct planting in small holes	22.6	29.2	16.5	19.3	21.9	59.8	88.0	201.2	115.9	116.2

Source: *Zhang Weite et al., 1998.*

Table 5. Effect of cultural practices on root yield (t/ha) when cassava was grown on about 12% slope in GSCRI, Nanning, China, during 1990-1999.

Treatment[1)]	1990	1991	1992	1993[2)]	1994[2)]	1995[2)]	1996	1997	1998	1999	Avg.
1. Plow+disc, no ridges, no fertilizer	18.5	18.0	13.6	18.3	13.8	12.8	10.0	17.3	11.9	13.0	13.9
2. Plow+disc, no ridges, with fertilizers	12.2	19.0	13.9	23.8	19.7	19.0	14.0	23.1	15.2	26.5	20.2
3. Plow+disc, contour ridges, with fertilizers	15.6	20.5	12.2	20.4	25.4	21.4	29.0	24.8	20.1	23.3	23.5
4. Plow+disc, up-down ridges, with fertilizers	-	-	-	-	-	-	16.7	-	-	-	-
5. Plow+disc, no ridges, with fert., high population	20.5	14.1	13.9	-	-	-	18.3	-	-	22.7	-
6. Plow only once, no ridges, with fertilizers	-	-	-	21.6	18.4	18.2	-	-	-	-	-
7. Plow+disc, no ridges, with fert., *Crotalaria* intercrop	-	-	-	21.6	23.0	20.0	17.7	21.9	-	-	-
8. Plow+disc, no ridges, with fert., vetiver hedgerows	-	-	-	22.5	28.1	17.9	13.5	22.4	17.9	22.5	20.7
9. Plow+disc, no ridges, with fert., branching variety	14.3	15.0	13.4	-	-	-	16.5	-	-	-	-
10. Plow+disc, no ridges, with fert., vertical planting	21.3	16.0	13.5	-	-	-	-	-	-	-	-
11. Plow+disc, no ridges, with fert., mango contour strips	-	-	-	-	-	-	-	21.2	13.8	19.3	-
12. Plow+disc, no ridges, with fert., peanut intercrop	20.8	15.0	14.3	23.4	22.7	21.6	13.0	25.2	14.7	23.8	20.6
13. Plow+disc, no ridges, with fert., munbean intercrop	-	-	-	-	-	-	14.3	22.7	14.6	23.3	-
14. Plow+disc, no ridges, with fert., soybean intercrop	-	-	-	-	-	-	15.0	27.8	-	24.8	-

[1)]Cassava was planted horizontally except in T_{10} and at a spacing of 1.0x1.0 m except in T5 (0.8x0.8m); the intercrops produced little or no yield.

[2)]Average yield of SC201 and SC205.

Table 6. Effect of cultural practices on dry soil loss (t/ha) due to erosion when cassava was grown on about 12% slope in GSCRI, Nanning, China, during 1990-1999.

Treatment[1)]	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg. 93-99
1. Plow+disc, no ridges, no fertilizer	11.0	23.7	13.9	44.2	11.5	3.9	7.4	6.6	23.8	37.5	19.3
2. Plow+disc, no ridges, with fertilizers	7.0	27.1	9.7	23.9	4.8	1.8	2.4	2.6	13.9	12.1	8.8
3. Plow+disc, contour ridges, with fertilizers	9.5	4.6	3.0	8.3	2.1	2.3	0.8	1.9	11.3	8.6	5.5
4. Plow+disc; up-down ridges, with fertilizers	-	-	-	-	-	-	21.5	-	-	-	-
5. Plow+disc, no ridges, with fert., high population	9.5	14.1	4.3	-	-	-	2.0	-	-	14.8	-
6. Plow only once, no ridges, with fertilizers	-	-	-	22.5	7.5	2.2	-	-	-	-	-
7. Plow+disc, no ridges, with fert., *Crotalaria* intercrop	-	-	-	23.6	5.0	2.2	1.5	2.8	-	-	-
8. Plow+disc, no ridges, with fert., vetiver hedgerows	-	-	-	6.1	1.8	0.9	1.9	1.6	11.4	7.0	4.4
9. Plow+disc, no ridges, with fert., branching variety	6.8	29.8	15.3	-	-	-	1.9	-	-	-	-
10. Plow+disc, no ridges, with fert., vertical planting	8.5	20.4	11.9	-	-	-	-	-	-	-	-
11. Plow+disc, no ridges, with fert., mango contour strips	-	-	-	-	-	-	-	3.6	11.3	15.4	-
12. Plow+disc, no ridges, with fert., peanut intercrop	3.7	13.6	2.2	12.1	2.9	1.8	3.5	1.7	13.1	8.2	6.2
13. Plow+disc, no ridges, with fert., mungbean intercrop	-	-	-	-	-	-	2.6	3.4	20.4	11.8	-
14. Plow+disc, no ridges, with fert., soybean intercrop	-	-	-	-	-	-	1.0	2.8	-	9.8	-

[1)]Cassava was planted horizontally except in T_{10}, and at a spacing of 1.0x1.0 m except in T_5 (0.8x0.8 m)

5. Use of Plastic Film to Cover the Soil

The use of plastic film to cover the soil before planting crops is a new cultural method that has been recommended in China in recent years. Covering the soil with plastic film increases the temperature of the soil in early spring and maintains the moisture in the soil. Planting could be done 1-2 months earlier than without the plastic mulch, while the harvesting time could also be earlier, resulting in a higher price for the crops. The use of plastic film to cover the soil also resulted in an increased percent germination, it controlled weeds and reduced soil loss from erosion. Due to the high cost of plastic film in the past, this method was mainly used for planting high-value crops, such as watermelon, vegetables, maize etc. As the price of plastic progressively decreased, being now only about 450 yuan/ha, farmers began to use plastic film for planting cassava, either in monoculture or intercropped. A study on the use of plastic film for planting cassava intercropped with maize was conducted in Wuming county, Guangxi, in 1999. Maize was planted first with a plastic film covering the soil in early Feb; after one month cassava was interplanted between maize rows. The results shown in **Table 7** indicate that with plastic film higher yields of cassava were obtained than without plastic film, while the intercropped maize produced additional income.

6. Plant Spacing

Cassava spacing trials have been conducted in various locations in China during several years. **Table 8** shows the results of a recent spacing trial conducted in Wuming county, Guangxi, in 1999. There were no significant differences in yield when the plant spacing ranged from 1x0.5 to 1x1 m. A plant density of 12,500-20,000 plants/ha was considered most suitable for cassava in China.

Adoption of Improved Practices

Due to the low profitability of cassava and the lack of recommendations for cultural practices in the past, farmers paid little attention to the cultivation of the crop. The recent expansion of cassava processing factories in Guangxi created greater demand for raw materials, resulting in an increase in the price of cassava roots. Farmers began to request information on new technologies and started to devote more attention to adoption of improved practices. Compared with the traditional cultural practices, the adoption of improved practices in China mainly involved the use of more intensive production, better varieties, more fertilizer use, higher plant populations, better intercropping systems and the use of plastic film to cover the soil before planting. **Table 9** summarizes the main practices that were adopted in China. Some recommended practices, such as soil conservation and the optimum rate, time and method of fertilizer application, had little obvious impact on yield while requiring additional labor or money; they were therefore difficult to be accepted by farmers and were rarely used to cultivate cassava on a large scale. Practices which are simple but highly profitable will be readily adopted by farmers. Farmer participatory research will identify the needs of farmers and will help develop practical solutions to their problems. This is the future direction for cassava research.

Talble 7. Effect of using plastic film to cover the soil to plant cassava intercropped with maize on yields in Wuming county, Guangxi, China in 1999.

Treatments	Yield (t/ha) cassava	Yield (t/ha) maize
Cassava intercropped with maize and using plastic film to cover the soil	54.3	5.3
Cassava monoculture without plastic film	46.5	

Source: *Science and Technology Bureau of Wuming county, Guangxi, China.*

Table 8. Effect of plant spacing on the yield of cassava, SC205, in Wuming county, Guangxi, China in 1999.

Plant spacing (m)	No. of plants/ha	Root yield (t/ha)
1x0.5	20,000	54.2
0.8x0.8	15,625	46.5
1x0.8	12,500	46.5
1x1	10,000	40.4

Source: *Science and Technology Bureau of Wuming county, Guangxi, China.*

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Table 9. The main cultural practices for cassava that have been adopted in China.

1. Cropping system:	Monoculture mainly in mountainous areas or in soils that are too poor or too dry for other crops. Intercropping with food crops mainly in more fertile soils or in plots near the road to facilitate transport.
2. Variety:	Basically two-varieties, SC201 and SC205, but the planting areas of new varieties SC124, GR911 and GR891 are rapidly expanding.
3. Planting time:	Febr-April.
4. Land preparation:	On the flatter areas: plow once at 15-20 cm depth with oxen or tractor, followed by once disc-harrowing. On the steeper slopes: prepare planting holes with hoe or plow with oxen.
5. Planting method:	Mainly horizontal.
6. Plant spacing:	80x80 cm, 80x100 cm or 50x100 cm.
7. Fertilization:	When cassava is intercropped with other crops, farm-yard manure (FYM) and chemical fertilizers such as urea, SSP and calcium cyanamide are often applied to the intercrops, but this will also benefit cassava; when cassava is planted in monoculture, farmers also apply FYM at planting or 15-15-15 compound fertilizers after the first weeding. But in the mountainous areas, fertilizers are seldom applied to cassava.
8. Weeding:	2-3 times manually, at 30-40 days and 2-3 months later.
9. Harvesting time:	Nov-Jan.
10. Intercrop:	Mainly maize, watermelon, peanut, soybean or young fruit trees.
11. Stake storage:	In the northern regions, stems are normally stored in soil trenches or pits covered with straw and soil to protect them from frost damage; in the southern regions, stems are usually stored under the shade of trees covered with dry straw.
12. Erosion control:	Usually dig diversion channels to prevent water from entering the cassava fields.

CASSAVA AGRONOMY RESEARCH AND ADOPTION OF IMPROVED PRACTICES IN THE PHILIPPINES – MAJOR ACHIEVEMENTS DURING THE PAST 20 YEARS

Fernando A. Evangelio [1]

ABSTRACT

Over the years, research conducted on the crop focused mainly on agronomic, soil fertility maintenance and soil conservation practices. Very few studies were conducted on the basic physiology of the plant.

Except for the use of fertilizers and a change in varieties, very few farmers adopted the recommended technology in cassava cultivation. Despite repeated exposure to modern technology, most farmers still follow their own traditional ways of growing the crop. Details of results obtained in the area of cassava agronomy research are presented.

INTRODUCTION

Intense competition due to globalization has energized the Philippine agriculture sector to reorient its research and development efforts in order to cope with the changing needs of world markets. With the birth of the Agriculture and Fisheries Modernization Act (AFMA), eighteen commodities were given priority by the government through the Department of Agriculture to adjust their R&D/E Programs to the current thrust. Root crops, such as cassava, are among these commodities.

The cassava industry in the Philippines is now gaining momentum with the existence of various market opportunities. Cassava is grown not only for human food, but also for starch, animal feed and industrial uses such as alcohol. Aside from the San Miguel Corporation, which currently uses cassava domestically as an ingredient in animal feeds, other firms like La Tondeña, are also working with cassava as a potential raw material for the production of alcohol. This is due to the scarcity of molasses resulting from low sugarcane production. Moreover, various food products from cassava have been developed, further increasing the demand for the crop.

Cassava Area, Yield and Production

For the past twenty years cassava production in the Philippines showed an irregular trend. For example, in the late 1970s cassava production was at its peak. There was an increase of 108% in area from 87,420 ha in 1973 to 181,770 ha in 1978, which resulted in a 356% increase in total volume of production and a 120% increase in average yield (FAOSTAT, 2001). The increase in the national average cassava yield of 6.38 t/ha during that period was attributed to the growth of large plantations, especially in Mindanao where the growing areas are free from typhoons and generally have fertile soils. Although there was a slight increase of 12% in area planted to the crop in the mid-80s, the average yield showed a considerable decrease from 11.7 t/ha in 1978 to 8.2 t/ha in 1985. A slight increase in cassava area in the early to mid 1990s, especially in Mindanao, was again due to the continued promotion of the crop. Increasing awareness on the use of cassava as food, feed and as raw material for industry, as well as the scarcity of molasses have triggered the increased demand

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for the crop. Up to the present, cassava cultivation is still concentrated in Mindanao because of the greater market opportunities, particularly the presence of chips traders, feed millers and starch processors.

CASSAVA AGRONOMY RESEARCH

Over the years the Philippine Root Crops Research and Training Center (PRCRTC) - now renamed PhilRootcrops, the national root crop center for research and development - on its own and in collaboration with the CIAT cassava program in Asia, conducted research focused on agronomy, soil fertility and soil conservation. A few studies were also conducted on the basic physiology of the plant. Results of some of these studies are as follows:

Land Preparation/Tillage

Despite the great demand for cassava-based-products, like starch, cassava continues to be grown at minimum input levels, since the primary interest of farmers with the crop is for home consumption rather than as a commercial market crop (Pardales, 1985).

Tillage or land preparation is one of the most labor-intensive operations in growing the crop (Pardales, 1985), and is one of the factors that most affects the yield of cassava, as reported by Villamayor (1983a) and (Pardales (1986) (**Table 1)**. The conventional method, consisting of harrowing-plowing-harrowing-and making furrows, gave the highest percentage germination and yield. It was also reported by several researchers that planting on ridges or mounds in areas susceptible to waterlogging is preferable to planting in flat beds or furrows, as the yield is generally higher in the former than the in the latter (Labra and Tisang, 1979; Secreto, 1981). Abenoja and Baterna (1982) stated that in newly opened areas such as in a "kaingin" (slash and burn), no tillage is necessary for at least two seasons, except that required for inserting the planting stakes into the soil. Castroverde (1983) showed that minimum tillage together with herbicide application is profitable, but suggests that some tillage operation is necessary to obtain a loose and well-aerated soil for the development of the storage roots. This was confirmed by Pardales (1986) who showed that conventional tillage (plowing and harrowing an entire area) or minimum tillage (row plowing only plus herbicide application) were better than zero tillage. In terms of plowing depth, however, Villamayor (1983a) found no advantage in preparing the soil deeper than 20 cm.

Table 1. Effect of land preparation and tillage on the yield of cassava in ViSCA, Baybay, Leyte, in 1995.

Land preparation/tillage	Root yield (t/ha)
Zero tillage	15.95b
Minimum tillage	30.83a
Conventional tillage	29.14a

Source: *Pardales, 1986.*

In a physiological study, Pardales (1985) showed that conventional tillage resulted in an increase in dry matter (DM) and nitrogen (N) accumulation; DM and N accumulation followed the order: conventional tillage > minimum tillage > zero tillage.

Selection and Preparation of Planting Materials

Good quality planting material usually results in better germination and yield of cassava. Thus, it is necessary to properly select and prepare the planting material. The presence of scale insects can reduce the sprouting percentage and yield of cassava. However, treatment of the stakes with insecticide before planting or planting horizontally minimized the yield reduction, even though sprouting percentage was not improved (Villamayor and Perez, 1986; Villamayor and Perez, 1987).

The performance of stakes produced under shade of coconut was not reduced compared with those produced in the open (Villamayor and Perez, 1986). The first planting of stakes produced under shade even gave higher yields than those produced in the open, but there were no yield differences in the subsequent stake evaluation.

One study (Ocampo, 1956) has shown that stakes cut from the base of the stem produced higher yields than those taken from the middle, which in turn produced higher yields than those taken from the top of the stem (**Table 2**).

Table 2. Effect of the part of stem used as planting material on the yield of the subsequent cassava crop (cv. Valencia) in Iloilo, in 1956.

Part of stem	Root yield (t/ha)
Top	7.91c
Middle	10.41b
Base	12.49a

Source: *Ocampo, 1956.*

There are many studies on the effect of length of cassava stakes. Some workers showed no significant difference in yield among stake lengths between 10 and 50 cm (Dacpano, 1980; Velasco, 1982). Others showed short stakes to be better than longer stakes (Pardales and Forio, 1979; Mateo, 1981; Apilar and Villamayor, 1981; Soriano, 1986; Villamayor *et al*., 1992), while still others showed the long stakes to be better than short stakes (**Table 3**). These effects were amplified by the significant interaction between stake length and cultivar. Apparently, the disagreement in results was due to the differences in the length of the stakes used in the study, the variety and the position of planting, as has been reported by Villamayor *et al*. (1992). In general, it appears that short stakes are better than long stakes when planted vertically and long stakes better than short stakes when planted horizontally.

Table 3. Effect of stake length on the yield of two cassava varieties in ViSCA, Baybay, Leyte, in 1989.

Stake length (cm)	Root yield (t/ha)	
	VC - 1	Golden Yellow
10	9.3	19.4
15	12.4	19.8
20	15.5	20.9

Source: *Villamayor et al., 1992.*

Storage of Planting Material

Parcasio (1982) showed that storage of stems for a period of up to 15 days had no significant effect on yield. Storing cassava stems for one month under a tree and protected from direct sunlight, did not affect the yield of the crop (Villamayor and Perez, 1983), but storage for one or two months significantly reduced yields even though germination was not markedly reduced. In another study (Villamayor, Perez and Destriza, unpublished) it was found that cassava stems placed vertically in the open but covered with coconut fonds could be stored for up to four months without affecting the yield of the subsequently planted crop (**Table 4**). For long-term storage of three or four months, Villamayor *et al*. (1987) reported that burying the basal part of the stem into the soil at about 2 cm depth and protecting the stems from direct sunlight did not reduce the yield compared with the use of unstored stakes. An earlier report stated that treatment of stakes to be stored with coal tar had no effect on viability and shoot development (Mendaira, 1973).

Table 4. Yield evaluation of cassava stakes (cv. Golden Yellow) stored vertically in the open for various duration and covered with coconut fonds in ViSCA, Baybay, Leyte, in 1989.

Storage duration (months)	Root yield (kg/m^2)
Zero	3.1a[1)]
One	1.6c
Two	2.4b
Three	2.7ab
Four	2.8ab

[1)] Mean seperation (LSD, 0.05)

Source: *Villamayor, Perez and Destriza. (unpublished data)*

Planting

Cassava can be planted any time of the year as long as rainfall is adequate. In areas with a distinct dry season it is best to plant at the onset of the rainy season since yields are reduced when planting is delayed towards the dry season (PRCRTC, 1986). A significant positive correlation was observed between rainfall received during the initial seven-month period and yield (Villamayor and Davines, 1987). Bernardo and Esguerra (1981) also recommended planting 3-5 months before the onset of the dry season to avoid spider mite damage. Villamayor *et al*. (1992) reported that except for the Jan planting, the three other times of plantings (Sep, Nov, Mar) had similar yield patterns at different ages of harvest. Yields increased from the 9th to the 10th month, declined at the 11th month, and increased again during the 12th month, except for the Nov planting when the yield decreased slightly. The Jan planting had the highest yield at the 11-month harvest. In general, higher yields were obtained with an increase in harvest age, particularly from the 9th to the 10th month.

Planting is usually done manually but a mechanical planter is available that can plant a hectare in seven hours; it is sometimes used in large plantations. In one pass the implement furrows the soil, drops fertilizer and planting stakes, covers the stakes and compacts the soil.

Planting position, whether vertical, slanted or horizontal, did not affect yield (Tizon, 1980; Abenoja, 1981; Credo, 1982; Soriano, 1986) of a particular variety, but the effect varied significantly among varieties (Villamayor *et al*., 1992). In vertical planting, the inverted position should be avoided since germination is low and the yield is reduced (Evangelio, 1981). However, an earlier report (Reyes and Esperidion, 1976) stated that horizontal planting is better than vertical or slanted planting. The conflicting results are probably due to the difference in soil type, climate and method of soil preparation, whether in mound, furrow, ridge, or flat. The general recommendation is to plant vertically on ridges when rainfall is heavy, especially for heavy soils, and horizontally in furrows when rainfall is scarce during planting, especially for light soils (Mendiola, 1958)

Depth of vertical planting, from 5 to 20 cm, did not affect yield (Corpuz, 1980). Baludda (1980) also did not find any significant differences in yield among 20 to 35 cm depth of planting, but there was a trend that the deeper the planting, the lower the yield. When the whole stem was buried vertically, yield was reduced compared with a planting depth of 15 cm (Villamayor, 1988). This was attributed to the development of the underground part of the stem into storage organs, as the yield reduction was minimized when the underground shoots were removed while still young (1 month old), allowing only the above-ground shoots to develop.

PCARRD (1983) recommends planting only one stake per hill, but about 45% of farmers surveyed plant two stakes per hill (Villamayor *et al*., 1987). Villamayor (1988) stated that cassava can tolerate about 30% missing hills without a significant yield reduction, regardless of variety, population density and fertilization levels used. He recommended that replanting should be done as soon as possible as the yield of the replants were drastically reduced when replanting was delayed beyond 13 days after planting.

Plant Population/Spacing

Varying the planting density from 7,000 to 28,000 plants/ha did not affect total yield (Secreto, 1981; Villamayor and Destriza, 1982a), but there was a trend that the marketable yield decreased with increasing plant density. On the other hand, Occiano (1980) and Bansil (1980) found that a spacing of 75x75 cm was better than the 75x50 cm or 75x25 cm spacing between hills compared with 60, 50 and 40 cm spacing or 50, 100 and 125 cm spacing, respectively. The conflicting results may be due to differences in variety, soil fertility and climatic conditions. For example, Villamayor and Apilar (1981) found the yield of the short-statured variety Golden Yellow not to be affected by the different populations used, but the yield of the tall-statured variety Kadabao was reduced at higher populations.

The yield in a double row system of planting, where an unplanted row alternate with two planted rows, did not differ significantly compared with a single row system (Villamayor and Destriza, 1982a). In the former, the vacant row can be planted with intercrops without interfering in the weed control operations such as off-barring and hilling-up.

In an other spacing trial conducted under mature coconut trees, Villamayor *et al.* (1992) reported that cassava planted at closer spacing or higher population (> 12,500/ha) had more roots and higher yields than those planted at wider spacing. In an open field trial, marked increases in cassava yields were also obtained when the plant density was increased to 15,625-27,780 plants/ha (Evangelio and Ladera, 1998) (**Table 5**).

Table 5. Effect of plant spacing on the yield of cassava in BES, Ubay, Bohol, in 1996.

Spacing (cm)	Plant population (no./ha)	Root yield (t/ha)
60 x 60	27,778	21.85a
80 x 80	15,625	20.97a
100 x 100	10,000	16.18b

Source: *Evangelio and Ladera, 1998.*

Weed Control and Post-plant Cultivation

It was found that the critical period for weed control in cassava is during the first two months of growth (Jumadiao, 1982; Bacusmo, 1978; Bacusmo and Talatala, 1980) (**Table 6**). Although hand weeding is the most practical method of weed control when labor is cheap (Mariscal, 1984), cultivation is also beneficial to cassava, especially during the early establishment period of the crop (Pardales, 1985). Villamayor and Reoma (1987) found off-barring two weeks after planting (WAP) followed by hand weeding within the row 3 WAP and hilling-up at 5 and 7 WAP to be the most profitable among the treatments used under ViSCA conditions.

Table 6. Effect of weeding on the yield of cassava in ViSCA, Baybay, Leyte, in 1977.

Weeding practices	Root yield (t/ha)
No weeding	8b
Weed free during 2 MAP	18a

Source: *Bacusmo and Talatala, 1980.*

Irrigation

There have been no studies conducted on the irrigation of cassava, but Villamayor and Destriza (1985) showed that watering the plants during the period of very low rainfall increased the yield of cassava significantly (Pardales *et al*., 1999) (**Table 7**). Pardales and Esquibel (1996) reported that water stress or lack of soil water during the first three months after planting remarkably reduced all growth indicators, both the above-ground (e.g., number of leaves) or below-ground (e.g., number of roots) parts of the plant. They emphasized in their succeeding study (Pardales and Esquivel, 1997) the importance of soil moisture on the development of cassava plants: a moisture content equivalent to 30% of field capacity (30% FC) of the soil significantly reduced growth and development of the plant when compared with a soil moisture contents of 80% FC or 100% FC. In a root physiology study of cassava and sweetpotato, Pardales *et al*. (1999) found that root zone temperature, which is affected by soil moisture regime, is an important factor that affects the establishment of the crop in the field. They found that 25^0C was the optimum root temperature.

Table 7. Comparative root and shoot growth (gm/plant) of cassava plants subjected to drought at various stages of crop development in ViSCA, Baybay, Leyte, in 1996.

Treatments	Shoot weight (gm/plant)	Root weight (gm/plant)
Early watered	7.53	1,020
Early drought stress, then watered	7.85	1,319
Early drought stress	2.25	887
Early watered, followed by drought stress	-	1,096
Continuously watered (no drought stress)	10.25	1,492
Continuous drought stress	-	582

Source: *Pardales et al., 1999.*

Fertilization/Liming

Many studies have been conducted on the response of cassava to N, P and K levels, either singly or in combination, or a comparison between levels of fertilizers, or between organic and inorganic fertilizers (Evangelio *et al*., 1995; Evangelio and Ladera, 1998; Villamayor *et al*., 1992; Serrame, 1982; Pineda, 1980; de Guzman, 1982; Lagrimas, 1982; Agustin, 1983; Musngi, 1985). Liquid fertilizers have also been tried (Silangan, 1982).

In Bohol, with the following soil characteristics: pH 5.5, 1.0% O.M., 6.9 ppm available P and 96 ppm exchangeable K, Villamayor *et al*. (1992) reported that no significant yield differences due to N, P or K application were observed during the first year (1989/90) of the long-term fertility trial, but that cultivar VC-1 yielded significantly more than Golden Yellow. However, Evangelio *et al*. (1995) reported significant differences in yield due to fertilizer levels in the second until the fourth (1991-1993) cropping cycles. The main responses were to K and N application (**Table 8**). Cassava yields decreased by about 50% in the second cropping cycle, but with fertilizer application yields increased again in the 3rd and 4th year.

In Leyte, a six year (1989-1995) long-term fertility trial under coconut showed a significant response to fertilizer application only after the second cropping cycle (**Table 8**). Highest yields were obtained in treatments with 60 kg of N, 90 P_2O_5, and 60 K_2O/ha, while lowest yields were obtained in treatments without P application. When maize was intercropped within cassava rows, the yield of cassava was not reduced if the fertilizer requirements of both crops were met and the population of maize was only half of that of the monocrop (Evangelio, *et al*., 1995). In Negros Occidental the long-term (1989-1992) fertility trial showed a significant yield response only to the application of N (**Table 8**). There were significant differences among the two cultivars, but no significant interaction between fertilizer rates and cultivars.

Table 8. Long term fertility trials conducted in three locations of the Philippines.

Location and duration	Response
Leyte (under coconut); 1989-1995	Occasional response to P and N only
Bohol (open field); 1989-1993	Response to K and N only
Negros (open field); 1989- 1992	Response to N only

The lack of response in some cases may be due to the high fertility of the soil used. For example, the area used by Suerte (1980) and Villaflor (1981) had a pH of 6.1, 0.28% total N, 35 ppm available P and 229 ppm exchangeable K. The yield of marketable roots alone was as high as 58 t/ha in ten months. An example of a positive response to N fertilization is the work of Abenoja (1978), as shown in **Table 9.** The soil used had a pH of 6.9, 2.0% organic matter, 19 ppm (Olsen) P and 372 ppm H_2SO_4-extractable K.

Table 9. Total root yield of cassava (cv. Golden Yellow) under different levels of fertilizer in ViSCA, Leyte, in 1977.

Fertilizer level[1)]	Total root yield (t/ha)
00 - 00 - 00	17.25 a
30 - 00 - 00	28.05 b
60 - 30 - 30	31.39 b
90 - 60 – 60	29.39 b

[1)] Initial soil analysis: 2.0% OM, 19 ppm Olsen P, 372 ppm H_2S0_4-extractable K

Source: *Abenoja, 1978.*

Continuous application of the same level of fertilization every cropping cycle could not maintain the yield of cassava in ViSCA (Quirol and Amora, 1987) as shown in **Table 10**. This was probably due to a marked reduction in the amount of K in the soil (**Table 11**). **Table 10** also shows that animal manure, especially cow manure, had some residual effect, especially during the cropping season immediately after the last application.

Table 10. Root yield (t/ha) of cassava (cv. Golden Yellow) during the first, third, fourth and sixth cropping cycle as affected by the application of different sources of chemical fertilizer or manures in ViSCA, Leyte, in 1986.

Fertilizer source[1)]	Cropping cycle			
	1	3	4	6
To - Control	31.39 b	16.58 c	11.79 d	8.78 c
T1 - inorganic (60-60-60)	38.95 a	31.71 a	23.10 ab	21.32 a
T2 - chicken manure (1.3 t/ha)	37.61 a	27.33 ab	18.17 bc	12.75 bc
T3 - pig manure (3.4 t/ha)	40.47 a	28.49 a	16.46 cd	10.33 bc
T4 - cow manure (4.4 t/ha)	39.07 a	27.51 ab	25.13 a	16.14 b
T5 - guano	34.85 ab	23.62 b	18.04 bc	12.92 bc
CV (%)	8.17	9.02	15.86	17.71

1) Inorganic fertilizer applied every cropping cycle; manure applied up to the 3rd crop only.
2) Mean separation (DMRT, 0.05).
Source: *Quirol and Amora, 1987.*

Table 11. Effect of different sources of chemical fertilizer and manures on the soil chemical characteristics at the end of the sixth crop in ViSCA, Leyte, in 1986.

Fertilizer source[1)]	Chemical analysis[2)]		
	OM (%)	Olsen P (ppm)	NH_4 Ac-K (ppm)
To - Control	2.55	4.8	42.7
T1 - inorganic (60-60-60)	3.31	13.7	96.7
T2 - chicken manure (1.3 t/ha)	3.43	6.3	50.3
T3 - pig manure (3.4 t/ha)	3.56	8.2	48.3
T4 - cow manure (4.4 t/ha)	3.65	5.4	75.3
T5 - guano	3.75	4.7	44.7

1) Inorganic fertilizer applied every cropping; manure applied up to the 3rd crop only.
2) Initial : 2.94% OM, 9 ppm Olsen P and 148 ppm NH_4Ac-K
Source: *Quirol and Amora, 1987.*

In the Philippines, most areas grown to cassava are of marginal fertility. Thus, the application of the full fertilizer recommendation based on the level recommended by the Bureau of Soils, as determined through soil analyses, was the most profitable in five out of seven trials (Villamayor and Destriza, 1986), as shown in **Table 12.**. There was little or no response in two areas (Butigan II and Igang) which were near the river and have alluvial soils.

Table 12. Total root yield and net income of cassava (cv. Golden Yellow) without fertilizer (F_0), 1/2 the fertilizer recommendation (F_1), and full fertilizer recommendation (F_2) in various locations in Baybay, Leyte, in 1985.

Location and fertilizer recommendation (N-$P_2 0_5$-$K_2 0$ in kg/ha)	Total root yield (kg/ha)			Net income ('000 P/ha)[3]		
	F_0	F_1	F_2	F_0	F_1	F_2
Maganhan (35-35-35)	9.00	18.32	20.05	1.50	7.17	7.82
Igang [1] (50-50-50)	20.83	21.73	26.76	9.44	9.25	10.85
Cantagnos (40-30-30)	5.67	16.08	23.21	-1.52	4.47	8.29
Butigan I (40-30-30)	10.66	14.60	16.10	2.76	4.47	5.40
Butigan II[1] (40-30-00)	21.26	21.62	20.46	10.15	9.92	8.56
Can-ipa (40-30-00)	11.58	21.56	18.90[2]	4.07	10.30	7.69
Bubon	15.44	23.29	26.25	6.55	11.59	12.84

[1] Near the river
[2] Lodged at 6 months
[3] Exchange rate: $ 1 = P 20
Source: *Villamayor and Destriza, 1986.*

Application of green manures and animal manures increased cassava yields (Lauron, 1980; Lorenzo, 1980; Ratilla, 1983; Castroverde, 1983; Molina, 1983; Mirambel, 1983; PRCRTC, 1985; Pascual *et al.*, 1987; Quirol and Amora, 1987). As an example, the data of Mirambel (1983) on the effect of animal manures is shown in **Table 13**. Evangelio *et al*. (1995) also reported that green manures (cowpea, soybean, mungbean, and peanut) incorporated into the soil at any growth stage — vegetative, flowering or harvestable — did not affect the yield of cassava (Molina, 1983). This suggests that harvesting the pods may be possible before incorporating the crop residues into the soil, which is essentially the same as crop rotation.

The time of fertilizer applications, from planting to two months after planting, did not significantly affect cassava yields (Laguna, 1977; Abenoja, 1978; Cotejo and Talatala, 1978). This is illustrated in **Table 14**. However, if application was delayed to 90 days, yields were reduced (David, 1981). The best application time of complete fertilizer was ½ basal and ½ sidedressed one month after planting (MAP). Split application (1/4 each) at planting, one, two, and three MAP was the least effective among the application times used.

For most acidic soils, liming is not necessary since cassava usually does not respond to liming (Ramos and Mosica, 1982; PRCRTC, 1983; Pardales *et al*., 1984).

Almendras (1982) showed that mycorrhizal inoculation significantly increased the shoot P concentration and uptake in pot experiments.

Talatala (1982) showed that fertilization with 60-0-0 or 60-60-120 kg N-P_2O_5-K_2O/ha did not affect the HCN contents of the roots of three varieties of cassava at 6, 8, 10 and 12 MAP.

Table 13. Root yield of cassava (cv. Golden Yellow) and net return under various soil amendments in ViSCA, Baybay, Leyte, in 1982.

Type of soil amendment[1)]	Root yield[2)] (t/ha)	Net return[3)] (Pesos/ha)
Control	5.45 c	-1,773.21
10 tons coal ash/ha	6.88 c	-2,268.08
10 tons chicken manure/ha	14.04 b	4,128.78
10 tons cattle manure/ha	9.12 d	410.47
10 tons goat manure/ha	11.36 c	1,937.14
Inorganic fertilizer (60-60-90 kg N-P_20_5-K_20/ha)	16.82 a	4,107.57

[1)] Soil analysis: 4.7 pH, 1.24% OM, 13 ppm P, 141 ppm K
[2)] Mean separation (DMRT, 0.05)
[3)] Exchange rate: $ 1 = P 20
Source: *Mirambel, 1983.*

Table 14. Effect of fractionation of fertilizer application (90 kg N, 60 P_20_5 and 60 K_20/ha) on the root yield of cassava (cv. Golden Yellow) in ViSCA, Baybay, Leyte, in 1977.

Time of fertilizer application			Root yield[1)] (t/ha)
At planting	1 MAP	2 MAP	
Check (no fertilizers)	-	-	17.25 c
1/2 N, all P and K	1/2 N	-	31.62 a
1/3 N, all P and K	1/3 N	1/3 N	29.29 ab
1/3 N, 1/2 P and K	1/3 N, 1/2 P and K	1/3 N	30.13 a
1/2 N, all P and K	-	1/2 N	26.99 ab

[1)] Mean separation (DMRT, 0.05)
Note: Initial soil analysis: 2.0% OM, 19 ppm Olsen-P, 372 ppm H_2SO_4-extractable K
Source: *Abenoja, 1978.*

Topping/Pruning

Abenoja and Cerna (1983) found that removing the upper 15 cm of shoots at 4, 6 or 8 week intervals, starting at 4, 5 or 6 MAP, did not affect root yields. On the other hand, Villamayor and Labayan (1982) found that a single pruning of 20 cm shoot length or longer at 3 MAP reduced yields significantly. Santiago (1980) reported that topping at 2-3 MAP reduced yields significantly, while Araña (1979) reported an increased yield with pruning at 2 MAP. The differences may be due to the intensity of shoot removal, the variety, the time of pruning and the length of pruning. This was confirmed by Villamayor *et al*. (1992) who reported that cassava plants pruned at 30 cm above-ground at 6, 8 or 10 months after planting produced significantly higher root yields than unpruned plants 5 months after pruning, but not at 1 or 3 months after pruning.

In a pruning and planting distance trial, Evangelio and Ladera (1998) reported marked increases in cassava yields when the plant density was increased to 15,000-25,000 plants/ha, but no significant differences were observed when the age of pruning cassava was varied from 5 to 9 months after planting.

Soil Conservation

Studies on cultural practices to control soil erosion were conducted for six years to determine their effect on soil loss and yield of cassava. During the 1988/89 trial, Villamayor *et al*. (1992) reported that minimum tillage (weed-underbrushed plot) had the lowest soil loss, and the conventional tillage (clean-weeded plot) had the highest. However, the conventional tillage/fertilized plot had the highest yield. In the 1989/90 trial, the same group of investigators observed that conventional tillage/fertilized plot had the highest yield and soil loss, while the conventional tillage/*Desmodium ovalifolium* intercropped plot had the lowest soil loss, but also the lowest yield. Similar results were obtained in 1990/91.

Evangelio *et al*. (1995) reported that during the 1991/92 erosion control trial, large soil losses were obtained in plots where vetiver or lemon grass had been recently planted as contour barriers, especially during the first year of establishment. Application of grass mulch continued to be the most effective treatment in reducing erosion, while it also resulted in the highest yield. During the 1992/93 cropping cycle, it was observed that plots with complete fertilizer (60-60-60 kg/ha) application had the highest soil loss, while plots with the application of mulch had again the lowest. Root yields were highest with the application of mulch and lowest in plots with lemon and vetiver grass barriers. Evangelio and Ladera (1998) reported similar findings for the 1993/94 trial (**Table 15**).

Harvesting

To get a maximum return the crop should be harvested at the right time. If harvested early, yields will be low and roots may still be fibrous. The right time of harvest depends on the variety. Harvesting is the most expensive operation in cassava production. A cassava grower of Bohol mentioned that harvesting costs accounted for 20% of his expenses. He pays ₱50.00/t for harvesting, which includes sacking. For fast and cheaper harvesting, the use of a carabao drawn plow is recommended. If the soil is hard, manual harvesting can be facilitated by a harvesting aid that grasps the stem as it is raised (Bandalan, 1985; Anon, 1985).

Table 15. Cassava yield and soil loss due to erosion during six cropping cycles of cassava grown under various cultural practices on 25% slope in Baybay, Leyte, Philippines from 1988 to 1994.

Treatments[1)]	Root yield (t/ha)[2)]	Soil loss (t/ha)[2)]
First cropping 1988/89 (2153 mm rainfall)		
CT with clean culture	5.3 c	190 a
Strip tillage	2.6 d	10 f
MT with herbicide	1.6 d	21 ef
MT with underbrushing	1.3 d	3 f
CT with 60-60-60 fertilizer	9.2 a	114 d
CT with sweetpotato intercrop	0.8 e	138 c
CT with *Gliricidia sepium* hedgerows	4.1 c	173 b
CT with dried grass mulch	7.5 b	31 e
CT with *Desmodium ovalifolium* intercrop	1.1 d	188 a
CT with underbrushing	9.2 a	113 d
CT with stone walls	3.5 a	65 e
Second cropping 1989/90 (1673 mm rainfall)		
CT with *Desmodium ovalifolium* intercrop	4.0 c	6.2 d
CT with 60-60-60 fertilizer	33.1 a	37.3 a
CT with *Gliricidia sepium* hedgerows	15.7 b	31.6 b
CT with dried grass mulch	28.2 a	9.7 d
CT with *Cajanus cajan* hedgerows	19.1 b	15.4 c
Third cropping 1990/91 (2526 mm rainfall)		
CT with *Desmodium ovalifolium* intercrop	5.3 e	0.7 c
CT with 60-60-60 fertilizer	16.4 b	7.9 ab
CT with *Gliricidia sepium* hedgerows	9.0 d	8.4 a
CT with dried grass mulch	19.5 a	6.1 b
CT with *Cajanus cajan* hedgerows	13.3 c	6.3 ab
Fourth cropping 1991/92 (1867 mm rainfall)		
CT with lemon grass hedgerows	18.9 b	62.8 ab
CT with 60-60-60 fertilizer	26.0 a	52.7 b
CT with vetiver hedgerows	18.9 b	70.8 a
CT with dried grass mulch	28.1 a	28.0 c
CT with *Crotalaria juncea* intercrop	17.5 b	31.0 c
Fifth cropping 1992/93 (2188 mm rainfall)		
CT with lemon grass hedgerows	12.7 d	21.7 c
CT with 60-60-60 fertilizer	25.6 b	39.8 a
CT with vetiver hedgerows	13.1 d	20.7 c
CT with dried grass mulch	32.1 a	6.6 d
CT with *Crotalaria juncea* intercrop	17.8 c	30.3 b

(Table 15 continued**)**

Treatments[1)]	Root yield (t/ha)[2)]	Soil loss (t/ha)[2)]
Sixth cropping 1993/94 (3154 mm rainfall)		
CT with lemongrass hedgerows	3.5 c	17.9 c
CT with 60-60-60 fertilizers	8.4 bc	45.0 a
CT with vetiver hedgerows	5.7 c	8.1 d
CT with dried grass mulch	14.5 a	10.7 d
CT with *Crotalaria juncea* intercrop	10.7 b	28.5 b

[1)] CT = conventional tillage (clean weeded by hand before planting) ; MT = minimum tillage
[2)] Mean separation: DMRT (0.05)
Source: *Evangelio et al., 1995.*

Cropping Systems

Intercropping legumes, like peanut, soybean, mungbean, cowpea, pigeon pea and bush sitao, oftentimes did not significantly reduce the yield of cassava (Pagaran, 1981; Tabugan, 1982; Villanueva, 1983; PRCRTC, 1983). Some researchers even reported an increase in yield of cassava (Laguna, 1982; Corpin, 1977)). However, others showed a significant reduction in yield (Evangelio and Posas, 1983; Alava, 1980). Obviously, the results vary with differences in the kind of intercrop, the spacing used, the growth duration, the time of planting the main crop and intercrop, the fertility of the soil, and the climatic conditions.

Evangelio and Posas (1983) found that maximum economic benefits were obtained when root crops and legumes in an intercropping system were planted at the same time. Alava (1980) showed that intercropping with bush sitao (*Vigna unguiculata* x *Vigna sesquipedalis*) produced better yields and income than intercropping with maize. Furthermore, maize or bush sitao planted between and within cassava rows produced the highest yield compared with those planted within cassava rows, mainly because of differences in population density. Also the yield of cassava intercropped with maize was lower than that of the monocrop.

Villamayor and Destriza (unpublished data) found that one hill of sweet corn between cassava hills did not significantly affect the yield of cassava, while two hills of sweet corn did. However, even a single hill of field corn between cassava hills reduced the yield of cassava because of the longer growth duration of field corn compared with sweet corn.

To obtain the maximum benefit from the intercrops, it is necessary to determine the best population density. Laguna (1982) found two rows of mungbean was optimum considering both the yields of cassava and mungbean. Also, Villamayor and Destriza (1981) found no advantage in having more than three rows of mungbean between cassava planted in a double row system.

In hillsides, contour strips of ipil-ipil (*Leucaena leucocephala*) planted at an interval of 3 meters and spaced 15 cm apart resulted in a reasonable yield of intercropped cassava, but the cassava monocrop produced higher yields (Escalada, 1981). On the other hand, Pascual *et al*. (1986) found that the width of the ipil-ipil buffer strip, varying from 1 to 2.5 m, did not significantly affect cassava yields, in spite of the reduction of cassava population as a result of the ipil-ipil strips. Padullo (1983) found that ipil-ipil grown in between cassava may or may not affect root yields depending on the spacing between ipil-ipil hills. Erosion was minimized, especially at 10 cm spacing between ipil-ipil hills. Pascual *et al*. (1987) found that cassava planted in between strips of N fixing trees, with their pruning applied to the soil, had a similar yield as monocropped cassava applied with 60-40-40 kg of N-P_20_5-K_20/ha.

Crop rotation is recommended, especially with legumes to minimize nutrient depletion. Escalada *et al*. (1983) found that when cassava was rotated with legumes the yield reduction was less than when cassava was grown continuously as a monocrop. A verification trial conducted by Javier and Laranang (1987) showed that cassava rotated with peanut produced a less economic benefit compared with successive croppings of cassava or cassava alternated with fallow.

In an intercropping trial conducted in Bohol (Evangelio and Ladera (1998) even after three cropping cycles cassava yields were not significantly affected by interplanting of either soybean, mungbean, cowpea, peanut or pole sitao (yard-long bean). However, row spacing significantly affected the yields of cassava and intercrops

ADOPTION

In the Philippines, there are about 2 million farming households dependent on cassava. However, over the years, these cassava farmers are still slow in adopting the technology developed by research institutions. In subsistence type agriculture, which accounts for 50% of the Filipino farming households, very few farmers adopt the new varieties; for the small-scale commercial types, which accounts for 33.33%, the farmers used both new varieties and improved cultural practices. While for commercial or plantation types (16.67%) all the production technologies, such as new varieties, improved cultural practices and fertilizers, are used.

FUTURE DIRECTIONS

With more intense competition resulting from trade liberalization, there is a need for tremendous transformation of cassava production technologies in the country, in order to make it more competitive. Thus, the integrated national rootcrops RD/E program addresses these goals in transforming cassava agriculture in the Philippines.

The national RDE program on rootcrops is focused on improving and expanding specific sectors of a rootcrop industry, namely: food, feed and starch. Development and expansion of these specific industry sectors will be attempted through the generation and promotion of appropriate technologies, provision of adequate support services, and the advocation of favorable policies for the industry. This endeavor, however, should be market-led, based on advanced and sustainable technologies, highly integrated and participatory.

CONCLUSION

Cassava agriculture in the Philippines still lags behind other Asian neighbors. But, given adequate support, it is reasonable to expect productivity and profitability of rootcrops to rapidly improve compared to other crops that have already been supported tremendously.

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EFFECT OF DATE OF PLANTING AND RAINFALL DISTRIBUTION ON THE YIELD OF FIVE CASSAVA VARIETIES IN LAMPUNG, INDONESIA

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ABSTRACT

Improved cassava varieties have been widely disseminated to farmers in Lampung and this has resulted in substantial economic gains to both factories and farmers. But, considering that the rainfall distribution in Lampung province is not uniform and that there is a prolonged dry period about every three years, it is important to know the response of each variety to drought during its growth cycle. In this way, varieties with greater drought tolerance can be selected before being disseminated to farmers and planted throughout the year. Thus, an experiment was conducted to study the effect of dry periods during different stages of the growth cycle on cassava yield and starch production of five selected varieties in Umas Jaya Farm (UJF).

Five selected varieties, i.e. Adira 4, Rayong 60, Rayong 90, Kasetsart 50, and CMR30-56-1, were planted in plots with an effective plot size of 0.1 ha, without replication. Subplots of each variety were planted every month starting in July, 1996. At harvest, fresh root yields and root starch contents (using the Reimann scale) were determined, and from those starch production was calculated.

The effect of planting dates and rainfall on the root yield, starch content and starch yield of the various varieties showed a decrease in root yield when the crop was subjected to a dry period, defined here as a period of two or more months with less than 100 mm rainfall; the decrease ranged from 14.88 t/ha for Kasetsart 50 to 20.11 t/ha for Rayong 60. Without a dry period during the growth cycle, the average fresh root yields did not differ significantly among varieties, ranging from 38.39 to 44.02 t/ha.

The average starch content was higher without than with a dry period. However, in four of the five varieties (Kasetsart 50 being the exception) the highest starch content was observed when cassava was subjected to two or three dry months just prior to harvest.

Average starch yields of all varieties were reduced by about 50% when plants were subjected to a dry period during the growth cycle, as compared to those receiving uniform rainfall without a dry period. When subjected to drought stress, the lowest starch yield was obtained with Adira 4, and the highest with CMR30-56-1.

In conclusion, when subjected to a long dry period during the growth cycle, both the fresh root yield and starch yield of all tested varieties decreased. But, under non-uniform rainfall distribution, the fresh root yields of Rayong 60, Kasetsart 50 and CMR30-56-1 were much higher than that of Adira 4, and the starch yields of all four varieties were also higher than that of Adira 4. Under uniform rainfall distribution, starch yields of Rayong 90, Kasetsart 50 and CMR30-56-1 were higher than those of Adira 4 and Rayong 60. A dry period from the 3rd to the 8th month after planting is the most critical in reducing both the root and starch yields as well as the starch content of all tested varieties.

INTRODUCTION

Lampung province is the main producer of cassava starch in Indonesia. In 1996 the area planted to cassava in the province was about 183,000 ha (Puspitorini *et al*., 1996). Even in 1997 when Indonesia suffered a severe drought, the cassava planted area increased as compared to previous years. The expansion of area was not accompanied by an increase

[1] Umas Jaya Farm (UJF), Great Giant Pineapple Co., Lampung, Indonesia.

in the average national yield, which remained stable at 11.4 t/ha (Koeshartoyo and Wargiono, 1999).

Due to the disuniform rainfall distribution throughout the year, farmers usually plant cassava at the beginning of the wet season and harvest during the dry season. As a consequence, there is an eneven availability of raw material for starch processing and great fluctuations in the fresh root price occur almost every year.

Improved cassava varieties have quickly been disseminated to farmers in Lampung and this has resulted in substantial economic gains to both factories and farmers (Puspitorini *et al.*, 1996). Considering that the rainfall distribution is not uniform and that there is a prolonged dry period about every three years, it is important to know the response of each variety to drought during its growth cycle. In this way, varieties with greater drought tolerance can be selected before being disseminated to farmers and planted throughout the year. Thus, an experiment was conducted to study the effect of dry periods during different stages of the growth cycle on cassava yield and starch production of five selected varieties in Umas Jaya Farm (UJF).

MATERIALS AND METHODS

The experiment was conducted at the Umas Jaya Farm (UJF) Research Station in Central Lampung located at $4^0$49' S and $105^0$13' E, and at an altitude of 25 m above sea level. The soil is classified as a loamy Aquic Dystropept and has a pH of 4.5. The agroclimate of the area is classified as type C-2 (Oldeman *et al.*, 1979), i.e. it has 5-6 wet months and 2-3 dry months in the years, where a wet month is defined as having >200 mm rainfall and a dry month as having <100 mm rainfall.

Five selected varieties, i.e. Adira 4, Rayong 60, Rayong 90, Kasetsart 50 and CMR30-56-1, were planted in plots with an effective plot size of 0.1 ha, without replication. Subplots of each variety were planted every month starting in July 1996; fertilizers were applied at a rate of 200 kg urea, 100 TSP and 100 KCl/ha. Each subplot was harvested ten months after planting. Up to May 1999 there had been 25 planting and harvesting times. At harvest, fresh root yields and root starch contents (using the Reimann scale) were determined, and from those the starch yield was calculated.

RESULTS AND DISCUSSION

1. Effect of Rainfall on Fresh Root Yield

The effect of planting dates and rainfall on the root yield, starch content and starch yield of the various varieties are shown in **Table 1**. Although cassava can adapt well to a water shortage by reducing its leaf canopy, when it is subjected to a long dry period during its growth cycle, this will usually lead to a reduction in root yield. Of the 25 cropping cycles, in 23 cycles cassava was subjected to two or more months of drought (<100 mm rainfall), while in the other 2 cycles there was no such dry period and the rainfall distribution was thus considered uniform.

Table 1. Effect of date of planting and rainfall during the growth cycle on the fresh root yield, starch content and starch yield of five varieties grown in Umas Jaya Farm, Lampung, Indonesia from 1996 to 1999.

Planting month	Harvest month	Rainfall (mm)[1]	No. dry months (<60mm)	Fresh root yield (t/ha)					Starch content (%)					Starch yield (t/ha)				
				Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1	Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1	Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1
Jul-96	May-97	2,092	0	43.06	46.13	48.68	34.38	43.87	26.82	24.46	24.96	30.56	27.34	11.55	11.28	12.15	10.51	11.99
Aug-96	Jun-97	1,989	1	39.30	41.91	37.19	42.39	42.10	28.90	25.95	31.54	32.10	28.40	11.36	10.88	11.73	13.61	11.96
Sep-96	Jul-97	1,780	2	23.13	17.24	24.79	18.04	22.57	27.40	28.20	30.12	29.20	28.80	6.34	4.86	7.47	5.27	6.50
Oct-96	Aug-97	1,656	3	17.68	22.42	25.13	26.88	34.87	29.20	28.32	31.50	27.87	28.26	5.16	6.35	7.91	7.49	9.85
Nov-96	Sep-97	1,561	4	21.34	28.07	21.30	27.01	29.82	24.94	26.18	25.44	24.72	24.22	5.32	7.35	5.42	6.68	7.22
Dec-96	Oct-97	1,412	5	18.68	19.76	18.80	22.00	23.58	22.86	25.28	22.24	21.88	20.94	4.27	5.00	4.18	4.81	4.94
Jan-97	Nov-97	1,059	5	11.83	18.49	13.94	18.00	21.67	16.86	19.68	17.04	18.22	12.15	1.99	3.64	2.38	3.28	2.63
Feb-97	Dec-97	1,094	5	8.86	14.77	14.00	15.70	17.38	11.08	20.00	17.06	16.44	15.18	0.98	2.95	2.39	2.58	2.64
Mar-97	Jan-98	789	5	9.36	17.91	11.54	12.24	14.30	11.86	16.22	19.36	17.90	14.47	1.11	2.91	2.23	2.19	2.07
Apr-97	Feb-98	1,407	5	28.98	27.98	16.07	15.73	21.44	12.20	21.25	19.10	22.25	19.50	3.54	5.95	3.07	3.50	4.18
May-97	Mar-98	1,719	5	12.05	26.49	14.39	17.33	25.93	18.90	19.50	21.70	20.70	20.10	2.28	5.17	3.12	3.59	5.21
Jun-97	Apr-98	1,869	4	29.26	29.26	24.12	21.53	31.34	17.00	17.85	19.20	20.05	17.75	4.97	5.22	4.63	4.32	5.56
Jul-97	May-98	2,012	3	17.07	15.63	6.17	13.81	20.15	18.16	16.17	15.80	20.60	16.00	3.10	2.53	0.97	2.84	3.22
Aug-97	Jun-98	2,080	3	12.91	16.74	17.74	17.54	20.35	17.86	19.16	20.46	19.40	18.86	2.31	3.21	3.63	3.40	3.84
Sep-97	Jul-98	2,212	2	20.64	14.07	12.37	24.11	24.72	16.20	17.80	16.80	18.00	20.00	3.34	2.50	2.08	4.34	4.94
Oct-97	Aug-98	2,322	2	25.27	19.31	19.95	13.15	26.90	21.10	26.30	22.50	18.00	23.50	5.33	5.08	4.49	2.37	6.32
Nov-97	Sep-98	2,385	3	25.21	20.00	25.79	24.19	36.74	20.20	24.00	24.50	21.40	22.90	5.09	4.80	6.32	5.18	8.41
Dec-97	Oct-98	2,157	3	27.23	29.16	26.25	28.94	25.29	18.80	22.70	20.60	21.30	22.50	5.12	6.62	5.41	6.16	5.69
Jan-98	Nov-98	1,928	3	30.00	24.92	21.05	27.84	12.00	21.40	23.60	24.10	24.90	26.30	6.42	5.88	5.07	6.93	3.16
Feb-98	Dec-98	1,285	3	27.26	25.91	21.01	27.41	27.94	22.20	21.70	24.50	24.30	23.50	5.99	6.06	4.87	5.76	6.57
Mar-98	Jan-99	2,063	3	34.49	33.72	33.10	33.31	34.49	22.20	21.70	24.50	24.30	23.50	7.66	7.32	8.11	8.09	8.11
Apr-98	Feb-99	1,992	3	32.23	25.00	23.75	30.67	36.79	20.90	23.40	23.50	24.00	23.30	6.74	5.85	5.58	7.36	8.57
May-98	Mar-99	2,025	3	29.81	32.55	45.53	34.17	46.34	26.33	24.18	25.42	26.95	25.02	7.85	7.87	11.57	9.21	11.59
Jun-98	Apr-99	2,086	2	23.89	31.17	48.94	30.63	37.01	22.70	25.10	26.40	24.70	25.30	5.42	7.82	12.92	7.57	9.36
Jul-98	May-99	2,095	2	32.27	39.28	44.25	40.54	35.60	25.70	27.30	26.70	29.10	26.50	8.29	10.72	11.81	11.80	9.43
Avg.				**24.07**	**25.52**	**24.63**	**24.70**	**28.53**	**20.87**	**22.64**	**23.00**	**23.15**	**22.17**	**5.26**	**5.91**	**5.98**	**5.95**	**6.56**

[1] During growth period [2] Dry period = two or more dry months (<60 mm rainfall)

All tested varieties showed a significant decrease in root yield when subjected to a long dry period (**Table 2** and **Figure 1**). The extent of the decrease in average fresh root yield due to drought differed among varieties, ranging from 14.88 t/ha for Kasetsart 50 to 20.11 t/ha for Rayong 60. When subjected to a long dry period Adira 4 produced the lowest yields (22.58 t/ha) while CMR30-56-1 had the highest yield (27.27 t/ha). Without a dry period during the growth cycle the average fresh root yields did not differ significantly among varieties, ranging from 38.39 to 44.02 t/ha.

Table 2. The effect of a long dry period during the growth cycle on the average yield of five selected varieties grown in Umas Jaya Farm, Lampung, Indonesia, from 1996 to 1999.

	Average fresh root yield (t/ha)		Decrease due to drought	
Variety	With dry period[1)]	Without dry period	Root yield (t/ha)	(%)
Adira 4	22.58 a	41.18 b	18.60	45
Rayong 60	23.91 a	44.02 b	20.11	46
Rayong 90	23.04 a	42.94 b	19.90	46
Kasetsart 50	23.51 a	38.39 b	14.88	39
CMR30-56-1	27.27 a	42.99 b	15.72	37

[1)] two or more months with <100 mm rainfall.

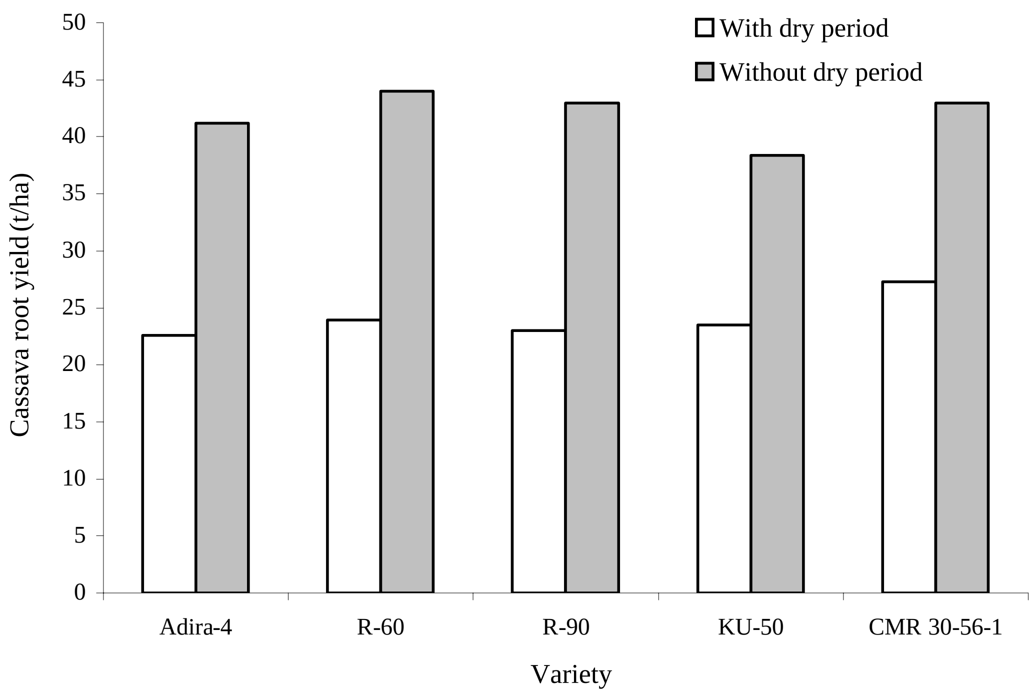

Figure 1. Effect of the presence of a prolonged dry period (two months or more of less than 100 mm rainfall) on the average root yields of five selected cassava varieties grown in Umas Jaya Farm, Lampung, Indonesia from 1996 to 1999.

The greatest decrease in yield of all varieties was found when the dry period occurred from the 3rd to the 7th month or from the 4th to the 8th month after planting; in that case the root yields ranged from 8.86 to 17.91 t/ha (**Table 3**). These yields were generally much lower than those obtained when the dry periods occurred at other times during the growth cycle. This indicates that adequate water availability between 3 and 8 months after planting is very important to maintain optimum plant metabolism and growth necessary for root bulking. Similar results were also reported by Zhang Weite *et al*. (1998) and by CIAT (1998).

Table 3. Fresh root yield of five selected varieties when affected by a dry period during various stages of the growth cycle.

Planting dates	Harvesting dates	Total rainfall (mm)	Dry months[1] (month after planting)	Fresh root yield (t/ha)					
				Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1	Average
29-Sep-96	21-Jul-97	1780	9,10	23.13	17.24	24.79	18.04	22.57	21.15
24-Oct-96	29-Aug-97	1656	8,9,10	17.68	22.42	25.13	26.88	34.87	25.40
18-Nov-96	17-Sep-97	1561	7,8,9,10	21.34	28.07	21.30	27.01	29.82	25.51
26-Dec-96	17-Oct-97	1412	6,7,8,9,10	18.68	19.76	18.80	22.00	23.58	20.56
24-Jan-97	11-Nov-97	1059	5,6,7,8,9	11.83	18.49	13.94	18.00	21.67	16.79
28-Feb-97	29-Dec-97	1094	4,5,6,7,8	8.86	14.77	14.00	15.70	17.38	14.14
24-Mar-97	19-Jan-98	789	3,4,5,6,7	9.36	17.91	11.54	12.24	14.30	13.07
29-Apr-97	26-Feb-98	1407	2,3,4,5,6	28.98	27.98	16.07	15.73	21.44	22.04
23-May-97	23-Mar-98	1719	1,2,3,4,5	12.05	26.49	14.39	17.33	25.93	19.24
25-Jun-97	25-Apr-98	1869	1,2,3,4	29.26	29.26	24.12	21.53	31.34	27.10
30-Jul-97	13-May-98	2012	1,2,3	17.07	15.63	6.17	13.81	20.15	14.57
5-Aug-97	5-Jun-98	2080	1,2,10	12.91	16.74	17.74	17.54	20.35	17.06
9-Sep-97	7-Jul-98	2212	1,9	20.64	14.07	12.37	24.11	24.72	19.18
25-Oct-97	27-Aug-98	2323	8,10	25.27	19.31	19.95	13.15	26.90	20.92
24-Nov-97	30-Sep-98	2385	7,9,10	25.21	20.00	25.79	24.19	36.74	26.39
28-Dec-97	27-Oct-98	2157	6,8,9	27.23	29.16	26.25	28.94	25.29	27.37
20-Jan-98	22-Nov-98	1928	5,7,8	30.00	24.92	21.05	27.84	12.00	23.16
28-Feb-98	28-Dec-98	1285	4,6,7	27.26	25.91	21.01	27.41	27.94	25.91
14-Mar-98	12-Jan-99	2063	3,5,6	34.49	33.72	33.10	33.31	34.49	33.82
1-Apr-98	5-Feb-99	1992	2,4,5	32.23	25.00	23.75	30.67	36.79	29.69
5-May-98	5-Mar-99	2025	1,3,4	29.81	32.55	45.53	34.17	46.34	37.68
5-Jun-98	5-Apr-99	2086	2,3	23.89	31.17	48.94	30.63	37.01	34.33
5-Jul-98	5-May-99	2095	1,2	32.27	39.28	44.25	40.54	35.60	38.39
Average		1782		22.58	23.91	23.04	23.51	27.27	24.06

[1] <100 mm rainfall.

The fresh root yield of all varieties were significantly reduced with an increase in the length of the dry period, with r-values ranging from 0.79 to 0.80, except for Rayong 60 where r was only 0.31 (**Figure 2**). In general, the decrease in fresh root yield was greater when the dry period was longer.

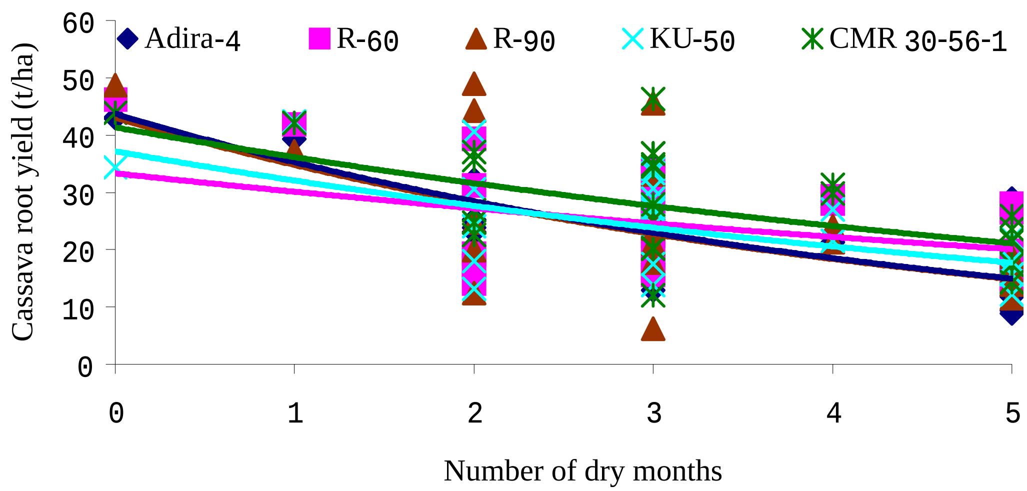

Figure 2. Effect of the duration of the dry period (less than 100 mm rainfall per month) on the fresh root yields of five selected varieties grown in Umas Jaya Farm, Lampung, Indonesia from 1996 to 1999.

However, when cassava grew under uniform rainfall conditions, the fresh root yield was not positively correlated with total rainfall during the growth cycle. Fresh root yields of all varieties were almost the same under these conditions (**Table 4**). Even though total rainfall was not so high, as long as the distribution was more or less uniform it was sufficient to meet the crop's requirement throughout the growth cycle. As a result, the yield did not differ significantly with differences in total rainfall.

Tabel 4. Fresh root yield of five selected varieties when not affected by a dry period during the growth cycle.

Planting dates	Harvesting dates	Total Rainfall (mm)	Dry months[1] (month after planting)	Fresh root yield (t/ha)					
				Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1	Average
24-Jul-96	25-May-97	2092	None	43.06	46.13	48.68	34.38	43.87	43.22
24-Aug-96	20-Jun-97	1989	10	39.30	41.91	37.19	42.39	42.10	40.58
Average		2041		41.18	44.02	42.94	38.39	42.99	41.90

[1] <100 mm rainfall.

2. Effect of Rainfall on Starch Content

If the price of fresh roots is also determined by its starch content, the higher the starch content of the cassava variety the more profitable for both farmers and factories. For that reason, root starch content is a very important criterion in varietal selection, especially when cassava is cultivated in upland areas with an uneven rainfall distribution.

Table 5 shows the effect of having a dry period or not on root starch content. With a dry period of two months or more the starch content varied from 20.26% in Adira 4 to 22.44% in Kasetsart 50. Without a dry period the starch content varied from 25.21% in Rayong 60 to 31.33% in Kasetsart 50. The starch content of all varieties was higher in the absence of a dry period and these differences were highly significant.

Table 5. The effect of a long dry period during the growth cycle on the average starch content of five selected varieties grown in Umas Jaya Farm, Lampung, Indonesia, from 1996 to 1999.

	Average starch content (%)		Decrease due to drought	
Variety	With dry period[1)]	Without dry period	Starch content (%)	(%)
Adira 4	20.26 a	27.86 b	7.60	27
Rayong 60	22.42 a	25.21 b	2.79	11
Rayong 90	22.55 a	28.25 b	5.70	20
Kasetsart 50	22.44 a	31.33 b	8.89	28
CMR30-56-1	21.68 a	27.87 b	6.19	22

[1)] two or more months with <100 mm rainfall.

Tables 6 and **7** show that in all varieties except Kasetsart 50 the highest starch content was encountered when there was a dry period during the last 1-3 months before harvest. This was also observed in China (Zhang Weite, 1996; Zhang Weite *et al*., 1998) and in two experiments conducted in Thailand (Tongglum *et al*., 1992; CIAT Annual Report, 1998). The starch content decreased, however, when the dry period before harvest extended for more than 2-3 months. The starch content was lowest when the dry period extended for five months, especially if this occurred towards the middle of the growth cycle, i.e. from the 3rd to the 7th or 8th month. When there was no dry period during the growth cycle the starch content was not much affected by date of planting (**Table 7**); on average, the starch content ranged from 25.21% for Rayong 60 to 31.33% for Kasetsart 50.

3. Effect of Rainfall on Starch Yield

Average starch yields of all varieties were reduced by about 50% when plants were subjected to a prolonged dry period during the growth cycle, as compared with those receiving uniform rainfall without a long dry period (**Table 8** and **Figure 3**). When the crop was subjected to a long dry period, the lowest starch yield was obtained with Adira 4, and the highest with CMR30-56-1; without a dry period the lowest starch yield was obtained with Rayong 60 and the highest with Kasetsart 50.

Table 6. Starch content of five selected varieties when affected by a dry period during various stages of the growth cycle.

Planting date	Harvesting date	Total rainfall (mm)	Dry months[1)] (month after planting)	Starch content (%)					
				Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1	Average
29-Sep-96	21-Jul-97	1,780	9,10	27.40	28.20	30.12	29.20	28.80	28.74
24-Oct-96	29-Aug-97	1,656	8,9,10	29.20	28.32	31.50	27.87	28.26	29.03
18-Nov-96	17-Sep-97	1,561	7,8,9,10	24.94	26.18	25.44	24.72	24.22	25.10
26-Dec-96	17-Oct-97	1,412	6,7,8,9,10	22.86	25.28	22.24	21.88	20.94	22.64
24-Jan-97	11-Nov-97	1,059	5,6,7,8,9	16.86	19.68	17.04	18.22	12.15	16.79
28-Feb-97	29-Dec-97	1,094	4,5,6,7,8	11.08	20.00	17.06	16.44	15.18	15.95
24-Mar-97	19-Jan-98	789	3,4,5,6,7	11.86	16.22	19.36	17.90	14.47	15.96
29-Apr-97	26-Feb-98	1,407	2,3,4,5,6	12.20	21.25	19.10	22.25	19.50	18.86
23-May-97	23-Mar-98	1,719	1,2,3,4,5	18.90	19.50	21.70	20.70	20.10	20.18
25-Jun-97	25-Apr-98	1,869	1,2,3,4	17.00	17.85	19.20	20.05	17.75	18.37
30-Jul-97	13-May-98	2,012	1,2,3	18.16	16.17	15.80	20.60	16.00	17.35
5-Aug-97	5-Jun-98	2,080	1,2,10	17.86	19.16	20.46	19.40	18.86	19.15
9-Sep-97	7-Jul-98	2,212	1,9	16.20	17.80	16.80	18.00	20.00	17.76
25-Oct-97	27-Aug-98	2,323	8,10	21.10	26.30	22.50	18.00	23.50	22.28
24-Nov-97	30-Sep-98	2,385	7,9,10	20.20	24.00	24.50	21.40	22.90	22.60
28-Dec-97	27-Oct-98	2,157	6,8,9	18.80	22.70	20.60	21.30	22.50	21.18
20-Jan-98	22-Nov-98	1,928	5,7,8	21.40	23.60	24.10	24.90	26.30	24.06
28-Feb-98	28-Dec-98	1,285	4,6,7	22.20	21.70	24.50	24.30	23.50	23.24
14-Mar-98	12-Jan-99	2,063	3,5,6	22.20	21.70	24.50	24.30	23.50	23.24
1-Apr-98	5-Feb-99	1,992	2,4,5	20.90	23.40	23.50	24.00	23.30	23.02
5-May-98	5-Mar-99	2,025	1,3,4	26.33	24.18	25.42	26.95	25.02	25.58
5-Jun-98	5-Apr-99	2,086	2,3	22.70	25.10	26.40	24.70	25.30	24.84
5-Jul-98	5-May-99	2,095	1,2	25.70	27.30	26.70	29.10	26.50	27.06
Average		1,782		20.26	22.42	22.55	22.44	21.68	21.87

1) <100 mm rainfall.

Table 7. Starch content of five selected varieties when not affected by a long dry period during the growth cycle.

Planting date	Harvesting date	Total rainfall (mm)	Dry months[1)] (month after planting)	Starch content (%)					
				Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1	Average
24-Jul-96	25-May-97	2,092	None	26.82	24.46	24.96	30.56	27.34	26.83
24-Aug-96	20-Jun-97	1,989	10	28.90	25.95	31.54	32.10	28.40	29.38
Average		2,041		27.86	25.21	28.25	31.33	27.87	28.10

1) <100 mm rainfall.

Table 8. The effect of a long dry period during the growth cycle on the average starch yield of five selected varieties grown in Umas Jaya Farm, Lampung, Indonesia from 1996 to 1999.

Variety	Average starch content (t/ha)		Decrease due to drought	
	With dry period[1)]	Without dry period	Starch yield (t/ha)	(%)
Adira 4	4.72 a	11.46 b	6.74	59
Rayong 60	5.46 a	11.08 b	5.62	51
Rayong 90	5.46 a	11.94 b	6.48	54
Kasetsart 50	5.42 a	12.06 b	6.64	55
CMR30-56-1	6.09 a	11.98 b	5.89	49

[1)] two or more months with <100 mm rainfall.

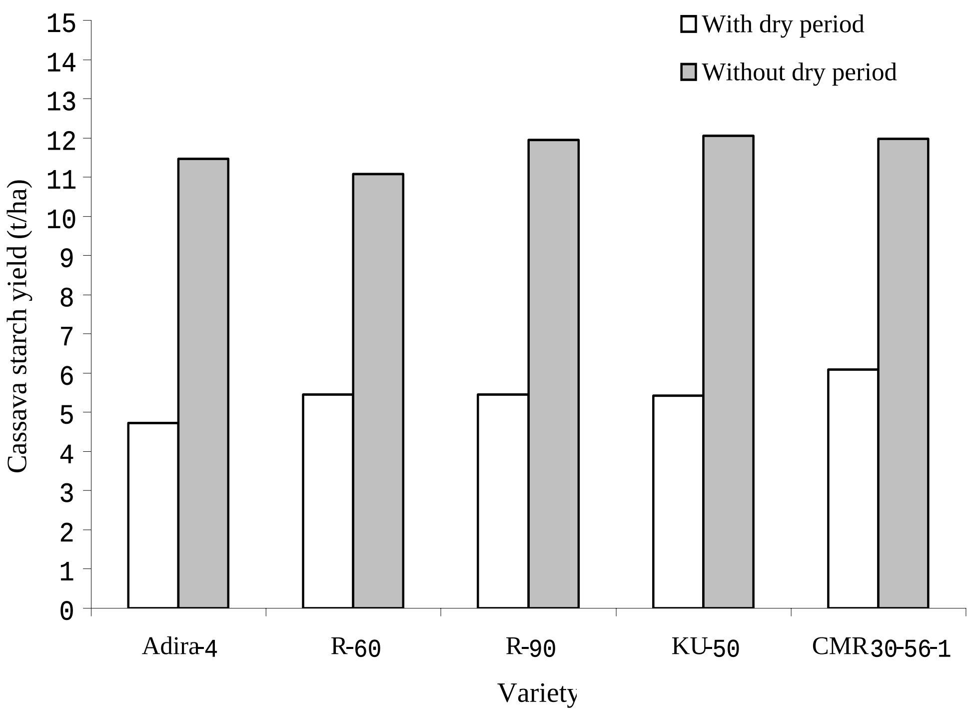

Figure 3. Effect of the presence of a prolonged dry period (two months or more of less than 100 mm rainfall) on the average starch yield of five selected cassava varieties grown in Umas Jaya Farm, Lampung, Indonesia from 1996 to 1999.

When affected by a dry period, CMR30-56-1 produced 29% more starch (1.37 t/ha) than Adira 4; under uniform rainfall distribution, the starch yield of CMR30-56-1 was only 4.5% higher (0.52 t/ha) than that of Adira 4. The starch yields of all four varieties were higher than those of Adira 4 when subjected to a dry period (**Table 8**). This indicates that Adira 4 was the least drought tolerant, while CMR 30-56-1 was the most drought tolerant variety.

The greatest reduction in starch yield was found when plants were subjected to a 5-month dry period, either from the 3rd to the 7th month or from the 4th to the 8th month after planting. When a prolonged drought occurred during these periods, starch yields were very low, ranging from 0.98 to 2.95 t/ha (**Table 9**). These yield were much lower than those obtained under a uniform rainfall distribution; these ranged from 10.88 to 13.61 t/ha (**Table 10**). Starch yields of Adira 4 were usually lower than those of the other tested varieties when subjected to a dry period of 2 to 5 months (**Table 9**).

Similar to fresh root yields, starch yields were also significantly reduced by an increase in the length of the dry period. There was a negative correlation between the length of the dry period and starch yields, with r-values ranging from 0.751 to 0.997 (**Figure 4**). Starch yields of Adira 4 were usually lower than those of other varieties when subjected to a dry period of more than two months.

Table 9. Starch yield of five selected varieties when affected by a dry period during various stages of the growth cycle.

Planting Date	Harvesting date	Total rainfall (mm)	Dry months[1] (month after planting)	Starch yield (t/ha) Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1	Average
29-Sep-96	21-Jul-97	1780	9,10	6.34	4.86	7.47	5.27	6.50	6.09
24-Oct-96	29-Aug-97	1656	8,9,10	5.16	6.35	7.91	7.49	9.85	7.35
18-Nov-96	17-Sep-97	1561	7,8,9,10	5.32	7.35	5.42	6.68	7.22	6.40
26-Dec-96	17-Oct-97	1412	6,7,8,9,10	4.27	5.00	4.18	4.81	4.94	4.64
24-Jan-97	11-Nov-97	1059	5,6,7,8,9	1.99	3.64	2.38	3.28	2.63	2.78
28-Feb-97	29-Dec-97	1094	4,5,6,7,8	0.98	2.95	2.39	2.58	2.64	2.31
24-Mar-97	19-Jan-98	789	3,4,5,6,7	1.11	2.91	2.23	2.19	2.07	2.10
29-Apr-97	26-Feb-98	1407	2,3,4,5,6	3.54	5.95	3.07	3.50	4.18	4.05
23-May-97	23-Mar-98	1719	1,2,3,4,5	2.28	5.17	3.12	3.59	5.21	3.87
25-Jun-97	25-Apr-98	1869	1,2,3,4	4.97	5.22	4.63	4.32	5.56	4.94
30-Jul-97	13-May-98	2012	1,2,3	3.10	2.53	0.97	2.84	3.22	2.53
5-Aug-97	5-Jun-98	2080	1,2,10	2.31	3.21	3.63	3.40	3.84	3.28
9-Sep-97	7-Jul-98	2212	1,9	3.34	2.50	2.08	4.34	4.94	3.44
25-Oct-97	27-Aug-98	2323	8,10	5.33	5.08	4.49	2.37	6.32	4.72
24-Nov-97	30-Sep-98	2385	7,9,10	5.09	4.80	6.32	5.18	8.41	5.96
28-Dec-97	27-Oct-98	2157	6,8,9	5.12	6.62	5.41	6.16	5.69	5.80
20-Jan-98	22-Nov-98	1928	5,7,8	6.42	5.88	5.07	6.93	3.16	5.49
28-Feb-98	28-Dec-98	1285	4,6,7	5.99	6.06	4.87	5.76	6.57	5.85
14-Mar-98	12-Jan-99	2063	3,5,6	7.66	7.32	8.11	8.09	8.11	7.86
1-Apr-98	5-Feb-99	1992	2,4,5	6.74	5.85	5.58	7.36	8.57	6.82
5-May-98	5-Mar-99	2025	1,3,4	7.85	7.87	11.57	9.21	11.59	9.62
5-Jun-98	5-Apr-99	2086	2,3	5.42	7.82	12.92	7.57	9.36	8.62
5-Jul-98	5-May-99	2095	1,2	8.29	10.72	11.81	11.80	9.43	10.41
Average		1782		4.72	5.46	5.46	5.42	6.09	5.43

[1] <100 mm rainfall.

Tabel 10. Starch yield of five selected varieties when not affectedby a dry period during the growth cycle.

Planting date	Harvesting date	Total rainfall (mm)	Dry months[1)] (month after planting)	Starch yield (t/ha)					
				Adira 4	Rayong 60	Rayong 90	Kasetsart 50	CMR 30-56-1	Average
24-Jul-96	25-May-97	2092	None	11.55	11.28	12.15	10.51	11.99	11.50
24-Aug-96	20-Jun-97	1989	10	11.36	10.88	11.73	13.61	11.96	11.91
Average		2041		11.46	11.08	11.94	12.06	11.98	11.70

[1)] <100 mm rainfall.

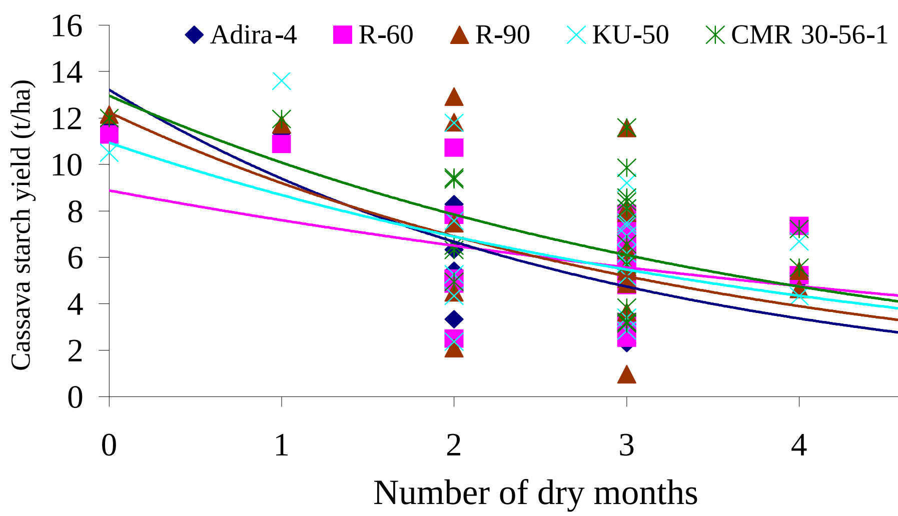

Figure 4. Effect of the duration of the dry period (less than 100 mm rainfall per month) on the starch yields of five selected cassava varieties grown in Umas Jaya Farm, Lampung, Indonesia from 1996 to 1999.

CONCLUSIONS

1. When subjected to a dry period during the growth cycle, both the fresh root yield and starch yield of all tested varieties decreased; when subjected to a long dry period, especially during the middle of the growth cycle, the root starch content also decreased.
2. Under non-uniform rainfall distribution, the fresh root yield of Rayong 60, Kasetsart 50 and CMR30-56-1 were much higher than that of Adira 4, and the starch yields of all four varieties were higher than that of Adira 4. Under uniform rainfall distribution, starch yields of Rayong 90, Kasetsart 50 and CMR30-56-1 were higher than these of Adira 4 and Rayong 60.
3. A dry period from the 3rd to the 7th month after planting is the most critical in reducing both the root and starch yields of all tested varieties.

4. The average root starch content of all varieties was generally higher when the crop was subjected to 1-3 dry months before harvest than when there was no dry period; this was not the case, however, for Kasetsart 50.
5. Among the five varieties tested, Adira 4 was found to be the least drought tolerant, while CMR 30-56-1 was considered the most drought tolerant variety.

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CASSAVA AGRONOMY RESEARCH IN ASIA: HAS IT BENEFITTED CASSAVA FARMERS?

Reinhardt H. Howeler[1]

ABSTRACT

During the past decade (1990-2000) the area planted to cassava in most countries in Asia has generally decreased, while production has remained stable or also decreased. Cassava yields have increased mainly in India, Indonesia and China but remained nearly the same in Malaysia, Thailand and the Philippines, and actually decreased in Vietnam. Yield stagnation or declines, inspite of widespread adoption of higher yielding varieties, is partly due to displacement of cassava to more marginal regions, and partly a result of the deterioration of the soil resources due to erosion and inadequate or unappropriate fertilizer use.

The paper describes research results obtained in the development of improved cultural practices, such as time and method of planting, weed control, fertilization, intercropping and erosion control. Experiments have shown that cassava yields are seriously reduced if either low rainfall or low temperatures are limiting growth during the period of 3-5 months after planting; that planting vertically or inclined produces higher yields than planting horizontally, especially during periods of drought; that planting on ridges is better in the rainy season but planting on the flat is better in the dry season; that high yields can be sustained over many years of continuous cassava planting if adequate amounts of N and K are applied annually; that intercropping with peanut generally increases total income and protects the soil from erosion; and that fertilization, intercropping, contour ridging and contour hedgerows of grasses are very effective ways to reduce erosion. Areas in which additional research is needed are suggested.

Improved cultural practices, such as the use of chemical fertilizers and herbicides have been adopted in some regions or countries, such as Tamil Nadu, Malaysia, Thailand (to some extent), Indonesia and south Vietnam (mainly fertilizers). Constraints to adoption are identified and policy changes are suggested that will enhance the adoption of better practices that will contribute to increasing the income of cassava farmers and maintaining or improving the productivity of the soil.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) was introduced to Asia about 200 years ago, first to the Philippines, India and Indonesia and later spreading to Malaysia, Thailand, Vietnam and China. Initially it was grown mainly as a food security crop, but was later used for small-scale starch processing and on-farm pig feeding. After the Second World War cassava production expanded rapidly, while in some countries its role changed from a source of human food to a raw material for production of animal feed and starch. Cassava production in Asia increased rapidly from the early 1960s to the late 1980s, mainly due to a rapid increase in planted area in Thailand, and to a lesser extent in the other countries. Cassava production reached its peak in Asia in 1989, after which production declined, mainly due to reduction in planted area, not only in Thailand but also in most other countries. **Table 1** shows the trend in harvested area, production and yield over the past eight years. During that period the harvested area declined at an annual rate of 2.02%, while production declined at 1.68%. The significant reduction in area was only partially

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offset by a slight increase in yield, from 13.28 t/ha in 1992 to 13.60 t/ha in 1999, corresponding to an annual growth rate of 0.34%.

Table 1. Trend in cassava harvested area, production and yield in Asia from 1992 to 1999.

	Area ('000 ha)	Production ('000 t)	Yield (t/ha)
1992	3,872	51,419	13.28
1993	3,892	50,429	12.96
1994	3,818	48,622	12.73
1995	3,646	46,083	12.74
1996	3,716	48,301	13.00
1994	8,507	47,549	13.56
1998	3,316	44,416	13.39
1999	3,366	45,768	13.60
% Annual growth	-2.02	-1.68	+ 0.34

Source: *FAOSTAT, 2001.*

In India the first improved varieties were released in 1971 and since then a total of 11 new varieties have been released, which contributed to a remarkable increase in yield from about 15 t/ha in 1971 to 24 t/ha in 1999. In Thailand the first new variety was introduced in 1983 followed by seven others up till 1999; these new varieties are now planted in about 87% of the total cassava area (Sarakarn *et al*., 2001). In contrast to India, this did not result in a substantial increase in the national average yield, which remained constant at about 14 t/ha, increasing only during the past five years from 13 to 16 t/ha. In most other countries, harvested area declined while yields increased only slightly, in spite of the release of about 18 new high yielding varieties during the past decade. Many of these varieties have the potential to increase yields 10-20%, and in some cases (Vietnam) up to 100%. Still, this expected yield increase has not materialized, except in India. In India yields in Kerala increased modestly, from 15.85 t/ha in 1976/77 to 18.23 t/ha in 1996/97 (Edison, 2001); this is partially due to a shift from the infertile uplands to more fertile lowland soils. While planted area declined rapidly in Kerala, the area increased in Tamil Nadu, where yields during the same period also increased markedly, from 23.5 to 46.3 t/ha. The very high yields in Tamil Nadu are attributed to production of cassava on high-fertility Alfisols and Vertisols, the use of high-yielding varieties for industrial purposes, high inputs of fertilizers, pesticide, and most importantly, irrigation during the long dry season (with high solar radiation). In most other countries, on the other hand, cassava has been displaced from more favorable areas to those with more marginal soils or climatic conditions. Thus, in Thailand, the cassava planted area has moved from the slightly better soils in the east to the highly infertile sandy loam soils in the northeast as well as to hilly areas in the lower north (Sriroth *et al*., 2001). In Indonesia, the cassava area is decreasing on the more fertile soils in Java and increasing in acid infertile soils in Sumatra (Nasir Saleh *et al*., 2001). In China cassava production on the better soils of

Guangdong province has shifted mainly to the poorer soils in Guangxi province (Tian Yinong *et al*., 2001). Similarly, within a particular area, cassava tends to be replaced by higher value crops from the better areas to the more marginal areas, from flat land to hilly land, and from areas with high rainfall to areas that are more drought prone. This may explain at least partially why cassava yields in Asia have not increased dramatically in spite of the fact that now about 1/3 of the cassava area (over 1 million ha) is planted with new high-yielding varieties.

Another reason for stagnating yields may be the decline in soil productivity as a result of continuous cassava production without adequate fertilization and measures to control erosion. In Asia there are no serious pests and diseases (except in India), so declining yields can be attributed mainly to declining soil productivity. There is good evidence for that in south Vietnam (Cong Doan Sat and Pol De Turck, 1998; Nguyen Huu Hy *et al*, 2001), where continuous production of cassava was found to result in a decline in physical, chemical and biological conditions of the soil, compared with those soils under forest, sugarcane, rubber or cashew. Long-term fertility trials conducted in India (Kabeerathumma *et* al, 1990), Malaysia (Chan, 1980), Thailand (Tongglum *et al*, 2001), Vietnam (Nguyen Huu Hy *et al*, 2001), Indonesia (Wargiono *et al*., 2001) and China (Li Jun *et al*., 2001) all indicate that cassava yields will decline when the crop is grown continuously on the same land without adequate fertilizer inputs, especially K and N. While little cassava in Asia is grown in the highlands, much cassava is grown on sloping land with slopes ranging from 0-10% in Thailand to 40-60% in Hainan and Yunnan provinces of China. Surprisingly, soil erosion is more serious on the gentle slopes in Thailand (due to the sandy nature of the soil) than on the steeper slopes in China (with heavier and well-aggregated soils). In any case, serious erosion will result in substantial losses of nutrients, both in runoff water and in eroded soil (Puthacharoen *et al*., 1998; Howeler, 2001; Howeler *et al*., 2000) resulting in a decline in soil productivity and yields (Howeler, 1986). While most cassava farmers do apply some farm-yard manure (FYM) and/or chemical fertilizers, the rates of application are usually insufficient to compensate for the removal of nutrients in the harvested products. For instance, calculations of nutrient balances in Vietnam, based on results of a country-wide survey conducted in 1990/91 (Pham Van Bien *et al*., 1996) indicate that the N and K balances were highly negative in three of the six regions, while the P balance was slightly negative in only one of six regions (Howeler, 2001b). Thus, in Vietnam cassava farmers were applying too much P and not enough N and K. A similar situation probably exist in India, Thailand and Indonesia where fertilizer applications tend to be high in N and P but too low in K. Thus, while recent research has indicated the importance of adequate K fertilizer inputs for maintaining high cassava yields, this has not yet translated in a significant change in fertilizer recommendations and applications in most countries. Similarly, many erosion control trials have shown that erosion can be controlled effectively by various simple soil and crop management practices, but these practices are not yet adopted extensively by farmers, leading to a continued degradation of the soil. Thus, to improve this situation and achieve real increases in productivity it is necessary to develop still better cultural practices (in addition to high-yielding varieties), and more importantly, to develop more effective ways of enhancing the adoption of these practices by cassava farmers.

RESULTS OF CASSAVA AGRONOMY RESEARCH IN ASIA DURING THE PAST 25 YEARS

Agronomic practices used by cassava farmers in Asia vary markedly between countries and even between regions within countries, depending mainly on farm size, availability of labor, soil and climatic conditions, as well as on socio-economic factors and cultural traditions. These practices are broadly summarized in **Table 2**. The results of cassava agronomy research in the major cassava growing countries in Asia have been summarized by Evangelio (2001), George *et al*. (2001), Nguyen Huu Hy *et al*. (2001), Li Jun *et al*. (2001), Tan (2001), Tongglum *et al*. (2001) and Wargiono *et al*. (2001). These results will be briefly described and compared among countries in order to identify areas where further research may be necessary.

1. Time of Planting

Time of planting studies have been conducted in Thailand (Tongglum *et al*, 2001), Indonesia (Wargiono, 2001; Fauzan and Puspitorini, 2001), China (Zhang Weite, 1998) and the Philippines (Villamayor and Daviner, 1987). In general, yields were found to be higher when cassava was planted in the early part of the rainy season (May-June in most countries, but Oct-Nov in Indonesia) or the early part of spring (Feb-March in north Vietnam and China). In many countries some cassava is also planted at the end of the rainy season, such as Aug-Sept in Kerala, or Sept-Nov in Thailand and south Vietnam (**Table 2**). In Hainan island of China it was found that cassava can be planted throughout the year when harvested at 12 months after planting (MAP), but only from Feb-May when harvested at 8 MAP; starch contents were always highest when the roots were harvested in the dry and cold months of Nov-March (Zhang Weite *et al*., 1998). Several reports indicate that root yields were best correlated with rainfall during the 3^{rd}-5^{th} month (Zhang Weite *et al*, 1998), during the initial 7 months (Villamayor and Davines, 1987) or during the 4^{th}-11^{th} month (CIAT, 1998), while Fauzan and Puspitorini (2001) reported the lowest yields when a long drought occurred during the middle part of the growth cycle, i.e. the 3^{rd}-7^{th} or 4^{th}-8^{th} months. Obviously, cassava needs adequate soil moisture at planting for the stakes to germinate, but once established the crop seems to tolerate drought better in the early than in the middle part of the growth cycle, i.e. highest yields are obtained when cassava is planted 3-4 months before the start of the rainy season as long as soil moisture is adequate for land preparation and germination of stakes (**Table 3**). Thus, in sandy soils of Thailand cassava is now often planted during the dry season (Jan-April), usually immediately after an occasional rain storm.

Figure 1 and **Table 4** show that the root starch content was positively correlated with rainfall during the 6^{th}-9^{th} month, but was slightly negatively correlated with rainfall during the last one or two months before harvest (CIAT, 1998). Similar results were obtained in China (**Figure 2**), while Vichukit *et al*. (1994) and Fauzan and Puspitorini (2001) reported the highest starch content when the crop was subjected to drought during the last 2-3 months before harvest. There was no significant correlation between total rainfall received during the growth cycle and either root yield or starch content as long as rainfall was more or less well distributed (Fauzan and Puspitorini, 2001).

Table 2. Characteristics of cassava cropping systems and cultural practices used in major production zones in Asia in 1999/00.

	China	India		Indonesia		Malaysia	Philippines	Thailand	Vietnam	
		Kerala	Tamil Nadu	Java	Sumatra				North	South
-Cassava area (ha/farm)	0.2-0.4	<0.1	0.5-1.0	0.3-0.5	0.5-1.0	4-500	-	2-3	0.1-0.3	0.2-0.9
-Intercrops	none/peanut	none	none/ vegetables	maize+rice- soybean/peanut	maize	rubber	none/maize	none (95%) maize (5%)	none/peanut	none/maize
-Land preparation	manual/ animal	manual	tractor	manual/ animal	animal/ tractor	tractor	animal/ manual	tractor 3disc+7disc	animal/ manual	animal/ tractor
-Fertilizer use										
-organic (t/ha)	3-5	10-20	10-20	3-10	low	none	none	little	2-7	0-5
-inorg. (kg $N+P_2O+K_2O$/ha)	some NPK	some	high	N only	medium	>400	little	30-120	0-80	0-60
-Seasonality in planting	Feb-Apr (90%)	Apr-Jun (60%)	Jan-Mar (90%) Sept-Oct	Oct-Dec (90%)	Oct-Dec (90%)	year round	year round	March- May(70%) Sept-Nov	Jan-Mar (70%)	Feb-May (80%) Oct-Nov
-Harvest time	Nov-Jan	Jan-Mar	Oct-Jan	Jul-Sept	Jul-Sept	year round	year round	Dec-May Aug-Dec	Nov-Jan	Feb-Mar Sept-Oct
-Planting distance (m)	1.0x1.0 0.8x0.8	1.0x1.0	1.0x1.0	1.0x0.8 2.0x0.5	1.0x0.8 2.0x0.5	1.0-1.2x 0.8-1.0	1.0x0.8	0.8x1.2 0.8x0.8	1.0x1.0 0.8x0.8	1.2x0.8 0.8x0.8
-Planting method	horizontal	vertical	vertical	vertical	vertical	horizontal	horizontal	vertical	horizontal	horizontal
-Weed control	hoe 2-3x	hoe 2-3x	hoe 4-5x	hoe 1-2x	hoe 1-2x	herbicides/ hoe	animal/ hoe 2-3x	hoe 2-3x small tractor/ Paraquat	hoe 2-3x/ animal	hoe 2-3x
-Harvest method	hand	hand	hand	hand	hand	hand/tractor	hand	hand/tractor	hand	hand
-Main varieties	SC205 SC201 SC124	local var. M-4	H-226 local var. H-165	many local varieties	Adira 4	Black Twig	Golden Yellow Lakan	KU50 Rayong 90 Rayong 60 Rayong 5	Vinh Phu La Tre[2] KM60	KM94 KM60 H34 HL23
-Labor use (m-days/ha)	90-180	150-200	200-350	200-300	150-200	50-60	100-200	50-60	200-450	100-200
-Variable prod. costs ($/ha)[1]	300-450	500-600	400-700	300-600	250-300	390-520	350-700	300-400	300-600	350-400
-Fixed costs ($/ha)	5-100	200-500	50-250	NA[3]	50	NA	NA	50	20	20

[1]including family labor, harvest + transportation.
[2]La Tre = SC205; KM60 = Rayong 60; KM94 = KU50.
[3]NA = data not available

Source: *modified from Hershey et al., 2000.*

Table 3. Effect of different planting dates on the average rainfall received, soil losses due to erosion, cassava growth and yield, as well as the gross income obtained when cassava, cv Rayong 90, was grown for three consecutive cycles on 4.2% slope at Rayong Field Crops Research Center in Thailand from 1994 to 1998.

Month of planting[1)]	Total rainfall[2)] (mm)	Dry soil loss (t/ha)	Canopy cover[3)] (%)	Final plant stand (%)	Root yield (t/ha)	Starch content (%)	Gross income[4)] ('000B/ha)
June	1402	15.64	77.3	97	23.32	21.27	19.25
August	1409	18.21	55.0	97	18.92	22.33	16.02
October	1267	15.73	55.0	91	24.56	25.73	22.46
December	1665	12.88	82.0	90	32.18	25.07	29.01
February	1633	13.05	89.2	88	27.92	30.35	28.11
April	1616	14.30	87.8	87	25.67	26.13	23.68

[1)]roots were harvested after 11 months
[2)]rainfall received during the 11 month growth cycle
[3)]percent canopy cover averaged over all months of the growth cycle
[4)]assuming a price of B 1.0/kg fresh roots with 30% starch, and a reduction in price of B 0.02/kg for each per cent drop in starch content
Source: *CIAT, 1998b.*

Figure 1 and **Table 4** also show that soil loss due to erosion was significantly correlated with rainfall during the 1st-3rd months, which is to be expected as high rainfall when plants are still small will result in high runoff and erosion. Tongglum *et al* (2001) reported that while cassava yields tended to be slightly higher when the crop was planted in the early rainy season as compared to the early dry season, the cost of weeding was much lower when planted in the dry rather than the wet season. Thus, it appears that cassava might best be planted before or very early in the wet season (if soil moisture permits planting and germination), and harvested in the middle of the dry season. Other times of planting and harvest may be feasible or desirable (to spread the harvest period) but may result in lower starch yields, higher weeding costs and more erosion.

2. Land Preparation

Table 2 shows that land preparation for cassava is usually done by hand, using a hoe, or by an animal-drawn plow. In Thailand, Malaysia, Tamil Nadu of India and much of South Vietnam, land is now prepared by tractor, usually on contract.

Mandal and Mohankumar (1973) reported no significant differences between shallow and deep tillage – either by hand or animal drawn plow - while Villamayor (1983) also reported no benefits from tillage beyond 20 cm depth. In most countries research has shown that highest yields were obtained with two plowings followed by disking and ridging. One or two passes with a 7-disk harrow followed by ridging produced the highest yields in Thailand (Tongglum *et al*., 1992), but ridging may not be necessary or recommended when planting during the dry season.

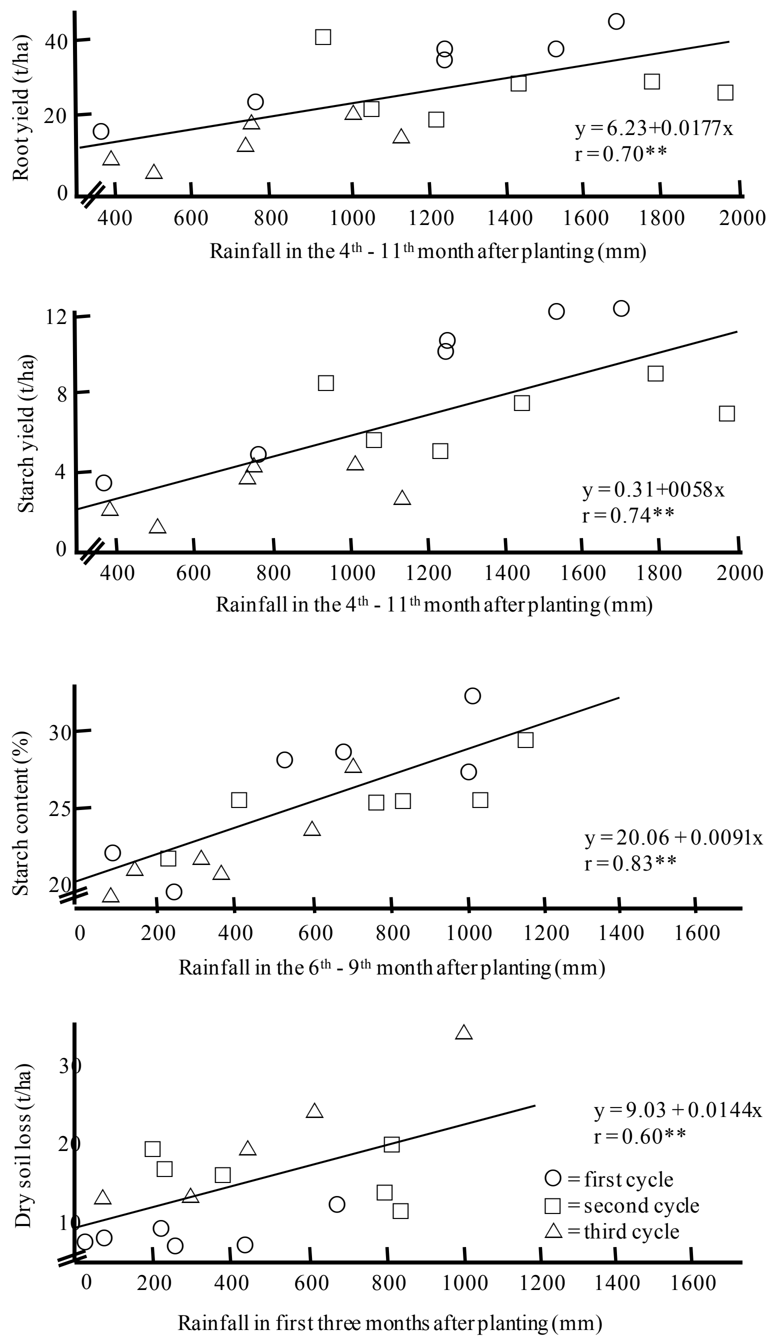

Figure 1. Linear regressions between cassava root yield, starch yield, starch content and dry soil loss due to erosion and the rainfall received during certain periods of the crop cycle when cassava, cv Rayong 90, was grown at bimonthly intervals for three complete cropping cycles on 4.2% slope at Rayong Research Center in Thailand from 1994 to 1998.
Source*: CIAT, 1998 b.*

Table 4. Correlation coefficients between cassava root yield, starch content and starch yield, as well as dry soil losses due to erosion and rainfall during certain periods in the cropping cycle when cassava, cv Rayong 90, was planted at bimonthly intervals for three consecutive cropping cycles on 4.2% slope in Rayong Research Center in Thailand from 1994 to 1998.

Parameters	Correlation Coef. (r)	%P
Cassava root yield vs rainfall from the 4^{th}-11^{th} MAP[1)]	0.7025	0.001
Cassava root yield vs rainfall from the 3^{rd}-11^{th} MAP	0.6726	0.002
Cassava root yield vs rainfall from the 2^{nd}-11^{th} MAP	0.6005	0.008
Cassava root yield vs rainfall from the 1^{st}-11^{th} MAP	0.5115	0.030
Cassava root yield vs rainfall during the 1^{st} MAP	-0,4258	0.078
Cassava root yield vs rainfall from the 1^{st}-2^{nd} MAP	-0,4146	0.087
Root starch content vs rainfall from the 6^{th}-9^{th} MAP	0.8298	0.000
Root starch content vs rainfall from the 5^{th}-9^{th} MAP	0.7981	0.000
Root starch content vs rainfall from the 6^{th}-8^{th} MAP	0.7966	0.000
Root starch content vs rainfall from the 10^{th}-11^{th} MAP	-0.1290	NS
Root starch content vs rainfall during the 11^{th} MAP	-0.0772	NS
Starch yield vs rainfall from the 4^{th}-11^{th} MAP	0.7411	0.000
Starch yield vs rainfall from the 4^{th}-10^{th} MAP	0.7096	0.001
Starch yield vs rainfall from the 5^{th}-11^{th} MAP	0.7090	0.001
Starch yield vs rainfall from the 5^{th}-10^{th} MAP	0.6950	0.001
Dry soil loss (erosion) vs rainfall from 1^{st} -3^{rd} MAP	0.6016	0.008
Dry soil loss (erosion) vs rainfall from 1^{st} -4^{th} MAP	0.5515	0.018
Dry soil loss (erosion) vs rainfall from 1^{st} -5^{th} MAP	0.5290	0.024
Dry soil loss (erosion) vs rainfall from 1^{st}-2^{nd} MAP	0.5087	0.031

Note: cassava was harvested after 11 months
[1)] MAP = month after planting
Source: *CIAT, 1998b.*

On steep slopes cassava can be planted by preparing only the planting holes with a hoe. This produced similar yields as twice plowing and disking in Hainan but resulted in much less erosion (Zhang Weite *et al*, 1998). Alternatively, zero tillage (with herbicides) sometimes produced good yields in Thailand (Tongglum *et al*, 1988; 1992; 2001) and may or may not reduce erosion (Jantawat *et al*., 1991). Zero tillage is most feasible when the land comes out of bush fallow or had previously a good crop of cassava which prevented excessive weed growth. In very weedy plots or in compacted soil, zero tillage will generally result in low yields and difficulty in planting, weeding and harvesting.

3. Preparation of Planting Material

Research in India, Indonesia, Philippines, Malaysia and Thailand on production of good-quality planting material, indicates that higher yields are obtained when stakes are cut from the mid- and lower-part of stems taken from mother plants that are about 8-12 months old.

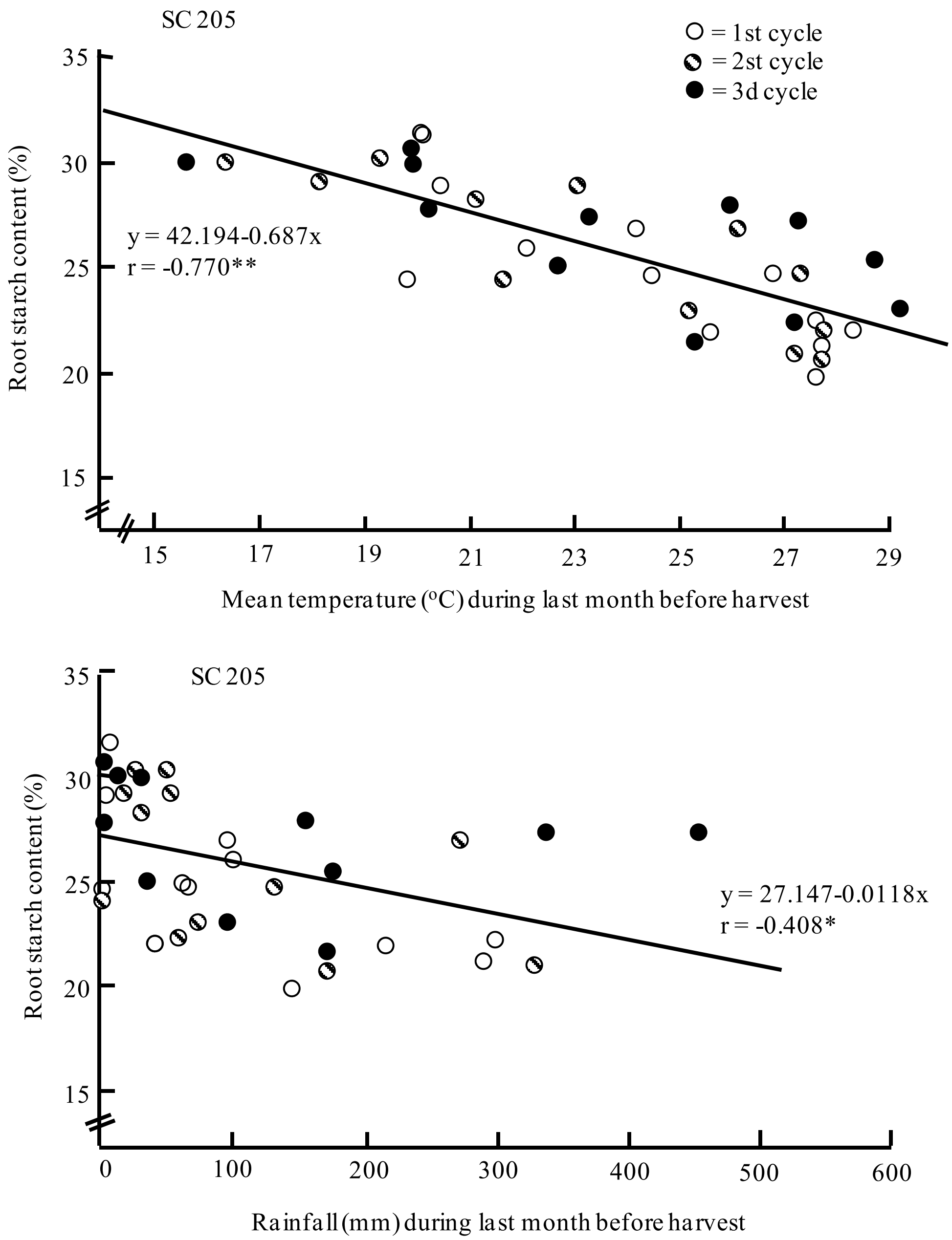

Figure 2. Linear regressions between root starch content and the mean temperature (top) or rainfall (bottom) during the last mouth before harvest of SC205 (harvested at 8 MAP) during three consecutive cropping cycles at CATAS, Danzhou, Hainan,China, from 1990 to 1993.

After cutting the stems, these can be stored for up to 1 month, preferribly in a vertical position under shade. Storing stems for more than 60 days resulted in a lower percentage of germination (George *et al*., 2001). On the other hand, Villamayor, Perez and Destriza (unpublished data) found that stems could be stored in a vertical position in the open and covered with coconut palm fonds for up to four months without affecting the yield of the subsequent crop (Evangelio, 2001). The length of time stakes can be stored depends a lot on the variety and climatic conditions during storage. In subtropical climates, such as in northern Guangxi and Guangdong provinces of China, stems need to be cut before the first frost and stored in trenches at least one meter deep and covered with straw and soil to prevent damage from frost. Again, some varieties are more tolerant to low temperatures during storage than others.

At time of planting the stems are cut into stakes or cuttings. The most suitable length of cuttings was found to be 15-20 cm in Thailand (Tongglum *et al*., 1988), 20-23 cm in Malaysia (Tan, 2001) and 25-30 cm in India (George *et al*. 2001). In the Philippines short stakes are recommended for horizontal planting and longer stakes for vertical planting (Villamayor *et al*., 1992). Most farmers will cut stakes at an angle with a machete, but in India it is recommended to make a smooth circular cut for uniform callus formation and root initiation (CTCRI, 1970, 1972). In some big plantations in Indonesia 50 stems are bundled together with rubber bands spaced at 20 cm distance. In between two rubber bands they are cut with a circular power saw and the top of each bundle of stakes is dipped in red ink to facilitate planting stakes vertically in the correct position with buds facing upward.

When planting material is scarce it is possible to use short stakes of 2-3 nodes placed for 7-10 days on wet paper towels to produce roots and sprouts before transplanting to the field (Wargiono *et al*., 1992). In India 1-3 node stakes are planted closely together in moist sand in a nursery for 20 days before transplanting to the field. This nursery method is particularly useful in areas with a very short rainy season (Mohankumar *et al*., 1998).

Chemical treatment of stakes was found to be unnecessary as few diseases and pests in Asia are transmitted via the planting material (except CMD in India). A stake dip in 2% $ZnSO_4$. $7H_2O$ solution for 15 minutes before planting is recommended in areas with high-pH soils resulting in Zn deficiency (Howeler, 2001a).

4. Planting

Planting position varies from country to country (**Table 2**) with vertical planting being practiced in India, Thailand and Indonesia, and horizontal planting in China, Malaysia, Philippines and Vietnam. Research on planting position usually shows no significant differences in yield due to planting position, although vertical or inclined planting produced slightly higher yields in China (Wen Jian, 1964; Zhang Weite, 1998) and significantly higher yields than horizontal planting in both the rainy and dry season plantings in Thailand (Tongglum *et al*., 1992). Horizontal planting may result in poor germination when the surface soil is very hot and dry. Horizontal planting tends to result in shallower roots which are easier to harvest. In the Philippines it is recommended to plant vertically on ridges in areas of heavy rainfall, and horizontally on flat land or in furrows in areas of low rainfall (Mendiola, 1958).

Depth of planting may vary from 5 to 15 cm, with the deeper planting producing better yields then shallow planting in the dry season (Tongglum *et al*., 1992). In India it is recommended to plant vertically to a depth of 5-10 cm (George *et al*. 2001).

The optimum plant population and spacing depends on the fertility of the soil, the branching habit of the variety and the cropping system. In general, cassava should be planted at a higher population (12,000-16,000 plants/ha) for non-branching varieties and for all varieties planted in infertile soil, and at a lower population (10,000-12,000 plants) in more fertile soils, especially for branching varieties (Nguyen Huu Hy *et al*., 1998). In India a planting distance of 90x90 cm is recommended for semi-branched and 75x75 cm for non-branched varieties (Mandal *et al*., 1973). In intercropping systems the cassava population can be maintained at 10,000 plants/ha, but the row spacing is often increased to 1.25 or ever 2.0 m, while in-row spacing is reduced to 0.8 or even 0.5 m. The wider row spacing allows for the planting of 1 or 2 rows of intercrops between cassava rows, resulting in reasonably good yields of both cassava and the intercrops. Planting cassava at 2 m between rows or in double rows of 2.73x0.6x0.6 m produced the highest net income in intercropping systems of cassava-upland rice-maize followed by peanut in Lampung, Indonesia (Wargiono *et al*. 1995; 1998); a double row system was also found superior to the single row system for intercropping cassava with sweet corn in Malaysia (Tan, 1990). In contract, a square planting pattern of 1.0x1.0 m produced the highest crop value during two years of planting in Yogyakarta, Indonesia (Wargiono *et al*., 1992) and also a higher net income than the double-row system for various intercrops in south Vietnam (Nguyen Huu Hy *et al*., 1995).

When stakes don't germinate, the surrounding plants will usually cover over the empty space and compensate for missing plants. Villamayor and Labayan (unpublished data) found that replanting of missing plants is justified only if more than 30% of plants are missing (Villamayor, 1988). They suggest replanting before plants are more than 13 days old. In India, research at CTCRI (1984) found that replanting with 40 cm long stakes produced 50% higher yields than replanting with normal 20 cm stakes; they suggest replanting at about 15 days.

5. Fertilization

a. Nutrient removal

Continuous cassava cultivation on the same land may lead to nutrient depletion due to nutrient absorption by the crop and nutrient removal in the harvested products. How much nutrients are actually removed from the field depends on whether only roots are harvested or the plant tops (sometimes including fallen leaves) are also removed from the field; it also depends on the root and top yield as well as the nutrient concentration in the various plant parts. In general, the nutrient removal in either the roots or the whole plant per tonne of fresh roots is higher at high than at low yield levels (**Figures 3** and **4**) because at higher levels of fertility, plants have higher nutrient concentrations, resulting in higher yields. From **Figures 3** and **4**, which are based on 19 data sets found in the literature, we can estimate that in an "average" crop producing 15 t/ha of fresh roots, the nutrient removal in those roots is only about 30 kg N, 3.5 kg P and 20 kg K/ha (**Figure 3**). If all plant parts are harvested, the nutrient removal will be about 80 kg N, 9 kg P and 50 kg K/ha (**Figure 4**); these values are considerably lower than previously reported (Howeler, 1981; 1991), as the latter were calculated from "average" nutrient removal per tonne of dry of fresh roots, based on data from experiments that tend to have much higher yields than those obtained by farmers. Thus, nutrient removal in an "average" yield of cassava (15 t/ha fresh roots) is much lower than that in the harvested product of most other crops (Howeler, 1991).

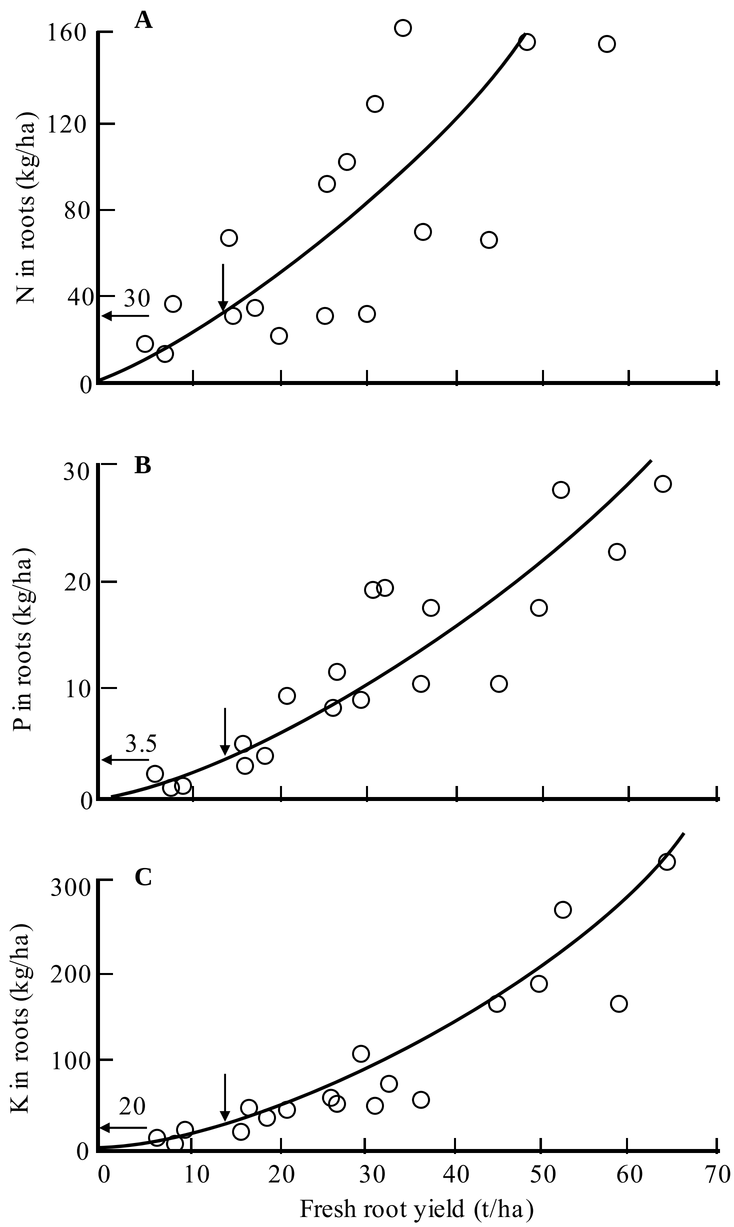

Figure 3. Relation between the amounts of N, P and K in cassava roots and the fresh root yields ,as reported by various sources in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t/ha. ***Source:*** *Howeler, et al., 2000.*

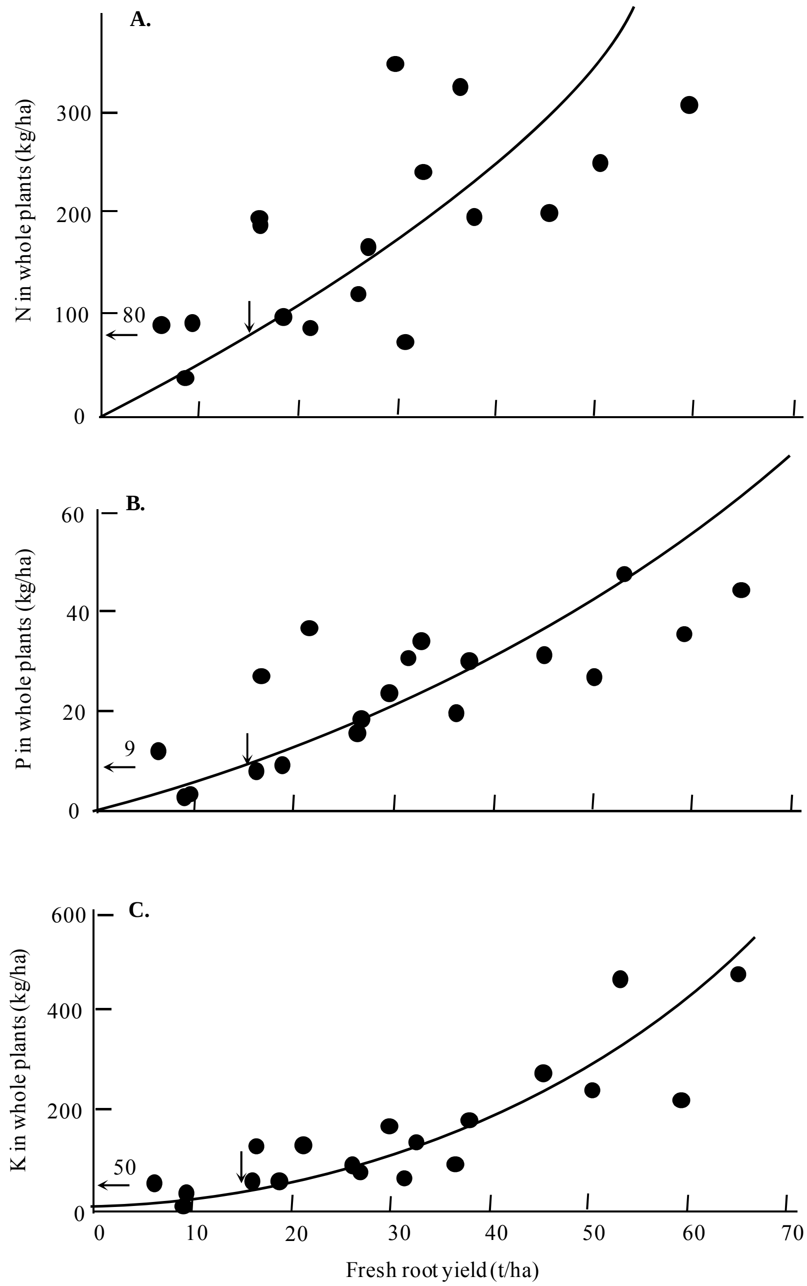

Figure 4. Relation between the amounts of N, P and K in the whole cassava plant at time of harvest and the fresh root yields, as reported by various sources in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t/ha.
Source: *Howeler et al., 2001.*

However, nutrients lost by crop removal, volatilization, leaching or erosion need to be replaced through the application of fertilizers, animal manures or through biological N-fixation.

b. Application of NPK fertilizers

Numerous short- and long-term fertilizer trials have been conducted to determine the optimum rates of application of N, P or K to produce maximum yields or maximum net income in a particular soil or region. Optimum rates of N, P_2O_5 and K_2O in kg/ha, as reported by researchers in various countries in Asia, are shown in **Table 5**.

Table 5. Optimum fertilizer applications for cassava production in various locations, soils and systems in Asia.

Location/Soil/System	N: P_2O_5: K_2O (kg/ha)	Reference
in Nanning, Guangxi, China	100:50:100	Zhang Weite *et al*., 1998
in CATAS, Danzhou, Hainan, China	200:100:200	Zhang Weite *et al*., 1998
in CTCRI, Thiruvananthapuram, Kerala, India	100:50:100	Susan John *et al*., 1998
for cassava monocrop in Tamanbogo, Lampung, Indonesia	90:25:45	Wargiono *et al*., 2001
in intercropped cassava in Tamanbogo, Lampung, Indonesia	90:50:90	Wargiono *et al*., 2001
in ViSCA, Baybay, Leyte, Philippines	60:90:60	Evangelio and Ladera, 1998
in Ubay, Bohol, Philippines	120:60:120	Evangelio *et al*., 1995
in La Granja, Negros Occidental, Philippines	100:50:100	Evangelio *et al*., 1995
in Hung Loc Center, Dong Nai, Vietnam	80:40:80	Nguyen Huu Hy *et al*., 1998
at Thai Nguyen Univ., Thai Nguyen, Vietnam	160:80:160	Nguyen Huu Hy *et al*., 1998
on mineral soils at MARDI in Serdang, Malaysia	60:30:160	Chan, 1980
on peat soils in Johor, Maysia	50:30:40	Tan, 2001
for most cassava soils in Thailand	100:50:50	Sittibusaya *et al*., 1995
in Khon Kaen with tops incorporated	50:50:50	Tongglum *et al*., 2001
for soils used continuous for cassava cultivation in Thailand	100-50-50	Sittibusaya *et al*., 1995
for Quartzipsamments (sandy loam Entisols) in Thailand	50-100:0:50-100	Ho and Sittibusaya (1984)
for Paleustults (sandy loam Ultisols) in Thailand	80-100:0-30:30-50	Ho and Sittibusaya (1984)

Most long-term fertilizer experiments have shown an increasing response to the application of N and K (**Table 6**), while many short-term on-farm fertilizer trials show an initial response mainly to N (Sittibusaya, 1993; Hagens and Sittibusaya, 1990; Sittibusaya and Karamarohita, 1978). In very general terms it is recommended to fertilize cassava with N-P_2O_5-K_2O ratios of 2:1:2 or 2:1:3. However, optimum fertilizer rates depend on soil fertility which can vary greatly from field to field. Thus, specific recommendations should be based on soil analyses results, supplemented with analyses of youngest-fully-expanded leaf (YFEL) blades taken at 3-4 months after planting. Critical levels for each nutrient in soil and YFEL-blades have been reported (Howeler, 2001a), and from those an approximate classification of the nutritional status of soils and YFEL-blades for cassava production has been developed, as shown in **Tables 7** and **8**. These tables can be used as a general guide in the interpretation of soil and plant tissue analyses results, and to diagnose nutritional deficiencies or toxicities.

Table 6. Response of cassava to annual application of N, P or K after several years of continuous cropping in long-term fertility trials conducted in various locations in Asia.

Country-location		Years of cropping	Response to		
			N	P	K
China	-Guangzhou	4	**[1)]	**	**
	-Nanning	8	**	**	NS
	-Danzhou	6	**	NS	*
Indonesia	-Umas Jaya	10	NS	NS	NS
	-Malang	8	**	NS	**
	-Lampung	6	**	*	**
	-Yogyakarta	4	NS	NS	NS
Philippines	-Leyte	6	NS	NS	NS
	-Bohol	4	**	NS	**
Vietnam	-Thai Nguyen	8	**	**	**
	-Hung Loc	8	**	NS	**

[1)] NS = no significant response
* = significant response ($P<0.05$)
** = highly significant response ($P<0.01$)

Source: *CIAT, 1998a.*

Table 7. 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	4.5-7.0	7.0-8.0	>8.0
Organic matter[2] (%)	<1.0	1.0-2.0	2.0-4.0	4.0-8.0	>8.0
Al saturation[3] (%)			<75	75-85	>85
Salinity (mS/cm)			<0.5	0.5-1.0	>1.0
Na saturation (%)			<2	2-10	>10
P[4] (µg/g)	<2	2-5	5-20	20-50	>50
K[4] (meq/100 g)	<0.10	0.10-0.15	0.15-0.25	>0.25	
Ca[4] (meq/100 g)	<0.25	0.25-1.0	1.0-5.0	>5.0	
Mg[4] (meq/100 g)	<0.2	0.2-0.4	0.4-1.0	>1.0	
S[4] (µg/g)	<20	20-40	40-70	>70	
B[5] (µg/g)	<0.2	0.2-0.3	0.3-1.0	1-2	>2
Cu[5] (µg/g)	<0.1	0.1-0.2	0.2-1.0	1-5	>5
Mn[5] (µg/g)	<5	5-10	10-100	100-250	>250
Fe[5] (µg/g)	<1	1-10	10-100	>100	
Zn[5] (µg/g)	<0.5	0.5-1.0	1.0-5.0	5-50	>50

[1]pH in H_2O.
[2]OM = Walkley and Black method.
[3]Al saturation = 100 x Al(Al+Ca+Mg+K) in meq 100 g^{-1}.
[4]P in Bray II; K, Ca, Mg and Na in 1N NH_4-acetate; S in Ca phosphate.
[5]B in hot water; and Cu, Mn, Fe and Zn in 0.05 N HCl+0.025 N H_2SO_4.

Source: *modified from Howeler, 1996a; 1996b.*

Table 8. Nutrient concentrations in YFEL blades of cassava at 3-4 MAP, corresponding to various nutritional states of the plants; data are averages of various greenhouse and field trials.

Nutrient	Nutritional states[1]					
	Very deficient	Deficient	Low	Sufficient	High	Toxic
N (%)	<4.0	4.1-4.8	4.8-5.1	5.1-5.8	>5.8	-[2]
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 (%)	<0.20	0.20-0.27	0.27-0.30	0.30-0.36	>0.36	-
B (µg/g)	<7	7-15	15-18	18-28	28-64	>64
Cu (µg/g)	<1.5	1.5-4.8	4.8-6.0	6-10	10-15	>15
Fe (µg/g)	<100	100-110	110-120	120-140	140-200	>200
Mn (µg/g)	<30	30-40	40-50	50-150	150-250	>250
Zn (µg/g)	<25	25-32	32-35	35-57	57-120	>120

[1] Very deficient = <40% maximum yield
Deficient = 40-80% maximum yield
Low = 80-90% maximum yield
Sufficient = 90-100% maximum yield
High = 100-90% maximum yield
Toxic = <90% maximum yield

[2] - = no data available

Source: *Howeler, 1996a; 1996b.*

c. Time and method of fertilizer application

Most researchers in Asia recommend the full application of P at time of planting while N and K should be split at planting and at 30 DAP; or alternatively, all fertilizers should be applied at 30 DAP. Zheng Xueqin *et al* (1992) reported highest yields with the application of all fertilizers at 30 DAP, or split at 30 and 90 DAP. In India, however, Mandal *et al* (1971) reported best results with application of all N and K at or shortly after planting, while Mohankumar *et al*. (1971) reported best results with ½ of K applied at planting and ½ at 1 MAP. In the Philippines there were no significant differences between various split applications between 0 and 2 MAP; the highest yield was obtained with all P and K applied at planting, and N split at planting and 30 DAP (Abenoja, 1978). Few studies in Asia have included a treatment with all NPK applied at planting, but in Latin America no significant differences were found between applying all three nutrients at planting and applying all P at planting and N and K split at 0, 1 and 2 MAP (CIAT, 1977; 1978).

In general, slow release fertilizers, such as lime, manures, rock phosphates and fused Mg-phosphate should be broadcast and incorporated before planting, while highly soluble fertilizers should be band applied at planting or shortly after planting. Early application is especially essential for P since small cassava plants can not yet rely on a mycorrhizal association for P uptake. Early application of N and K will result in rapid canopy cover, which will reduce weed competition and erosion.

d. Application of organic manures

Cassava farmers in many countries apply farm-yard manure (FYM), either alone or in combination with chemical fertilizers, to maintain or improve soil fertility. Thus, CTCRI in India recommends the application of 12 ½ t/ha of manure in combination with N, P and K fertilizers (Susan John *et al*., 1998), while in the Philippines an application of 10 t/ha of chicken manure and in Vietnam 5-10 t/ha of pig manure are recommended. Lower rates, ranging from 1.3 t/ha of chicken manure to 4.4 t/ha of cow manure, could not maintain soil fertility, especially K, and cassava yields declined during six cropping cycles (Quirol and Amora, 1987). In north Vietnam farmers obtained highest yields and net income with the application of 10 t/ha of pig manure in combination with 80 kg N and 80 K_2O/ha (Nguyen The Dang *et al*., 1998).

While animal manures may contribute to improving the soil's physical conditions and are an important source of Ca, Mg, S and micronutrients, they contain only low and highly variable amounts of N, P and K (**Table 9**). As a rough comparison, one 50 kg bag of 15-15-15 chemical fertilizers contains about the same amounts of N, P and K as one tonne of wet pig manure. Large applications of manure are probably economical only in areas where the manure is locally available; otherwise, transport and application costs may be higher than the cost of chemical fertilizers. Where available, a combination of 5-10 t/ha of manure with 50-80 kg/ha of N and K_2O is probably adequate to maintain soil fertility and high yields. However, if leaves and stems are also removed from the field, then higher rates of N, P and K (especially N) are recommended.

Table 9. Average nutrient contents of various manures, composts and wood ash.

Source of manure	Moisture (%)	N	P	K (% of dry matter)	Ca	Mg	S
Cattle manure	68.2	1.85	0.81	1.69	1.54	0.62	0.29
Pig manure	60.0	2.04	1.38	1.38	-	-	-
Chicken manure	43.0	2.91	1.37	1.54	4.56	0.83	-
Sheep manure	-	3.00	0.62	2.68	1.72	0.86	0.43
Human manure	-	1.20	0.06	0.21	-	-	-
City/rural compost	-	1.16	0.37	0.90	-	-	-
Rice straw compost	73.7	1.07	0.19	0.69	-	-	-
Peanut stems + leaves compost	58.6	0.81	0.10	0.38	-	-	-
Water hyacinth	-	2.00	1.00	2.30	-	-	-
Wood ash	-	-	0.87	4.17	23.2	2.10	0.40

Source: *Howeler, 2001b.*

e. Green manures and alley cropping

Many experiments have been conducted on the use of green manures to maintain soil fertility (Tongglum *et al*., 1992; 1998; Nguyen Huu Hy *et al*., 1998; 2001; Thai Phien and Nguyen Tu Siem, 1998; Mohankumar and Nair, 1996) using mainly forage or grain legumes to be incorporated before planting cassava, or leguminous shrub legumes in alley cropping systems. **Table 10** shows the results of a recent experiment in Thailand in which green manures were either intercropped at planting and cut and mulched at 45-60 DAP; interplanted at 6-7 MAP cassava and incorporated before the next crop; or planted as a normal green manure crop and incorporated before planting cassava, the latter being harvested after 18 months for a 2-year crop cycle. The last method was more productive than the first two, but application of chemical fertilizer was still more productive. Since most farmers in Asia can not afford to use their limited land for an unproductive green manure crop, green manuring or alley cropping has not been adopted anywhere, except for the use of *Tephrosia candida* as an erosion control barrier *cum* alley crop in north Vietnam. Most farmers opt for the use of animal manures or chemical fertilizers.

Table 10. Effect of three ways of planting four green manure species on the yield of cassava, Rayong 90, planted during three cropping cycles at Rayong Field Crops Research Center, Rayong, Thailand from 1994 to 1999[1).]

Treatments[1)]	Cassava root yield (t/ha)				
	1st cycle	2d cycle	3d cycle	Av.	Σ5 years[2)]
1. Cassava without GM, 156 kg/ha 13-13-26	17.56	30.06	14.39	20.67	103.3
2. Cassava without GM, 467 kg/ha 13-13-26	29.78	40.39	21.42	30.53	152.6
3. C+*Crot. juncea,* cut at 1½-2 months	23.75	29.19	14.02	22.32	111.6
4. C+*Canavalia,* cut at 1½-2 months	26.94	27.75	15.50	23.40	117.0
5. C+pigeon pea, cut at 1½-2 months	21.39	26.97	14.47	20.94	104.7
6. C+*Mucuna,* cut at 1½-2 months	20.28	18.75	11.31	16.78	83.9
7. C+*Crot. juncea,* planted at 6-7 months	8.75	31.44	14.97	18.39	91.9
8. C+*Canavalia*, planted at 6-7 months	22.83	24.17	12.94	19.98	99.9
9. C+pigeon pea, planted at 6-7 months	15.86	28.81	14.27	19.65	98.2
10. C+*Mucuna,* planted at 6-7 months	17.25	27.02	14.77	19.68	98.4
11. *Crot. juncea* GM, cut at 2-3m, C 18 months	46.17	49.04	36.94	44.05	132.1
12. *Canavalia* GM, cut at 2-3m, C 18 months	42.98	43.81	34.14	40.31	120.9
13. pigeon pea GM, cut at 2-3m, C 18 months	38.81	45.97	37.00	40.59	121.8
14. *Mucuna* GM, cut at 2-3m, C 18 months	38.86	46.32	30.22	38.47	115.4

[1)]C = cassava; GM = green manure
T_1-T_{10} were planted annually from 1994/95 to 1996/97, while T_{11}-T_{14} were planted in three 21-month cycles from 1994/96 to 1997/99.
[2)]for T_1-T_{10} estimated from the average yields in the first three years; for T_{11}-T_{14} actual yields during the three crop cycles completed in slightly over five years.
***Source:** CIAT, 2000.*

f. Mycorrhizal inoculation

Cassava grows well on low-P soils and usually does not respond much to P applications because of a very efficient symbiosis with VA-mycorrhizal fungi occurring in nearly all natural soils. Soon after germination and root formation, the fibrous roots become infected with vesicles, arbuscules and hyphea of mycorrhiza. These hyphae grow into the soil and play an important function in the transport and uptake of P (and Zn) into the roots. Since practically all natural soils have a native mycorrhizal population, there is seldom a need to inoculate with more effective VAM species. In Asia a significant response to VAM inoculation has only been reported by Potty (1988), who found that VAM inoculation increased yields when stakes were germinated in moist sand in the nursery before transplanting in the main field.

g. Application of lime, Mg, S and micronutrients

Cassava is extremely tolerant of soil acidity (Howeler, 1991b). Thus, in most cassava growing areas the crop does not respond to the application of lime (Pardales *et al*., 1984, Ramos and Mosica, 1982). Nevertheless, Mohankumar and Nair (1985) reported a significant response to liming up to a level of 3.5 t $CaCO_3$/ha in an experiment conducted at CTCRT. Similarly, Tan and Chan (1995) reported a significant response to application of 3 t/ha of lime on very acid peat soils in Johor, Malaysia. In many cases this is a response to Ca rather than the neutralizing effect of lime. High applications of lime can also have a detrimental effect by inducing Zn deficiency in soils with a low available Zn content (Howeler, 2001a).

In many low organic matter (OM) sandy soils cassava has shown symptoms of Mg deficiency, especially when only chemical fertilizers are applied. In that case an application of 20-40 kg Mg/ha as band applied $MgSO_4$ or fused Mg-phosphate can eliminate the symptoms and increase yields.

In Asia responses to S and micronutrient applications have been observed only in India, where Nair and Mohankumar (1980) reported a significant response to 12.5 kg Zn/ha, 1.0 kg Mo/ha and 10 kg B/ha, applied as zinc sulfate, ammonium molybdate and borax, respectively, while Mohankumar and Nair (1985) also reported a significant response to application of 50 kg S/ha in an acid lateritic soil of CTCRI. In addition, Chew *et al*. (1978) reported a significant response to application of 10-15 kg $CuSO_4.7H_2O$/ha in peat soils of Malaysia.

Symptoms of Fe or Zn deficiency are commonly observed in caleareous soils, such as in Tamil Nadu, southern Java, and the central part of Thailand. Zinc deficiency can be controlled with a stake dip for 15 min in a 2.0% solution of $ZnSO_4.7H_2O$ before planting, with a foliar spray of 1% $ZnSO_4.7H_2O$, or by band application of 10 kg Zn/ha as $ZnSO_4.7H_2O$. There are no reports of a significant responses to the application of Fe, but foliar sprays or a stake dip in 4% $FeSO_4.7H_2O$ may solve the problem. Large varietal differences in tolerance to Fe and Zn deficiency have been observed, and a change of variety may be a more practical solution than micronutrient applications.

6. Erosion Control

During the past decade numerous erosion control experiments have been conducted on experiment stations as well as in FPR trials on farmers fields. Most experiments showed that soil losses due to erosion can be marked reduced by zero tillage, contour ridging (Jantawat *et al*., 1994) or staggered mounds (Kabeerathumma *et al*., 1996), closer plant spacing, intercropping, mulch application (Evangelio and Ladera, 1998), fertilization and planting contour hedgerows of grasses, such as vetiver grass, lemon grass, elephant grass, *Paspalum atratum, Brachiaria brizantha (*Garrity *et al*., 2000), or legumes, such as *Arachis pintoi, Chamaecrista rotundifolia, Gliricidia sepium, Leucaena leucocephala* or *Calliandra* *calothyrsus* (Utomo *et al*., 1998). Some of these practices have long been adopted by farmers, such as intercropping in Indonesia, staggered mounds and bunds in Kerala, and closer plant spacing and fertilizer or manure application in many areas. Contour ridging is sometimes applied on gentle slopes, but up-and-down ridging is more common, especially in areas where land is prepared by tractor. Mulching has been shown to be highly effective (Evangelio, 2001) but is seldom practiced as mulching material is often not available and/or its transport is too labor intensive. Planting of contour hedgerows to control erosion is seldom practiced as it requires additional labor for planting and maintenance, it takes part of the land out of production and the hedgerows may compete with nearby crop plants. Moreover, in areas where land is prepared by tractor, contour hedgerows interfere with the commonly used practice of up-and-down tillage in straight lines. In the Claveria area of northern Mindanao, Philippines, farmers have accepted the use of contour strips of natural grasses (weeds) to control erosion (Fujisaka, 1998) as that requires less inputs in planting and maintenance, provides some cut-and-carry fodder for cattle, and does not interfere with carabao plowing.

In order to make farmers aware of the problem of soil erosion and the need for better soil conservation practices, it is important to conduct simple demonstrations and on-farm erosion control trials followed by farmer participatory research (FPR). These trials show farmers first of all the extent of soil loss due to erosion on their own land, and secondly, various alternative practices that can markedly reduce erosion. When farmers do their own FPR trials (in collaboration with researchers and/or extensionists), they realize that erosion may be a serious problem but that the practices they themselves tested and selected can be easily adopted to reduce erosion on their fields. This will enhance the adaption of soil conserving practices.

7. Weed Control

All farmers know that good weed control is essential for obtaining high crop yields. Most research conducted in Asia indicate that for cassava it is important to maintain the field weed free for at least the first three months after planting. In most countries weeds are controlled by hand weeding with a hoe, 2-3 times during the first 3 MAP. In parts of the Philippines this is done with a *bolo* and in Indonesia and Tamil Nadu of India with a short-handled hoe. Hand weeding may require between 25 (Thailand) and 100 mandays (Tamil Nadu) (Howeler, 1988). With the use of oxen or carabao labor use for weeding may be reduced to about 10 mandays/ha. In the Philippines it is recommended (Villamayor and Reoma, 1987) to use a carabao for off-barring at 2 weeks after planting (WAP) followed by hand weeding within the row at 3 WAP and hilling up at 5 and 7 WAP.

Research on chemical weed control has been limited to Malaysia, Thailand, South Vietnam and Lampung of Indonesia. In Malaysia the recommended practice is to use a pre-emergence mixture of 2 liters alachlor + 2 kg fluometuron/ha, followed by post-emergence control by hand weeding or directed spray of 2 liters/ha of paraquat and a pre-harvest spray of 2 liters/ha of paraquat (Tan, 1988).

In Lampung, Indonesia, best results were obtained with the application of a mixture of paraquat and diuron (3.75 l/ha) at 30 DAP (Bangun, 1990). Research in Thailand indicated best results with the pre-emergence application of 1.56 kg a.i./ha of metolachlor with or without post-emergence spraying with paraquat (0.5 kg a.i./ha) or with fluazifob-butyl (0.38 kg a.i./ha). This produced similar yields and resulted in similar weeding costs as twice cultivation with bullocks followed by spot treatment with paraquat (0.5 kg a.i./ha) (Tirawatsakul *et al*., 1988). Similarly, in south Vietnam best results were obtained with application of pre-emergence metolachlor (2.4 l/ha) (Nguyen Huu Hy *et al*., 2001). An alternative to paraquat is the application of glyphosate (1.5 kg a.i./ha) for post-emergence control of weeds. In all cases, it is recommended to use a shield on the sprayer to prevent damage of cassava plants.

8. Pruning

Research in some countries has indicated the benefit of removing excess stems, leaving only the two strongest stems per plant (Mandal *et al*., 1973; Wargiono and Sumaryono, 1981). Others report that the pruning of older leaves (Sugito, 1990) or young leaves (topping) at 2 MAP (Arana, 1979) improved yields. Others reported significant yield reductions due to pruning (Villamayor and Labayan, 1982; Evangelio and Ladera, 1998). The prunings can be used (after drying or ensiling) for animal feed.

9. Irrigation

Irrigation of commercial cassava fields is practiced only in Tamil Nadu, India. Experiments at CTCRI in Kerala, India indicate that highest yields were obtained when cassava was irrigated at a rate equivalent to cumulative pan evaporation (Nayar *et al*., 1985). The crop should be irrigated whenever the available soil moisture content drops below 75% (CTCRI, 1984). Similarly, Pardales and Esquivel (1996) found that plant development was reduced if the available moisture content dropped below 80% of field capacity, especially during the first 3 MAP.

10. Intercropping

Intercropping cassava with upland rice, maize and grain legumes is a common practice in Indonesia, while intercropping with maize is common in the Philippines and in some provinces of south Vietnam (**Table 2**). Intercropping with peanut is more common in north Vietnam and China, while vegetables are a profitable intercrop in Tamil Nadu of India. Intercropping is not practiced much in Kerala, Malaysia or Thailand, except for intercropping cassava in young rubber or old coconut plantations. Similarly, cassava is often grown among recently planted cashew nut trees in South Vietnam and among young fruit trees in north Vietnam. On good soils in Guangxi province of China cassava is sometimes intercropped with watermelon, which is planted in plastic mulch during the winter, while cassava is planted two months later. Numerous intercropping experiments have been conducted in Thailand, Indonesia, Vietnam and the Philippines. In Thailand, intercropping widely-spaced (1.25 x 0.8 m) cassava with two rows of either peanut or mungbean, spaced at 20 x 10 cm, was found to be most productive (Tongglum *et al*., 1988). The highest Land Equivalent Ratio (LER) was obtained with a cassava spacing of 1.80 x 0.55 m intercropped with three rows of mungbean, but the highest gross income was obtained with peanut planted at the same plant spacing (Tongglum *et al*., 1992). Intercropping with muskmelon, cucumber and pumpkin, can also be highly profitable (Tongglum *et al*., 1998) but also quite risky as either too much or too little rain can lead to crop failure. Long-term intercropping trials in Thailand have shown that intercropping with sweetcorn was by far the most profitable (Tongglum *et al*., 2001); a similar result was obtained in Malaysia (Tan, 1988).

In north Vietnam, Le Sy Loi (2000) reported highest gross and net income by intercropping cassava with peanut, planted at the same time as cassava, in two rows between cassava rows spaced at 1x0.8 m. This also markedly reduced erosion. Similarly, in Indonesia, Wargiono *et al*. (1998) reported that intercropping cassava with upland rice and maize followed by grain legumes resulted in the highest total crop value and low levels of erosion (Wargiono, 2001). In India, intercropping with French bean or vegetable cowpea was found to be most profitable (Gosh *et al*., 1987; Mohankumar and Ravindran, 1991), because their early harvest caused little reduction in cassava yields.

Since cassava is usually widely spaced and has slow initial development, intercropping at the early stage of crop development is highly feasible and usually results in higher total income and less erosion. However, cassava is a poor competitor and can easily be shaded out by tall intercrops like maize, or suffer from nutrient and/or water competition from intercrops that are planted too closely to the cassava row; cassava yields can also be seriously affected if the intercrop competition extends beyond 2 ½-3months, as is often the case with field maize. Thus, intercropping cassava with many other crops is feasible, but the most suitable crop combinations depends on the soil and climatic conditions, the varieties used, the availability of labor, and on market conditions.

AREAS REQUIRING FURTHER RESEARCH AND POLICY INITIATIVES

In the past, most agronomists have aimed at developing new crop and soil management practices that would maximize yields or net income for the farmer. However, in an era of globalization and removal of international trade barriers one also has to consider the crop's competiveness, not only *vis a vis* cassava grown in other countries but also with other crops which have similar end uses, such as maize and coarse grains for animal feed, maize and potato for starch and its derivatives, wheat for bakery products and sugarcane or molasses for sweeteners, MSG and alcohol production. To remain competitive farmers not only need to produce high yields but also at a low cost, so that the cost of production per tonne is low, resulting in a low-cost raw material for the various processing industries. **Table 11** compares the cost of production of cassava in various countries in Asia, using the latest and most complete data available. From this table it is clear that Thai cassava remains the most competitive on the world market due to the lowest cost of production per tonne and low profit margins for cassava farmers. This has been achieved through the widespread use of high-yielding varieties (Sarakarn *et al*., 2001) and low-cost production practices that limits labor and purchased inputs. In contrast, in spite of exceptionally high yields obtained in Tamil Nadu and the lowlands of Kerala, India, the cost of production per tonne is 2-3 times higher than in Thailand due to the use of extremely labor-intensive practices, the high cost of fertilizers and a very high cost of land.

Thus, for cassava to remain a remunerative crop for farmers as well as competitive in world markets (Hershey and Howeler, 2001), agronomist must develop cultural practices that increase yields *and* reduce costs, both labor costs and purchased input costs such as fertilizers, chemicals, fuel etc. Since much research on cassava cultural practices was conducted in the 1970s, using the then prevalent varieties, under quite different economic circumstances, it is recommended to review or repeat some of this research using the new high-yielding varieties and including economic as well as statistical analyses of the results. Some areas that warrant particular attention are:

Table 11. Cassava production costs (US $ /ha) and profitability in various countries in Asia in 1998-2000.

	China[1)]	India[2)]	Indonesia[3)]	Philippines[4)]	Thailand[5)]	Vietnam[6)]
Labor Costs ($/ha)	***167.40***	***421.70***	***185.37***	***218.80***	***167.18***	***213.60***
Labor costs ($/manday)	1.86	1.29	1.11	2.00	3.24	1.78
-land preparation (mandays/ha)	*7.5*	*1.5*	*45*	*8.1*	*2.4*	*5*
-preparation planting material	-	*1.9*	*5*	-	-	*5*
-planting	*15.0*	*14.8*	*15*	*9.4*	*9.1*	*10*
-application fert. and manures	*5.0*	*10.7*	*12*	*2.5*	*6.4*	*5*
-application other chemicals	-	*0.3*	-	-	-	-
-irrigation	-	*51.9*	-	-	-	-
-weeding and hilling up	*40.0*	*208.6*	*40*	*26.9*	*8.0*	*40*
-harvesting (includes loading)	*22.5*	*37.2*	*50*	*37.5*	*25.7*	*55*
-transport and handling	-	-	-	*25.0*	-	-
Total (mandays/ha)	*90.0*	*326.9*	*167*	*109.4*	*51.6*	*120*
Other Costs ($/ha)	***260.22***	***242.15***	***80.55***	***163.25***	***198.73***	***171.07***
-Fertilizers and manures	130.11	159.39	79.44	53.75	61.97	80.36
-Planting material	-	26.83	1.11	25.00	-	-
-Other materials (herbicides, sacks)	37.17	2.23	-	20.00	25.84	-
-Transport of roots	-	-	-	-	70.38	-
-Land preparation by tractor	92.94	53.70	-	64.50	40.54	90.71
Total Variable Costs ($/ha)	**427.62**	**663.85**	**265.92**	**382.05**	**365.91**	**384.67**
-Land rent and/or taxes	94.94	236.50	46.67	-	48.89	60.00
Total Production Costs ($/ha)	**520.56**	**900.35**	**312.59**	**382.05**	**414.80**	**444.67**
Yield (t/ha)	20	40	20	25	23.40	25
Root price ($/t fresh roots)	29.74	38.00	17.78	25.00	21.62	21.42
Gross income ($/ha)	294.80	1,520.00	355.60	625.00	505.91	535.50
Net income ($/ha)	74.24	619.65	43.01	242.95	91.11	90.83
Production costs ($/t fresh roots)	26.03	22.51	15.63	15.28	17.73	17.79

Sources: [1)]Tian Yinong for Guangxi, China
[2)]Srinivas, 2001; for irrigated cassava in Tamil Nadu, India
[3)]J. Wargiono for monoculture cassava in Lampung, Indonesia
[4)]Bacusmo, 1999; for monoculture cassava in the Philippines
[5)]Adapted from TTDI, 2000; average of 527 advanced farmers in Thailand
[6)]Farmers estimate for monoculture cassava in Dongnai province of Vietnam

Note: for more detailed information, see Appendix 1, Tables 1-6.

1. Weed control: weeding requires between 20 and 200 mandays/ha, making it one of the most costly cultural practices. Use of bullocks or hand tractors for intercrultivation, use of herbicides – especially pre-emergence herbicides which are presently hardly used at all – and intercropping, mulching or planting in the dry season, may all reduce weeding costs. Moreover, weeding after 3 MAP may not be necessary. The future deployment of herbicide resistant varieties may make the use of herbicides more cost-effective.

2. Fertilization: most cassava farmers apply between 5 and 10 tonnes of manure per ha, because it is available on the farm and thus considered free. Still, there is an opportunity cost to manure, as this input could also be applied to other crops, vegetables or fruit trees. Moreover, transport and application of manures require 10-20 times more labor than that of chemical fertilizers. While more and more farmers are now applying chemical fertilizers, they often apply too much (India, Malaysia) or the incorrect balance of N, P and K (Thailand, Vietnam, Indonesia). Both short- and long-term fertilizer trials have established without doubt the need for annual application of N and K, while P applications can be drastically reduced or applied less frequently. The challenge is to convince farmers, who traditionally have applied mainly N and P. This can best be done through on-farm and farmer participatory research (FPR), emphasizing not only yield but also economic returns to various fertilization practices. Similarly, farmers should be shown that fertilizers are most effective when applied at the early stage of the crop cycle.

Presently, few countries have a well-functioning soil testing service for farmers. Since soil fertility can vary markedly from field to field, accurate and economically optimum fertilizer recommendations can only be made based on soil test results. Fertilizer use efficiency could be improved and costs reduced if farmers had access to an efficient soil testing service, which would also have to be able to make cost-effective fertilizer recommendations. Moreover, governments have to make sure that a variety of compound fertilizers are available on the market, so farmers can purchase those that are most suitable for the crop and their particular soil.

3. Land preparation: presently, most cassava farmers prepare their land by 2-3 passes of a tractor- or bullock-drawn plow; in Kerala state of India and Java island of Indonesia it is mostly done by hand, requiring much input of labor. Plowing the soil with a tractor-mounted 3- and 7-disc plow leaves the soil surface smooth and clean, but also results in hardpan formation at the plow sole, which inhibits drainage, causing poor growth, root rots and excessive runoff and erosion. Moreover, the turning over of soil exposes soil organic matter to high temperatures and rainfall, resulting in rapid decomposition of soil OM. To counter these soil degrading effects of conventional land preparation practices, effective and efficient methods of "conservation tillage" must be developed; this probably requires a combination of minimum tillage with a chisel plow and the use of herbicides, both pre-emergence and post-emergence.

4. Harvesting: harvesting requires between 20 and 40 mandays per ha, and with transport of the roots constitutes a major part of production costs. The efficiency of harvesting depends a lot on the soil texture and moisture conditions, on weeds and the depth and the shape of roots. Selection of varieties with a compact root mass will facilitate the harvest. A well-developed crop that has outshaded weeds is also easier to harvest than a poorly established and/or maintained crop. Harvest costs may be further reduced with the use of a tractor-mounted implement that digs under the roots, loosening the soil and pushing the roots to the soil surface, where they can be easily collected.

5. Planting: while cassava planting can be mechanized, as done in parts of Brazil and Colombia, manual planting is still practiced throughout Asia (even in large plantations) as it does not require excessive hand labor. Experienced planting crews in Thailand can cut the stakes and plant in perfectly straight lines using only 8 mandays per ha. In large plantations, the cutting of stakes with a motorized saw may be justified.

6. Cassava for leaf production: it has long been known that cassava leaves are high in protein with a favorable balance of amino-acids. In spite of having a high content of cyanogens, they can be used for animal feeding after proper drying or ensiling. Numerous feeding trials with pigs, poultry, dairy and beef cattle have shown good results. Since cassava roots are high in carbohydrates and their leaves are high in protein, the combined use of dry cassava root and leaf powder (together with some minerals and vitamins) in commercial animal feed rations should be further investigated. Since in the past, cassava breeders have concentrated on the development of high harvest index varieties to maximize root production, these varieties may not necessarily be the best for high leaf protein production. Thus, new varieties may need to be developed for this purpose. Similarly, plant spacing, fertilization and pruning times and methods need to be optimized in order to obtain high leaf and protein yields at a low cost. If this can be achieved, cassava leaves in combination with roots may be able to enter the low-cost animal feed rations in many Asian countries, which presently spend foreign exchange for the importation of maize and soybeans. To realize this possibility will require a concerted effort among cassava agronomists and breeders, animal nutrition specialists and the private animal feed sector. It may also require government intervention and changes in importation policies so that cassava farmers may at least enjoy the same privileges presently extended to many maize, sugarcane and soybean farmers. Through this combined effort, the crop could become truly competitive on the world or domestic market as a highly efficient producer of both carbohydrates and proteins.

CONCLUSIONS

Much research on cassava cultural practices have been conducted over the past 20-30 years in many Asian countries. Optimum practices to increase yields have been identified and recommended to farmers. A constraints analysis conducted in 1996, indicate that Asian researchers estimate that improved soil and crop management combined could increase current cassava yields by 56%; this is much greates than the potential yield increase expected from better varieties or pest and disease control (Henry and Gottret, 1996; Van Norel, 1997). To what extent cassava agronomy research has led to adoption by farmers is difficult to gauge. No doubt much information has reached farmers and many recommended practices on methods of land preparation, planting, weeding and fertilization have been adopted by farmers. Still, the transfer of technology remains the weak link in the chain between technology development and adoption. More research conducted on-farm and with full farmer participation and decision making will enhance not only the relevance and quality of the research, but also the adaptation and adoption by farmers. Since both the biophysical and socio-economic conditions of cassava farmers are extremely diverse, the practices that have been developed by researchers on experiment stations need to be verified on-farms and with farmers, in order to make the necessary adaptations to the unique environment of each site. Only when farmers are empowered to participate in this research and make their own decisions will the research results be truly relevant to their conditions and adapted to their needs. Once farmers feel confident that they themselves contributed to the development of the technology, the adoption of the technology will follow naturally. To facilitate this process, the research and extension organizations at various levels should work in partnership with each other and with the farmers. There are hopeful signs that this is already happening in many countries in Asia, particularly in Thailand and Vietnam, but more needs to be done to institutionalize the participatory approach in order to achieve greater adoption of improved practices to the benefit of cassava farmers.

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Appendix 1.

Table 1. Cassava production costs (US $/ha) in China in 2000/01.

	Guangxi[1)]	Hainan[2)]	Kongba village, Hainan[3)]
Labor Costs ($/ha)	***167.40***	***339.45***	***232.50***
-Labor costs ($ /manday)	1.86	1.86	1.86
-land preparation (mandays/ha)	*7.5*	*45.0*	*26.0*
-preparation planting material	-	*2.5*	-
-planting	*15.0*	*15.0*	*6.0*
-application manures	-	-	-
-application fertilizers	*5.0*	*15.0*	*5.0*
-application other chemicals	-	-	-
-irrigation	-	-	-
-weeding	*40.0*	*60.0*	*41.0*
-harvesting (includes loading)	*22.5*	*45.0*	*32.0*
-transport	-	-	*15*
Total (mandays/ha)	*90.0*	*182.5*	*125.0*
-Other Costs ($/ha)	***260.22***	***130.81***	***77.43***
-Fertilizers	130.11	55.76	38.78
-Planting materials	-	13.94	7.00
-Other chemicals (herbicide)	37.17	5.35	11.65
-Transport of roots	-	55.76	20.00
-Land preparation by tractor	92.94	-	-
Total Variable Costs ($/ha)	**427.62**	**470.26**	**309.93**
Land rent or tax ($/ha)	94.94	34.70	3.72
Total Production Costs ($/ha)	**520.56**	**504.96**	**313.65**
Yield (t/ha)	20	20	20
Root price ($/tonne)	29.74	29.74	29.74
Gross income ($/ha)	594.80	594.80	594.80
Net income ($/ha)	74.24	89.84	281.15
Production costs ($/tonne cassava roots)	26.03	25.25	15.68

[1)] Estimate by Tian Yinong
[2)] Estimate by Li Kaimian
[3)] Based on RRA in 1998.
1 US $ = 8.07 yuan in 2000/01

Appendix 1.

Table 2. Cassava production costs (US $/ha) in India in 2000/01.

	Tamil Nadu		Kerala	
	Irrigated	Rainfed	Upland	Lowland
Labor Costs ($/ha)	***421.70***	***226.69***	***336.70***	***387.42***
-Labor costs ($ /manday)	1.29	1.12	2.09	2.20
-land preparation (mandays/ha)	*1.5*	*1.9*	*64.8*	*74.2*
-preparation planting material	*1.9*	-	-	-
-planting	*14.8*	*18.0*	*10.7*	*9.9*
-application manures	*4.8*	*4.1*	*15.2*	*16.6*
-application fertilizers	*5.9*	*5.4*	*0.6*	*2.6*
-application other chemicals	*0.3*	*0.2*	*3.7*	*1.2*
-irrigation	*51.9*	-	-	*9.2*
-weeding	*208.6*	*132.8*	*37.4*	*38.8*
-harvesting	*37.2*	*40.0*	*28.7*	*23.6*
Total (mandays/ha)	*326.9*	*202.4*	*161.1*	*176.1*
Other Costs ($/ha)	***242.15***	***201.40***	***198.33***	***174.36***
-Manures	78.84	55.96	122.45	105.37
-Fertilizers	80.55	50.97	63.83	61.67
-Planting materials	26.83	21.50	10.36	4.59
-Other chemicals (plant protection)	2.23	0.24	1.69	2.73
-Land preparation by tractor	53.70	72.73	-	-
Total Variable Costs ($/ha)	**663.85**	**428.09**	**535.03**	**561.78**
Land rent ($/ha)	236.50	68.54	190.22	527.27
Total Production Costs ($/ha)	**900.35**	**496.63**	**725.25**	**1,089.05**
Yield (t/ha)	40	25	15	25
Root price ($/tonne)	38	33	76	87
Gross income ($/ha)	1,520.00	825.00	1,140.00	2,175.00
Net income ($/ha)	619.65	328.37	414.75	1,085.95
Production costs ($/tonne cassava roots)	22.51	19.87	48.35	43.56

1 US $ = 46 Rp in 2000/01.

Source: *Adapted from Srinivas, 2001.*

Appendix 1.

Table 3. Cassava production costs (US $/ha) in Indonesia in 2000/01.

	Monoculture (Lampung)[1)]	Intercropped (E. Java)[1)]	Intercropped (Ringinrejo village)[2)]
Labor Costs ($/ha)	***185.37***	***414.75***	***218.67***
-labor costs ($ /manday)	1.11	1.11	1.11
-land preparation, hoeing (mandays/ha)	*40*	*55*	*44*
-land preparation, plowing	*5*	*6*	-
-preparation planting material	*5*	*5*	*5*
-planting	*15*	*28*	*23*
-application manures	*6*	*7*	*7*
-application fertilizers	*6*	*33*	*11*
-application herbicides/insecticides	-	*28*	*2*
-weeding + hilling up	*40*	*70*	*35*
-harvesting (includes loading)	*50*	*85*	*70*
-transport to house or market	-	-	-
Total (mandays/ha)	*167*	*317*	*197*
Other Costs ($/ha)	***80.55***	***152.36***	***93.05***
-Manure	35.00	50.00	50.00
-Fertilizers	44.44	55.00	24.72
-Planting materials	1.11	44.33	16.94
-Insecticides	-	1.56	1.39
-Herbicides	-	1.47	-
Total Variable Costs ($/ha)	**265.92**	**567.11**	**311.72**
Land rent ($/ha)	46.67	-	-
Total Production Costs ($/ha)	**312.59**	**567.11**	**311.72**
Yield -cassava (t/ha)	20	12	15
-maize (t/ha)	-	1.5	2.0
-rice (t/ha)	-	2.0	-
-soybean (t/ha)	-	0.5	-
Gross income ($/ha)[3)]	355.60	690.68	377.80
Net income ($/ha)	43.01	123.57	66.08
Production costs ($/tonne cassava roots)	15.63	-	-

[1)]Estimate by J. Wargiono
[2)]Based on RRA in Ringinrejo village, Blitar, E. Java in 1998
[3)]Prices: cassava $ 17.78/t fresh roots; maize $ 55.55/t dry grain; rice $100/t dry grain; soybean $388/t dry grain; labor costs for plowing =$2.77/day, herbicide application $ 3.00/day.
1US $ = Rp 9000 in 2000/01.

Appendix 1.

Table 4. Cassava production costs (US $/ha) in the Philippines in 1998/99.

	Monoculture	Intercropped with maize
1. Labor Costs ($/ha)	***218.80***	***425.60***
-Labor costs ($ /manday)	2.00	2.00
-land preparation	*8.1*	*8.1*
-planting	*9.4*	*11.2*
-application fertilizers/manures	*2.5*	*8.8*
-weeding	*18.8*	*37.5*
-cultivation	*8.1*	*10.0*
-harvesting	*37.5*	*56.2*
-shelling and drying of maize	-	*45.0*
-transport and handling	*25.0*	*36.0*
Total (mandays/ha)	*109.4*	*212.8*
Other Costs ($/ha)	***163.25***	***277.00***
-Fertilizers and chemicals	53.75	127.50
-Land preparation by tractor	64.50	64.50
-Planting materials	25.00	65.00
-Sacks	20.00	20.00
Total Variable Costs ($/ha)	**382.05**	**702.60**
Land rent ($/ha)	-	-
Total Production Costs ($/ha)	**382.05**	**702.60**
Yield - cassava (t/ha)	25	20
-maize (t/ha)	-	4.0
Gross income ($/ha)[1)]	625.00	1,100.00
Net income ($/ha)	242.95	397.40
Production costs ($/tonne cassava roots)	15.28	-

[1)]Prices: cassava $ 25.00/tonne fresh roots; maize $ 150/tonne dry grain
1 US $ = 40 Philpesos in 1998/99
Source: **Adapted from Bacusmo, 1999.**

Appendix 1.

Table 5. Cassava production costs (US $/ha) in Thailand in 1999/2000.

	Average all farmers[1)]	Average advanced farmers[2)]
1. Labor costs ($/ha)	***168.48***	***167.18***
-Labor costs ($ /manday)	3.24	3.24
-land preparation (mandays/ha)	*1.6*	*2.4*
-planting	*9.1*	*9.1*
-fertilizer application	*6.1*	*6.4*
-weeding	*14.0*	*8.0*
-harvesting	*19.4*	*25.7*
-loading	*1.8*	-
Total (mandays/ha)	*52.0*	*51.6*
Other costs ($/ha)	***125.68***	***198.73***
-Fertilizer and manures	20.23	61.97
-Planting meterials	26.66	-
-Herbicides and perticide	8.57	25.84
-Fuel and lulicants	2.15	-
-Inplements and others	3.64	-
-Land preparation by tractor	40.50	40.54
-Transport of harvest	-	70.38
-Interest and apportunity costs	23.93	-
Total Variable Costs ($/ha)	**294.16**	**365.91**
Land rent and taxes	44.15	48.89
Depreciation machinery	3.39	-
Total Production Costs ($/ha)	**341.70**	**414.80**
Yield (t/ha)	16.52	23.40
Root price ($/tonne)	21.62	21.62
Gross income ($/ha)	357.16	505.91
Net income ($/ha)	15.46	91.11
Production costs ($/tonne fresh roots)	20.68	17.73

1US $ = 37 baht in 1999/2000.; cost of labor 120 baht/day

Sources: [1)] *Office of Agric. Economics (OAE), 2001.*

[2)]*Adapted from TTDI, 2000.*

Appendix 1.

Table 6. Cassava production costs (US $/ha) in Vietnam in 2000/01.

	North Vietnam[1)]		Central Vietnam		South Vietnam	
	mono-culture	peanut intercrop	mono-culture[2)]	peanut intercrop[3)]	mono-culture[4)]	maize intercrop[5)]
Labor Costs ($/ha)	***198.80***	***337.96***	***175.45***	***482.80***	***213.60***	***281.24***
-Labor costs ($/manday)	0.71	0.71	1.21	1.42	1.78	1.78
-land preparation (mandays/ha)	*56[6)]*	*56[6)]*	*40*	*40*	*5*	*5*
-preparation planting material	-	-	-	-	*5*	*5*
-planting –cassava	*56*	*56*	*10*	*40*	*10*	*10*
-intercrop	-	*84*	-	*40*	-	*10*
-fertilizer application	-	-	*15*	*20*	*5*	*10*
-weeding –cassava	*56*	*56*	*35*	*80*	*40*	*30*
-intercrop	-	*56*	-	-	-	*20*
-harvesting – cassava	*56*	*56*	*45*	*60*	*55*	*50*
-intercrop	-	*56*	-	*60*	-	*18*
Total (mandays/ha)	*224*	*420*	*145*	*340*	*120*	*158*
Other Costs ($/ha)	***119.54***	***248.89***	***39.50***	***228.57***	***171.07***	***107.01***
-Fertilizers	48.11	52.55	34.86	100.00	80.36	44.64
-Manures	71.43	100.00	-	-	-	-
-Herbicides/pesticides	-	-	4.64	42.86	-	-
-Intercrop seed	-	96.43	-	85.71	-	26.66
-Land preparation by tractor	-	-	-	-	90.71	35.71
Total Variable Costs ($/ha)	**318.34**	**586.94**	**214.95**	**711.37**	**384.67**	**388.25**
Land rent and taxes	-	-	5.43	28.57	60	60
Total Production Costs ($/ha)	**318.34**	**586.94**	**220.38**	**739.94**	**444.67**	**448.25**
Yield (t/ha) -cassava	17	16	21	20	25	20
-intercrop	-	1.0	-	2.0	-	4.0
Price ($/t) -cassava	35.71	35.71	19.28	14.28	21.42	21.42
-intercrop	-	357.14	-	357.14	-	72.85
Gross income ($/ha)	607.07	928.50	404.88	999.88	535.50	719.80
Net income ($/ha)	288.73	341.56	184.50	259.94	90.83	271.80
Production cost ($/tonne fresh roots	18.72	-	10.49	-	17.79	-

1 US $ =14.000 dong in 2000/01

[1)]Based on RRAs in north Vietnam in 1999/00

[2)]Based on farmer estimates (average 5 locations) during FPR training course, Hue, Aug 2001

[3)]Based on RRA in Huong Van commune, Huang Tra district, Thua Thien-Hue province

[4)]Based on farmer estimates in Dongnai province during FPR training course, HCM city, Jan 2000

[5)]Based on RRAs in Chau Duc district of Baria-Vungtau province

[6)]labor costs for land preparation = $ 1.42/day

FARMER PARTICIPATORY RESEARCH IN CASSAVA SOIL MANAGEMENT AND VARIETAL DISSEMINATION IN VIETNAM – RESULTS OF PHASE 1 AND PLANS FOR PHASE 2 OF THE NIPPON FOUNDATION PROJECT

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ABSTRACT

Farmer participatory research (FPR) in Vietnam has been carried out since 1994 as part of the Nippon Foundation project. This is a collaborative project between Thai Nguyen University of Agriculture and Forestry (TNUAF), the National Institute for Soils and Fertilizers (NISF) and the Centro Internacional de Agricultura Tropical (CIAT). The objective of the project is to enhance the adoption of soil conservation practices and improved cultural techniques in cassava fields. Two villages in Pho Yen district, Thai Nguyen province, one in Thanh Ba district, Phu Tho province, and one in Luong Son district, Hoa Binh province, were selected as pilot sites for implementing the FPR methodology in phase 1 (1994-1998). By using RRA and PRA methods in conducting the participatory diagnosis some limiting factors in cassava production were identified. Demonstration plots with 16 treatments on different ways to improve soil fertility and methods to control soil erosion were also established at Thai Nguyen University.

Based on the results of the RRA and discussion, farmers selected four technical options, i.e. the use of contour hedgerows to control soil erosion, intercropping, application of fertilizers and new varieties, to test in FPR trials on their own fields.

Result of the FPR trials on farmers fields indicate that the combination of intercropping with peanut, planting of contour hedgerows of vetiver grass or *Tephrosia candida*, and the use of a well-balanced NPK application were considered as the most promising practices at both pilot sites; these practices not only increased farmers' income but also reduced soil erosion by 20-40% in comparison with the check plot of monocropping and without hedgerows. The results of the FPR trials were evaluated each year by the farmers during the field days at time of harvest and were used to plan the trials for the next year.

After four years of research, farmers have adopted the application of balanced NPK fertilizers and some are establishing contour hedgerows of *Tephrosia candida* or vetiver grass. However, the widespread adoption of new cassava varieties by the farmers was the best result of the first phase of the project. New cassava varieties, such as KM60, KM94, KM95-3, and KM98-7, are now planted extensively, not only by farmers that participated in the research program but also by other farmers. FPR is the best method to develop and transfer technologies with farmers. The number of farmers that wanted to participate increased from 1994 to 1998, indicating the effectiveness of the participatory research approach.

The main objectives in the second phase are:

- To develop new and innovative FPR methodologies by using various methods of participatory research at about 20 pilot sites in Vietnam, in order to overcome constraints identified at the farm level.
- To disseminate new technologies that increase income and help to conserve soil productivity, identified by farmers, to at least 3000 other cassava farmers.
- To build and strengthen the capacity of researchers, extensionists and cassava farmers in using participatory approaches for self-development.

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INTRODUCTION

Cassava is a traditional crop within the tropical world in general, and in Vietnam in particular. Therefore, farmers have a lot of experience in cultivating this crop. However, they have not yet adopted new technologies to increase their cassava yields, especially to maintain stable cassava production. During the past decade some serious cassava research has been undertaken by various universities and research institutions. This work has resulted in good results, but very few of these have been applied in practice. The main reason for the above situation is that there are major differences in environmental and practical conditions between research stations and farmers' fields. For that reason, improved techniques are not readily adopted by farmers. In addition, various limitations faced by farmers, as well as a lack of awareness, are also factors that contribute to the limited adoption of advanced technologies by farmers.

Because of this situation, a new research approach need to be developed that can combine careful on-station research with on-farms trials with participation from farmers. Farmer Participatory Research (FPR) methodologies can better meet the needs of farmers. For that reason, an FPR project, funded by the Nippon Foundation, has been implemented in close collaboration with CIAT. This includes a first phase from 1994 to 1998, and a second phase from 1999-2003. The first phase of the project has been implemented in four pilot sites: in two villages of Pho Yen district, Thai Nguyen province; in Thanh Ba district, Phu Tho province, and in Luong Son district, Hoa Binh province.

1. FPR Methodologies Used

The FPR project was divided into five steps:

- Conduct Rapid Rural Appraisals (RRA) to evaluate the current agricultural practices, the constraints in cassava production in the pilot sites, and potential solution to these problems.
- Identify with farmers research topics that deal with these problems, and plan FPR trials that test potential solutions.
- Conduct demonstration plots on experiment stations on various topics, such as new varieties and fertilization.
- Conduct FPR trials with farmers on their own fields with the following components:
  - Control of soil erosion by evaluating various soil/crop management practices
  - Cassava intercropping with grain legumes
  - Cassava fertilization
  - New cassava varieties.
- Organize farmers' field days to harvest and evaluate the FPR trials, present and discuss the results and decide further research needs.

2. Results of Phase I (1994-1998)

2.1 Baseline study and current cassava production evaluation

Information on bio-physical and socio-economic conditions as well as on agricultural practices in the selected pilot sites was collected by using RRA/PRA methods. Results indicate that the four pilot sites have similar natural conditions; for instance, total annual rainfall ranges from 1500 mm to 2100 mm, with more than 80% of the total rainfall concentrated during the summer months of April to Sept. Cassava is mainly grown on sloping land, resulting in the surface soil being seriously eroded every year(Nguyen The Dang *et al*., 1998). Farmers have experience with cassava planting, but they have applied only very simple practices. The main constraints at all sites are:

- Low inputs
- Old and degraded cassava varieties
- No special practices to reduce soil erosion

The low cassava yields (8-15 t/ha) are a result of this low-input technology.

2.2 Demonstration plots on methods of erosion control in cassava

To gain an understanding of the effect of different soil/crop management practices on soil erosion and to enable farmers to select the most suitable practices to evaluate on their own farms, we have conducted demonstrations with 16 treatments at Thai Nguyen University of Agriculture and Forestry (TNUAF) from 1994 to 1997. Averaged over three years, the treatment with balanced NPK gave the highest cassava fresh root yield compared to other treatments (**Table 1**). Without fertilizer application cassava yields decreased from 8.25 t/ha in the first year to 2.65 t/ha in the fourth year. When a balanced NPK application was combined with the return of residues to the soil, stable yields were obtained during four years. The most effective way to control soil erosion was to plant contour hedgerows combined with cassava intercropping with peanut. This pattern reduced the amount of soil loss to about 20-30% of that of cassava sole cropping without hedgerows (**Table 1**).

Table 1. Results of FPR demonstration plots conducted on 18-24% slope at Agro-forestry College of Thai Nguyen University, Thai Nguyen, Vietnam. Data are average values for 1995, 1996 and 1997.

Treatments[1)]	Cassava yield (t/ha)	Net income (mil. d/ha)	Dry soil loss (t/ha)	Farmers' preference (%)
1. C monoculture, no fertilizers, no hedgerows	4.49	1.87	28.3	0
2. C, with fertilizers (60 N-40 P_2O_5-120 K_2O)	16.49	7.67	23.0	0
3. C, with FYM (10 t pig manure/ha)	17.31	7.79	25.3	10
4. C, with FYM+fertilizers	23.56	10.39	24.9	58
5. C, with fertilizers, with *Tephrosia* green manure	19.60	9.63	24.3	2
6. C+P, with fertilizers, *Tephrosia*+vetiver hedgerows	17.53	10.73	5.8	78
7. C, with fertilizers, contour ridging	20.48	9.84	12.6	49
8. C, with fertilizers, *Tephrosia* hedgerows	16.39[2)]	7.51	13.6	16
9. C, with fertilizers *Flemingia* hedgerows	16.29[2)]	7.43	8.0	22
10. C, with fertilizers, vetiver grass hedgerows	18.96[2)]	9.12	4.7	32
11. C+B, with fertilizers, *Tephrosia* hedgerows	17.93	7.93	9.0	12
12. C, with fertilizers, cassava residues incorporated	24.75	12.40	18.1	25
13. C, no fertilizers, residues incorp., *Tephrosia* hedgerows	6.52	3.26	12.8	0
14. C, with fert., *Tephrosia* intercropped+mulched at 3 MAP	18.99	8.73	18.5	0
15. C, with fertilizers, no tillage	18.92	9.29	18.1	0
16. C, with fertilizers, closer plant spacing (0.8x0.6 m)	21.66	10.58	18.5	16

[1)]C=cassava, P=peanut, B=black bean; in all treatments except T_7 and T_{15} the soil was prepared with hoe and cassava was planted without ridging; in all treatments except T_{12} and T_{13} the cassava residues were removed after harvest; in all treatments except T_{16} cassava was planted at 1.0x0.8 m;

[2)]In 1997 in T_8, T_9 and T_{10} cassava was intercropped with peanut.

Another demonstration was conducted with ten treatments from 1998 to 2000. Results confirmed that intercropping cassava with peanut and planting contour hedgerows markedly reduced soil losses, and was able to maintain cassava yields (**Table 2**).

Farmers collaborating in the project had the opportunity to visit these demonstration plots during field days each year. After evaluation, they selected the most suitable treatments to include in their FPR trials on their own fields.

2.3 Results of FPR trials

2.3.1 Pho Yen district of Thai Nguyen province

FPR trials on four research topics (soil erosion control by planting methods, intercropping systems, balanced fertilization, new varieties) have been conducted in two villages (Dac Son and Tien Phong) in Pho Yen district of Thai Nguyen province from 1995 to 1998.

Trials on planting methods for soil erosion control consisted of 4-5 treatments which were adjusted every year (**Tables 3** to **5**). These trials have shown that contour hedgerows reduced soil losses compared to planting without contour hedgerows when cassava was grown on sloping land. Treatments that combined hedgerows with intercropping with peanut maintained high cassava yields and resulted in the highest net income compared to the traditional farmers' practice of monocropping.

From observations and evaluations at time of harvest each season, almost all farmers selected the planting method that combined hedgerows and intercropping cassava with peanut or black beans.

Trials on cassava intercropping with grain legumes in 1995 and 1996 (**Table 6**) indicate that cassava intercropped with peanut gave better results than intercropping with black bean, not only in terms of production but also in terms of soil conservation. Farmers have adopted this practice and have expanded intercropping with peanut on their own farms. Results of trials conducted in 1997 and 1998 by 17 households (**Table 7**) have confirmed that cassava grown at 1.0 m between rows and 0.6 m between plants in the row, and intercropped with one row of peanut between cassava rows resulted in the highest net income/ha. This technology was also easy to adopt. Therefore, farmers have selected this practice for dissemination in their village.

A survey had indicated that most farmers applied only phosphorus to cassava. So, FPR trials on the application of NPK for cassava were conducted by two farmers in 1995(Nguyen The Dang *et al*., 1998). These trials have shown that without K application cassava yields were reduced significantly, while the treatments without P gave equal cassava yields as those in which 40 kg P_2O_5/ha had been applied. Results of similar trials conducted in 1996 to 1998 (**Tables 8** to **10**) indicate that highest cassava yields were obtained with the application of 80 kg N, 40 P_2O_5, 80-120 K_2O and 10 tonnes of pig manure/ha. Farmers have now adopted NPK fertilization in their cassava fields. They have become aware of the importance of a balanced NPK application for cassava, especially the importance of potassium in maintaining high cassava yields.

Table 2. Results of FPR demonstration plots on 8-10% slope at Thai Nguyen University, Thai Nguyen, Vietnam. Data are average values for 1998 and 1999.

Treatment[2)]	Cassava yield (t/ha)	Peanut yield[1)] (t/ha)	Gross income	Product. costs (mil. dong/ha)	Net income	Dry soil loss (t/ha)
1. C monocult.; no fertilizers; no ridges; no hedgerows	4.61	-	1.12	2.93	-1.81	23.03
2. C monocult.; with fertilizers; contour ridges; no hedgerows	16.75	-	8.38	4.45	3.93	17.89
3. C+P; with fertilizers; no ridges; no hedgerows	16.79	0.61	11.47	4.73	6.74	16.12
4. C monocult.; with fert.; no ridges; vetiver+*Tephrosia* hedgerows	16.63	-	8.32	4.36	3.96	11.45
5. C+P; with fert.; no ridges; *Tephrosia candida* hedgerows	18.72	0.58	12.26	6.71	5.55	10.27
6. C+P; with fert.; no ridges; *Tephrosia*+pineapple hedgerows	18.86	0.51	11.95	7.03	4.92	11.37
7. C+P; with fert.; no ridges; natural grass hedgerows	16.56	0.46	10.58	4.73	5.85	15.44
8. C+P; with fert.; no ridges; vetiver grass hedgerows	17.46	0.48	11.16	6.89	4.27	9.17
9. C+P; with fert.; no ridges; vetiver+*Tephrosia* hedgerows	18.69	0.55	11.83	6.92	4.91	8.26
10. C monocult.; with fert.; no ridges; no hedgerows, closer spacing	24.38	-	12.19	4.38	7.81	12.30

[1)] Dry pods = fresh pods x 0.55.
[2)] C = cassava; P = intercropped peanut

Table 3. Average results of five FPR erosion control trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam in 1996.

Treatments[1]	Dry soil loss (t/ha)	Yield (t/ha) cassava	Yield (t/ha) peanut[2]	Gross income[3] (mil. dong/ha)	Production costs[4] (mil. dong/ha)	Net income (mil. dong/ha)	Farmers' preference (%)
1. C, Farmer's practice	8.33	11.56	-	6.94	4.39	2.55	0
2. C+P, *Tephrosia* hedgerows, no ridging,	6.62	10.91	0.372	8.41	5.54	2.87	0
3. C+P, vetiver grass hedgerows, contour ridges	6.34	12.80	0.280	9.08	5.54	3.54	39
4. C+P, *Tephrosia* hedgerows, contour ridges	4.85	12.44	0.318	9.06	5.91	3.15	38
5. C, vetiver+*Tephrosia* hedgerows, contour ridges	4.17	12.94	-	7.76	4.86	2.90	3

[1]Farmer's practice: cassava monoculture, 15 t/ha of FYM+65 kg N+20 P_2O_5+50 K_2O/ha;
all other plots received 10 t/ha of FYM+80 kg N+20 P_2O_5+80 K_2O/ha

[2]Dry pods

[3]Prices:

cassava:	dong	600/kg fresh roots
peanut:		5,000/kg dry pods

[4]Costs:

FYM:	dong	100/kg	Labor:	cassava monoculture without fert.:	200 mandays/ha
urea (45%N):		2,500/kg		fertilizer and manure application:	10 mandays/ha
SSP (17% P_2O_5):		1,000/kg		intercropping:	100 mandays/ha
KCl (60%K_2O):		2,500/kg		ridging:	50 mandays/ha
peanut seed:		6,000/kg; use 50 kg/ha		hedgerow planting/maintenance:	10 mandays/ha
cassava stakes:		0.63 mil.d/ha			
hedgerow seed:		0.20 mil.d/ha			
labor:		7,500/manday			

Table 4. Average results of five FPR erosion control trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1997.

Treatments[1]	Dry soil loss[1] (t/ha)	Yield (t/ha) cassava	Yield (t/ha) peanut[2]	Gross income[3] (mil. dong/ha)	Production costs[4] (mil. dong/ha)	Net income (mil. dong/ha)	Farmers' preference (%)
1. Farmer's practice	7.73	11.77	-	5.89	4.05	1.84	0
2. C+P, contour ridges	5.39	17.47	0.36	10.54	5.64	4.90	0
3. C+P, contour ridges, vetiver hedgerows	3.94	19.05	0.37	11.38	5.92	5.46	67
4. C+P, contour ridges, *Tephrosia* hedgerows	3.02	19.00	0.39	11.45	5.92	5.53	83
5. C+P, contour ridges, *Tephrosia*+vetiver hedgerows	2.73	17.92	0.41	11.01	5.92	5.09	3

[1] Farmer's practice: cassava monoculture, 11.4 t/ha of FYM+68 kg N+20 P_2O_5+50 K_2O/ha;
all other plots received 10 t/ha of FYM+80 kg N + 40 P_2O_5 + 80 K_2O/ha

[2] dry pods

[3] Prices:	cassava:	dong	600/kg fresh roots
	peanut:		5,000/kg dry pods
[4] Costs	FYM:	dong	100/kg
	urea (45%N):		2,500/kg
	SSP (17% P_2O_5):		1,000/kg
	KCl (60%K_2O):		2,500/kg
	peanut seed:		6,000/kg; use 50 kg/ha
	labor:		7,500/manday
	1 US $ = 11.000 dong		

Table 5. Average results of five FPR erosion control trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1998.

Treatments[1]	Dry soil loss (t/ha)	Yield (t/ha)		Gross income[3]	Production costs[4]	Net income	Farmers' preference (%)
		cassava	peanut[2]	(mil. dong/ha)			
1. Farmer's practice	6.78	8.30	-	4.15	4.05	0.10	0
2. C+P, no hedgerows	4.74	10.00	0.26	6.30	5.27	1.03	0
3. C+P, vetiver hedgerows	3.90	10.06	0.27	6.38	5.54	0.84	10
4. C+P, *Tephrosia* hedgerows	4.51	10.92	0.31	7.01	5.54	1.47	100
5. C+P, vetiver+ *Tephrosia* hedgerows	4.02	9.65	0.37	6.68	5.54	1.14	9

[1]Farmer's practice: cassava monoculture, 11.4 t/ha of FYM+68 kg N+20 P_2O_5+50 K_2O/ha;
all other plots received 10 t/ha of FYM+80 kg N + 40 P_2O_5 + 80 K_2O/ha
[2]Dry pods
[3]Prices: cassava: dong 600/kg fresh roots
peanut: 5,000/kg dry pods
[4]Costs: FYM: dong 100/kg
urea (45%N): 2,500/kg
SSP (17% P_2O_5): 1,000/kg
KCl (60%K_2O): 2,500/kg
peanut seed: 6,000/kg; use 50 kg/ha
labor: 7,500/manday
1 US $ = 13,800 dong

Table 6. Average results of 14 FPR intercropping trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1995 and 1996.

Treatments[1)]	Yield (t/ha) cassava	Yield (t/ha) intercrop	Gross income[2)] (mil. dong/ha)	Production costs[3)] (mil. dong/ha)	Net income (mil. dong/ha)	Farmers' preference[4)] (%)
1. Cassava monoculture	18.74	-	11.24	4.59	6.65	3
2. Cassava+black bean	17.82	0.31	12.24	5.43	6.81	-
3. Cassava+peanut	18.90	0.65	14.59	5.71	8.88	97

[1)]Applied 10 t/ha of pig manure, 80 kg N+40 P_2O_5 +80 K_2O/ha as urea, SSP and KCl, respectively; planted 15 kg of black bean and 61.7 peanut seed/ha.

[2)]Prices:

cassava:	dong	600/kg fresh roots:
peanut:		5,000/kg dry pods:
black bean:		5,000/kg dry grain

[3)]Costs:

FYM:	dong	100/kg
urea (45%N):		2,500/kg
SSP (17% P_2O_5):		1,000/kg
KCl (60%K_2O)		2,500/kg
peanut seed in pods:		6,000/kg
black bean seed:		6,000/kg
labor:		7,500/manday

[4)]Farmers' preference in 1996.

Table 7. Average results of 17 FPR trials on planting arrangement in intercropping cassava with peanut conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1997 and 1998.

Treatments	Yield (t/ha) cassava	Yield (t/ha) intercrop	Gross income[1)] (mil. dong/ha)	Production costs[2)] (mil. dong/ha)	Net income (mil. dong/ha)	Farmers' preference[3)] (%)
1. Farmer's practice[4)]	18.46	0.54	11.93	6.06	5.87	10
2. 1 row of peanut[5)], cassava 1.0x0.6m	24.55	0.28	13.67	5.43	8.24	55
3. 2 rows of peanut[6)], cassava 1.0x0.8m	19.40	0.41	11.75	5.76	5.99	52
4. 3 rows of peanut[7)], cassava 1.2x0.8m	16.98	0.48	10.89	6.09	4.80	0

[1)]Prices:

cassava:	dong	600/kg fresh roots
peanut:		5,000/kg dry pods
peanut seed:		6,000/kg dry grain

[2)]Peanut seed reguirements: T_1 =120, T_2=40, T_3 =70, T_4 =100 kg/ha

[3)]Farmers' preference in 1997

[4)]Cassava on ridges spaced at 1.0-1.2 m between ridges, peanut planted cross-wise on ridge in short rows, 0.6-0.8 m between rows (to reduce excess moisture)

[5)]1 row of peanut between cassava rows at 0.1 m between plants

[6)] 2 rows of peanut at 0.35x0.1 m
[7)] 3 rows of peanut at 0.35x0.1 m

Table 8. Average results of four FPR fertilizer trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1996.

Treatments	Cassava yield (t/ha)	Gross income[2]	Fertilizer costs[3] (mil. dong/ha)	Net income	Farmers' preference (%)
1) Farmer's practice[1]	8.93	5.36	1.79	3.57	0
2) 10 t/ha of FYM; 40 N + 40 K_2O	10.56	6.34	1.39	4.95	0
3) 10 t/ha FYM; 80 N + 80 K_2O	12.40	7.44	1.78	5.66	79
4) 10 t/ha FYM; 80 N + 40 P_2O_5 +80 K_2O	13.22	7.93	2.01	5.92	21

[1]Average farmer application: 13.3 t FYM +53 kg N + 7 kg P_2O_5+31 kg K_2O/ha
[2]Prices: cassava: dong 600/kg fresh roots
[3]Costs: FYM: dong 100/kg
urea (45%N): 2,500/kg
SSP (17%P_2O_5): 1,000/kg
KCl (60%K_2O): 2,500/kg

Table 9. Average results of five FPR fertilizer trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1997.

Treatments	Cassava yield (t/ha)	Gross income[1]	Fertilizer costs[2] (mil. dong/ha)	Net income	Farmers' preference (%)
1) Farmer's practice[3]	18.50	9.25	1.96	7.29	0
2) 10 t/ha of FYM; 40 N+40 K_2O	19.87	9.44	1.39	8.05	32
3) 10 t/ha FYM; 80 N+40 P_2O_5+80 K_2O	22.37	11.19	2.01	9.18	64
4) 10 t/ha FYM; 120 N+40 P_2O_5+120 K_2O	28.00	14.00	2.40	11.60	61

[1]Prices: cassava: dong 500/kg fresh roots
[2]Costs: pig manure: dong 100/kg
urea (45%N): 2,500/kg
SSP (17%P_2O_5): 1,000/kg
KCl (60%K_2O): 2,500/kg
[3]Average farmer's application: 12.8 t/ha of FYM +60 kg N + 30 P_2O_5+41 K_2O/ha

Table 10. Average results of four FPR fertilizer trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1998.

Treatments	Cassava yield (t/ha)	Gross income[1)]	Fertilizer costs[2)]	Net income	Farmers' preference (%)
		(mil. dong/ha)			
1) Farmer's practice[3)]	15.65	7.83	1.87	5.96	0
2) 10 t/ha of FYM; 40 N+40 K_2O	17.85	8.93	1.39	7.54	54
3) 10 t/ha FYM; 80 N+40 P_2O_5+80 K_2O	18.34	9.17	2.01	7.16	50
4) 10 t/ha FYM; 120 N+40 P_2O_5+120 K_2O	21.45	10.73	2.40	8.33	66

1)Prices: cassava: dong 500/kg fresh roots
2)Costs: FYM: dong 100/kg
urea (45% N): 2,500/kg
SSP (17% P_2O_5): 1,000/kg
KCl (60% K_2O): 2,500/kg
3)Average farmer's application: 10 t/ha of FYM +70 kg N + 40 P_2O_5+60 K_2O/ha

Trials on new cassava varieties (**Table 11**) have shown that KM60, KM94, KM98-7 (SM1717-12) and CM4955-7 gave higher fresh root yields and had a higher dry matter content than the local variety Vinh Phu. Therefore, those new varieties were easily adopted by farmers and were rapidly disseminated in cassava growing areas of Pho Yen district.

Table 11. Average results of 44 FPR variety trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam, in 1995, 1996, 1997 and 1998.

Variety	1995	1996	1997	1998	Average
Vinh Phu	14.30	20.22	18.83	16.89	17.56
KM60	18.37	22.49	22.54	20.40	20.95
CM4955-7	18.37	23.76	24.66	24.62	22.85
KM95-3=SM1157-3	-	23.81	24.60	18.45	22.29
KM94	-	-	25.75	21.91	23.83
KM98-7=SM1717-12	-	-	25.00	25.44	25.22
SM937-8	-	20.77	-	-	20.77
SM981-3	-	23.35	-	-	23.35
OMR25-33-105	-	21.80	-	-	21.80
OMR33-35-230	-	-	21.35	-	21.35

Besides conducting trials, farmers have adopted the practice of growing cassava intercropped with peanut or black bean; soil erosion control by planting hedgerows of *Tephrosia candida* and vetiver grass, balanced fertilization and new cassava varieties on a larger scale in Pho Yen district, as these practices produced higher income than the traditional practices.

In summary: four technology components have been studied in FPR trials, conducted by farmers on their own fields. The working together with farmers in Pho Yen district created favorable conditions for farmers to learn by doing and seeing; the methods helped train and increased farmers' capacity, and this enhanced their ability to adapt and adopt new technologies. These technologies were rapidly scaled up to their cassava production fields and resulted in higher income.

2.3.2 Thanh Ba district of Phu Tho province

At the end of 1994 fields days were organized at Thai Nguyen University of Agriculture and Forestry for farmers of Phuong Linh village in Thanh Ba district of Phu Tho province. After this, farmers decided to conduct FPR trials on three components, i.e. cassava soil conservation by planting methods, cassava fertilization and new cassava varieties.

A trial on planting methods for erosion control with seven treatments was conducted on a slope of 32-45%. Average results of this trial, conducted from 1995 to 1998, indicate that the highest amount of soil loss by erosion occurred in the traditional practice of cassava monocropping without hedgerows (**Table 12**). In other treatments soil losses were reduced significantly, especially when cassava was intercropped with peanut and hedgerows were planted along the contour. After observation/evaluation and calculating the economic benefits of each treatment (**Table 12**), almost all farmers selected the practice of cassava intercropping with peanut, balanced NPK fertilizer application and contour hedgerows of *Tephrosia candida* or vetiver grass for their fields.

Trials on cassava fertilization were conducted by five participating households (**Table 13**). Cassava fresh root yields increased from 16.7 t/ha in 1996 to 20.7 t/ha in 1998 with application of 60 kg N, 60 P_2O_5, 80 K_2O and 10 tonnes pig manure/ha. Cassava fresh root yields were slighly lower with application of 120 than with 80 kg K_2O/ha.

Trials on new cassava varieties (**Table 14**) indicate that CM4955-7, KM98-7, and KM94 produced highest fresh root yields among seven clones tested at Phuong Linh commune; these varieties are now being multiplied by farmers.

2.3.3 Luong Son district of Hoa Binh province

Three types of FPR trials have also been conducted at Dong Rang village in Luong Son district of Hoa Binh province.

Trials on cassava planting methods for soil erosion control showed that the practice of cassava intercropping with peanut and planting hedgerows of vetiver grass or *Tephrosia candida* was most effective in reducing soil erosion (**Table 15**). Highest cassava fresh root yields and net income were obtained with the combination of peanut intercropping, applying a balanced NPK fertilization and planting hedgerows of *Tephrosia candida*.

Trials on cassava fertilization conducted by three participating households (**Table 16**) indicate that the highest cassava fresh root yield was obtained with intermediate levels of NPK, followed by the treatment of 40 kg N and 80 K_2O/ha.

Table 12. Average results of an FPR erosion control trial conducted by six farmers in Kieu Tung village, Thanh Ba district, Phu Tho province, Vietnam, in 1995, 1996, 1997 and 1998.

Treatments[1]	Slope (%)	Dry soil loss (t/ha)	Yield (t/ha) cassava	Yield (t/ha) peanut[2]	Gross income[3]	Production costs: Labor	Fert/ manure	Peanut seed	Cassava stakes	Hedgerow seed	Total	Net income
					(mil. dong/ha)							
1. C monocult., with fertilizers, no hedgerows	40.5	55.1	21.93	-	10.96	1.57	2.07	-	0.63	-	4.27	6.69
2. C+P, no fertilizers, no hedgerows	45.0	52.4	16.22	0.75	12.23	2.25	1.00	0.32	0.63	-	4.20	8.03
3. C+P, with fertilizers, no hedgerows	42.7	40.5	17.92	0.93	14.07	2.32	2.07	0.32	0.63	-	5.34	8.73
4. C+P, with fertilizers, *Tephrosia* hedgerows	39.7	32.2	16.55	0.79	12.62	2.40	2.07	0.32	0.63	0.20	5.62	7.00
5. C+P, with fertilizers, pineapple hedgerows	32.2	28.1	20.49	0.87	15.03	2.40	2.07	0.32	0.63	0.20	5.62	9.41
6. C+P, with fertilizers, vetiver hedgerows	37.7	28.7	22.58	0.89	16.19	2.40	2.07	0.32	0.63	0.20	5.62	10.57
7. C monocult., with fert., *Tephrosia* hedgerows	40.0	30.7	23.04	-	11.52	1.65	2.07	-	0.63	0.20	4.55	6.97

[1]All plots received 10 t/ha of pig manure; fertilizers = 60 kg N+40 P_2O_5+120 K_2O/ha; C = cassava, P = peanut intercrop
[2]Dry pods

[3]Prices:	cassava: dong	500/kg fresh roots
	peanut:	5,500/kg dry pods
[4]Costs:	FYM: dong	100/kg
	urea (45%N):	2,500/kg
	SSP (17%P_2O_5):	1,000/kg
	KCl(60%K_2O):	2,500kg
	peanut seed:	6,500/kg dry pods; use 50 kg/ha
	labor:	7,500/manday

Table 13. Combined results of five FPR fertilizer trials with cassava conducted in Phuong Linh commune, Thanh Ba district, Phu Tho province from 1996 to 1998.

Treatments	1996		1997		1998		
	Cassava yield (t/ha)	Farmers' preference[1)] (%)	Cassava yield (t/ha)	Farmers' preference[1)] (%)	Cassava yield (t/ha)	Farmers' preference[1)] (%)	Average yield (t/ha)
1. 10 t/ha FYM	15.93	82.0	15.85	86.7	15.96	88.6	15.91
2. 10 t/ha FYM + 60 kg N+ 60 P_2O_5 + 120 K_2O/ha	17.64	80.6	20.18	80.0	18.22	82.9	18.68
3. 10 t/ha FYM + 60 kg N+ 60 P_2O_5 + 80 K_2O/ha	16.67	61.0	19.31	60.0	20.75	68.6	18.91
4. 10 t/ha FYM + 60 kg N+ 40 P_2O_5 + 120 K_2O/ha	17.89	70.0	17.64	56.7	17.72	65.7	17.75

[1)]Farmers' preference from field day

Table 14. Combined results of FPR cassava variety trials conducted in Phuong Linh commune, Thanh Ba district, Phu Tho province from 1996 to1998.

Varieties	1996		1997		1998		
	Cassava yield (t/ha)	Farmers' preference[1)] (%)	Cassava yield (t/ha)	Farmers' preference[1)] (%)	Cassava yield (t/ha)	Farmers' preference[1)] (%)	Average yield (t/ha)
1. Vinh phu	16.67	85	22.22	87	13.59	89	17.49
2. KM60	19.79	100	18.86	100	-	-	19.33
3. CM44	12.50	0	-	-	-	-	12.50
4. CM4955-7	-	-	38.57	83	15.23	86	26.90
5. OMR35-16-4	-	-	17.50	77	-	-	17.50
6. KM98-7 (SM1717-12)	26.04	100	35.20	100	17.90	100	26.38
7. KM94	-	-	28.90	80	14.53	83	21.72
8. KM95-3	-	-	-	-	18.10	100	18.10

[1)]Farmers' preference from field day

Table 15. Average results of an FPR erosion control trial conducted by Mr. Ngyyen Van Tho in Dong Rang village, Luong Son district of Hoa Binh province, Vietnam, in 1995, 1996, 1997 and 1998.

Treatments[1)]	Yield (t/ha) cassava	Yield (t/ha) intercrop	Gross income[2)] (mil. dong/ha)	Prod. costs[3)] (mil. dong/ha)	Net income (mil. dong/ha)	Dry soil loss (t/ha)
1. Farmer's practice	11	2.19	6.71	3.08	3.63	98.3
2. C+taro, with NPK, vetiver hedgerows	13	1.77	7.19	4.21	2.98	27.6
3. C+taro, with NPK, *Tephrosia* hedgerows	15	1.77	7.77	4.21	3.56	25.8
4. C+peanut, with NPK, vetiver hedgerows	14	0.76	9.06	4.31	4.75	11.0
5. C+peanut, with NPK, *Tephrosia* hedgerows	16	0.83	10.37	4.31	6.06	13.2

[1)]Farmer's practice: C + taro, no NPK, no hedgerows; NPK = 40 kg N, 40 P_2O_5 and 80 K_2O/ha

[2)]Prices:	cassava: dong	400/kg fresh roots
	taro	1,000/kg fresh corms
	peanut	4,500/kg dry pods
[3)]Costs:	urea (45%N): dong	2,500/kg
	fused Mg-phos. (15%P_2O_5):	1,000/kg
	KCl (60%K_2O):	2,200/kg
	labor:	7,500/manday
	cassava stakes:	0.63 mil. d/ha
	hedgerow seed:	0.20 mil. d/ha
	peanut seed:	0.30 mil. d/ha
	taro cormels:	0.20 mil. d/ha

Table 16. Combined result of three FPR fertilizer trials with cassava conducted in Dong Rang, Luong Son district, Hoa Binh province, from 1996 to 1998.

Treatments	Yield (t/ha) 1996	1997	1998	Average
1. Farmer's practice (no fertilizers)	8.94	11.63	10.95	10.51
2. 40 N + 40 P_2O_5 + 80 K_2O	15.42	15.88	16.50	15.93
3. 40 N + 40 P_2O_5	13.10	12.25	12.40	12.58
4. 40 N + 80 K_2O	14.96	15.13	15.35	15.15
5. 40 P_2O_5 + 80 K_2O	14.52	14.19	13.40	14.04

Trials on cassava varieties indicate that KM98-7, KM95-3 and KM94 produced the highest fresh root yields among 14 tested clones at Dong Rang village (**Table 17**).

When farmers were asked to evaluate the treatments most farmers selected the cropping system that combined cassava intercropping with peanut, and planting contour hedgerows of *Tephrosia candida* or vetiver grass (**Table 18**).

Table 17. Combined result of three FPR fertilizer trials with cassava conducted in Dong Rang, Luong Son district, Hoa Binh province, from 1995 to 1998.

	Yield (t/ha)				
Varieties[1)]	1995	1996	1997	1998	Average
1. Vinh Phu	7.50	19.03	15.49	12.21	11.87
2. KM60	17.29	19.71	-	-	18.50
3. KM94	-	23.01	19.63	19.71	20.78
4. KM95-3	-	-	23.13	20.14	21.64
5. KM95-1	-	12.92	-	-	12.92
6. CM4955-7	-	-	13.75	-	13.75
7. OMR29-56-101	11.55	-	-	-	11.55
8. OMR35-16-4	-	-	15.88	-	15.88
9. OMR35-17-15	-	-	19.13	19.71	19.42
10. OMR35-38-79	-	-	-	19.71	19.71
11. KM98-7 (SM1717-12)	-	-	25.00	24.00	24.50
12. SM981-3	-	21.21	-	-	21.21

[1)]Fertilizer: 5 t/ha of FYM + 20 kg N + 40 P_2O_5 + 80 K_2O/ha

Table 18. Farmers' preference for contour hedgerows in Dong Rang, Luong Son district, Hoa Binh province.

Treatment	Farmers' preference[1)] (%)
1. Without hedgerows	0
2. *Tephrosia candida* hedgerows	66.0
3. Vetiver grass hedgerows	53.0
4. *Tephrosia* hedgerows + peanut intercrop	76.6
5. Stone walls + *Tephrosia candida* hedgerows	19.2

[1)]Total number of farmers: 47

2.4 Farmer's field days

Farmers' field days were organized every harvesting season to evaluate the trials and to discuss the work plan for adoption of new technologies and the trials that farmers wanted to conduct the following year (**Table 19**). The number of farmers participating have increased during the four years of the project, with 77 farmers participating in various trials in 1998.

Table 19. Number of farmers who participated in the first phase of the project (1994 – 1998).

	Number of participating farmers[1)]			
Research site	1995	1996	1997	1998
1. Pho Yen	21	37	38	40
2. Thanh Ba	11	14	19	29
3. Luong Son	6	8	8	8
Total	**38**	**59**	**65**	**77**

[1)]Including extension workers.

3. Plans for Phase II (1999-2003)

3.1 Objectives of the project

- To continue to develop with farmers improved crop management practices that will increase productivity and maintain the soil resources.
- To disseminate new technologies at the local, provincial and national levels.
- To conduct research that overcomes constraints identified at the farm level.
- To develop new and innovative participatory methodologies for dissemination or scaling up of new technologies.
- To strengthen farmer participating approaches among institutions and farming communities.
- To develop and implement procedures for monitoring the impact of new technologies.

3.2 Principal activities

- Conduct FPR trials to develop integrated technologies that incorporate improved varieties, increased fertilizer use efficiency, intercropping and erosion control practices at 21 sites
- Develop and implement methodologies for scaling up and disseminating improved technologies.
- Train staff and key farmers in cassava agronomy and extension using participatory approaches.
- Conduct applied research for supporting extension activities.
- Monitor progress and assess impact of new technologies on farmers' welfare and resource sustainability.

3.3 Work plan

Table 20 shows the work breakdown schedule for various activities, while **Table 21** shows the responsibilities of each collaborating institution during the year 2000.

Table 20. General work plan during the 2nd phase of the project.

Contents	Year 1999	2000	2001	2002	2003
1. RRA for new sites	7	6	5	0	0
2. Demonstration plot	TUAF HARC	TUAF HARC Hong Ha	TUAF HARC	0	0
3. FPR research sites	6	8	10	11	5
4. Dissemination	+	+	+	+	+
5. FPE	0	+	+	+	+
6. Training for researchers	0	+	+	0	0
extensionists	+	+			
farmers	+	+	+	+	+
7. Workshop			HCM city		

Notes: Total number of pilot sites: 21 in 2003.

Table 21. Work plan for each collaborating institution during the year 2000.

Contents	Work of FPR teams: TUAF	NISF	VASI	HUAF	IAS	UAF4
1.FPR trials						
- PhoYen	+					
- Phuong Linh, Dong Rang		+				
- Thong Nhat, Chau Thanh					+	
- Phuoc Long					+	
2. Dissemination						
- Pho Yen	+					
- Phuong Linh, Dong Rang		+				
3. Demonstration plot	+				+	
4. New research sites (RRA and FPR trials)	+	+	+	+	+	+
5. Training						
- Researchers and extension workers					+	
- Farmers	+	+	+	+	+	+

CONCLUSIONS

Phase I

FPR is a new research and extension approach. It involves combining the knowledge of researcher/extension workers and the experience of farmers in solving problems identified at the farm level.

The project helped to strengthen the capacity of farmers to diagnose their problems, to find and select potential solutions and ways to test these in FPR trials on their own fields, to evaluate these trials, to select the most suitable practices for adoption, and to adopt these in their cassava production fields.

The project also strengthened the relationship between researchers, extensionists and farmers. Results of adopted technologies have been rapidly transferred into production fields, increasing the income of many small cassava farmers.

Phase II

The objective is to further strengthen the capacity of farmers to analyze their current situation, to conduct FPR trials in order to develop the most appropriate technologies that can be adopted and to disseminate the most suitable practices to other farmers.

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REDUCING SOIL EROSION IN CASSAVA PRODUCTION SYSTEMS IN THAILAND – A FARMER PARTICIPATORY APPROACH

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ABSTRACT

The project on Cassava Production System Adjustment to Reduce Soil Erosion is a cooperative project among the Department of Agricultural Extension (DOAE), Department of Agricultural (DOA) and the Centro Internacional de Agricultura Tropical (CIAT). The purpose of the project is to make farmers aware of the importance of soil erosion and to develop and disseminate suitable and effective measures to reduce the problem. This is done by the use of a farmer participatory approach, in which farmers are asked to select and test in their own fields cassava production practices that reduce soil erosion. The first phase of the project had a duration of five years (1994-1998) and was implemented in two pilot sites in Nakhon Ratchasima and Sra Kaew provinces.

The results of the project indicate that once farmers saw the amounts of soil loss in their own erosion control trials, they realized the importance of erosion and the need to control soil degradation in cassava areas. They also tested, evaluated and selected suitable methods for reducing soil erosion. The farmers in the two pilot sites selected mainly the use of vetiver grass contour barriers as the most effective and suitable technique. They now grow vetiver grass for this purpose on about 48 hectares, while the planting of vetiver grass is still expanding.

The method of participatory research involves farmers directly in decision making at every step, from planning the project to obtaining results and drawing conclusions, and lets farmers select the treatments to be tried by themselves. This encourages them to learn how to analyze problems and find solutions collectively that are in line with the needs of the community as a whole. The method of implementing this project is considered to be efficient for the development and transfer of new technologies to farmers and rural communities, in order to enhance the adoption of more sustainable and more productive agronomic practices.

INTRODUCTION

Cassava is an important cash crop in Thailand. Due to its favorable characteristics, such as relatively ease of cultivation, drought tolerance and adaptation to poor soils, cassava has become very popular, especially for poor farmers. During the past five years (1995-1999) the total planted area of cassava in Thailand ranged from 1.12-1.28 million hectares. The annual production of fresh roots was 16.2-18.1 million tonnes, while the value of exports of dry cassava products was more than 22 billion baht (U$ 578.95 million) per year. Most cassava is grown on light-textured and very poor soils and in drought–prone areas in the northeastern and eastern parts of Thailand.

Despite the poor soil and droughty conditions in these areas, cassava grows fairly well. However, when cassava is grown on slopy land, soil erosion may be serious even in

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areas with gentle slopes of less than 10%. Moreover, experiments have shown that under the soil and climatic conditions of Thailand, cassava cultivation may cause twice as much soil erosion as the cultivation of mungbean, and three times as much as that caused by maize, sorghum and peanut (Putthacharoen, 1992; Putthacharoen *et al*., 1998)

Due to the wide spacing used in planting cassava and its rather slow early growth during the first three months after planting, a lot of the soil surface remains exposed to the direct impact of falling rain, causing severe soil erosion. Therefore, the Department of Agriculture (DOA), Kasetsart University and the Centro Internacional de Agricultura Tropical (CIAT) have conducted collaborative research into practical ways to reduce erosion in cassava production areas. The research showed that there are many ways to manage or improve cassava-cropping systems that would result in less erosion. Each management practice has its advantages and disadvantages: for instant, some practices that control erosion require more money or more management, while the yield or income does not necessarily increase. The researchers did not know whether farmers would adopt these practices or not. Therefore, CIAT initiated, in collaboration with the Department of Agricultural Extension (DOAE) and DOA, a project to improve the sustainability of cassava–based cropping systems using a farmer participatory research approach. The objectives of this project is to enhance farmers' awareness of the importance of soil conservation, to demonstrate a wide range of soil erosion control practices, to let farmers select the most appropriate ones and test these methods on their own fields, so they will develop the most useful practices for their own conditions. This, in turn, is likely to enhance adoption and the continued use of these practices even after the project terminates.

THE NIPPON FOUNDATION PROJECT – 1ST PHASE

1. Objectives

To enhance the development and adoption by farmers of improved cassava cropping systems and cultural practices that will maintain soil productivity and reduce erosion while sustaining a reasonable farm income.

2. Responsible organizations

1) Field Crops Sub-division, Rice and Field Crops Promotion Division, Dept.of Agricultural Extension (DOAE).
2) Rayong Field Crops Research Center, Field Crops Research Institute, Dept. of Agriculture (DOA).
3) Centro Internacional de Agricultura Tropical (CIAT)

3. Budget

US $ 7,000-10,000 per year, donated by Nippon Foundation through CIAT
US $ 15,000 per year, contributed by DOAE

4. Project Duration

1994-1998

5. Pilot sites

1994-1998: 1) Nakhon Ratchasima province in the lower Northeast.

2) Sra Kaew province in the eastern part of Thailand.
1997-1998: 1) Kalasin province in the upper Northeast.
2) Chachoengsao province in the eastern part of Thailand.

6. Plan of Implementation

1. Training of field staff
2. Preparation of project sites
3. Farmers meeting and training
4. Demonstration plots on soil erosion control methods
5. FPR trials on farmers field
6. Field day and meeting at harvest
7. Pilot field demonstration plots in villages
8. Scale-up to production field

7. Activities

7.1 Preparation of field staff

7.1.1 Pilot project field staff training

A training course on Farmer Participatory Research (FPR) and Rapid Rural Appraisal (RRA) methodologies was organized by CIAT for field staff from five countries, i.e. Thailand, Vietnam, China, Indonesia and the Philippines, in 1994 in Rayong province, Thailand.

7.1.2 Extension project field staff training

Another training course was held for Thai field workers from collaborating organizations, both research and extension agencies, to allow for the project's expansion to other pilot sites. This training course was conducted in Nakhon Ratchasima province in 1998.

7.2 Preparation of project sites

7.2.1 Selection of project areas

Appropriate pilot sites were selected using the following criteria: i) cassava is an important crop in the area, both at present and in the future; ii) cassava is planted on slopes and soil erosion is a serious problem. In the first year of the project (1994), Sra Kaew and Nakhon Ratchasima provinces were selected . Later on, in 1997, pilot sites in Kalasin and Chachoengsao provinces were added.

7.2.2 Exploration of agro-ecological and socio–economic conditions

Information about the selected villages were obtained by conducting a rapid rural appraisal (RRA) in each potential pilot site. The most suitable sites were selected by analyzing the RRA results (Vongkasem *et al*., 1998).

7.3 Farmers meeting and training

7.3.1 Group meeting with farmers

A meeting was held in the selected pilot sites, to discuss the objectives, principles and procedures of the project with the farmers, local extension staff and village leaders. The farmers analyzed and decided for themselves whether they wanted to participate in the project.

7.3.2 Farmers training

Farmers from the selected sites that were interested in participating in the project were invited to join a training course with the objective of i) increasing the farmers' knowledge and understanding of soil conservation in cassava production areas; ii) to discuss with farmers how to conduct, with help of researchers and extension workers, FPR trials on their own fields. These farmers were invited to visit demonstration plots on various management practices to reduce erosion (see below), and to discuss the advantages and disadvantages of each treatment. Each farmer was asked to score the various soil erosion control treatments, considering their likely effect on yield and income, their effectiveness in reducing erosion and whether they would be useful under the farmer's own conditions in the village. The farmers then selected 4-5 soil erosion control treatments for testing in their villages.

7.4 Demonstration plots on soil erosion control method

Demonstration plots (**Table 1**) were established by the DOA and Kasetsart University with 24 treatments, including the application of chemical fertilizers, green manures, closer plant spacing, intercropping with different crops and contour hedgerows of different grasses. The size of the plot was 10 x 15 meters. Ditches were dug along the lower ends of each plot and covered with plastic to allow for the collection of soil sediments eroded from the plots. The farmers from the pilot sites visited these demonstration plots and selected those treatments they would like to try in their own fields (**Table 1**).

7.5 Farm trials on farmers' field

After the training course (7.3.2), staff from DOA and DOAE together with collaborating farmers surveyed and selected the most appropriate areas for conducting the trials in each farmer's field. For the FPR erosion control trials, the land should have at least 5% slope. The size of the plots were 10 x 10 meters. Each farmer tried 5-6 treatments. Along the lower end of each plot, a soil collecting ditch was dug, about 40 cm deep and 40 cm wide. Plastic sheets were placed in the bottom of the ditches to collect sediments eroded from the plot during the cassava production cycle. The amount of sediments from each treatment was weighed and a sample of this dried to determine dry soil loss due to erosion. This, along with yield data was shown and discussed by farmers on the field day at harvest time. Besides erosion control trials, there were also FPR variety and fertilizer trials. The FPR trials were repeated for at least two years in the same villages to confirm the results.

7.6 Harvesting field day and meeting

Collaborating farmers and project staff harvested the crops, recorded all data and calculated average results of each type of trial. Data on soil loss from every treatment were also presented to the participating farmers and others interested. The meeting then discussed the results of each trial and selected again the best treatments for next year's trials.

Table 1. Preference ranking by farmers of the best five of the 24 treatments in the demonstration plots, conducted in Pluak Daeng, Rayong in 1994/95, and the treatments selected for their own FPR erosion control trials in 1995/96.

Treatments	Farmers' ranking[1)]		Treatments selected by farmers	
	Soeng Saang	Wang Nam Yen	Soeng Saang	Wang Nam Yen
1. Traditional practice			1.up-down ridging	1.up-down ridging
2. closer spacing			2.contour ridging	2. contour ridging
3. no fertilizers applied			3.vetiver grass	3.vetiver grass
4. fertilizers	5		barriers	barriers
5. chicken manure			4.mulberry barriers	4. peanut
6. fertilizer + chicken manure	4		5.sugarcane barriers	intercrop
7. no tillage			6. peanut intercrop	5. mungbean
8. no tillage + cassava harvester			7. sweet corn	intercrop
9. reduced tillage			intercrop	6. wax gourd
10. up-down ridging				intercrop
11. contour ridging		2		7. ruzie grass
12. dry grass mulch				barriers
13. *Crotalaria* mulch				8. dry grass mulch
14. *Canavalia* mulch				
15. vetiver grass barriers	1	1		
16. elephant grass barriers				
17. ruzie grass barriers	3	4		
18. lemon grass barriers		3		
19. *Leucaena* barriers				
20. *Flemingia* barriers				
21. peanut intercrop		5		
22. mungbean intercrop				
23. maize intercrop	2			
24. water melon intercrop				

[1)] 1 = best or most useful

7.7 Scaling-up

After two years of FPR trials, farmers usually would be able to choose the most suitable methods for soil erosion control in their cassava fields. The DOAE then helped them to test these selected technologies in larger size plots (approximately 1500-3000 m^2) and make further adaptations and selections when necessary. These large plots were called pilot demonstration plots.

7.8 Adoption in production fields

Other farmers in the village also observed these pilot demonstration plots. Those who wanted to adopt the soil conservation practices from these demonstration plots were encouraged and supported to adopt these practices on a large scale in their production fields. For example, the practice of planting vetiver grass contour barriers were expanded to cover about 300 ha in Soeng Saang district of Nakhon Ratchasima and 50 ha in Wang Nam Yen district of Sra Kaew province.

8. Results Obtained

8.1 Selection of soil erosion control methods by farmers

The farmers who visited the demonstration plots at the research center observed and then discussed the advantages and disadvantages of each treatment; they also scored each treatment from 1 to 3. From these scores they selected some methods they considered most useful in their own fields and under their own conditions. In general, they selected the methods that gave higher cassava yields, provided yield and income from intercrops and were most effective in reducing soil erosion (**Table 1**). Furthermore, some farmers wanted to try out some soil conservation methods they thought of themselves, such as replacing hedgerows of elephant grass with sugarcane for chewing. They thought that those two plants are similar but they could earn more income from sugarcane.

8.2 Results from FPR trials in farmers' fields

The results of FPR trials in farmers' fields in the two pilot sites during the first phase of the project (1994-1998) can be summarized as follows:

8.2.1 Nakhon Ratchasima province

Farmers in Noong Sombuun village selected seven treatments for their FPR soil erosion control trials in the first year. In the second year, five of these treatments were reselected to confirm the results (**Table 2**). From these they selected two practices they considered most useful, i.e. contour hedgerows of vetiver grass alternated with sugarcane and intercropping with pumpkin, to conduct the pilot demonstration plots (about 1600 m^2) in the village. Finally, they selected only vetiver grass barriers to extend to the production fields at the community level (**Table 3**). Planting vetiver grass contour hedgerows was initiated on a large scale in various districts of Nakhon Ratchasima province.

8.2.2 Sra Kaew province

Farmers in Wang Sombuun village selected eight methods for the first year FPR trials and reselected five treatments for the second year (**Table 4**). In the third year farmers chose only vetiver grass barriers to test in their pilot demonstration plots and then extend this practice to about 50 ha of their production fields (**Table 5**).

During the later part of the first phase of the project two new sites were selected to conduct FPR trials. Farmers in Sahatsakhan district of Kalasin province conducted FPR trials for two years, while farmers in Sanaam Chaikhet district of Chachoengsao province joined the project only during the final year.

9. Problems and Constraints

Project staff from DOAE in the central office in Bangkok and from DOA in Rayong Field Crops Research Center were often very busy with their own routine work, so it was difficulty to find time to go and work in the FPR project in the field. And the project sites were far away in the provinces, so they could not spend much time in the project.
Since the project staff were busy and live far away from the project sites, they sometimes took temporary workers or laborers to work in the FPR trials instead of working with the farmers. The farmers generally participated only in the meetings to make

Table 2. Average results of FPR soil erosion control trials conducted by farmers in Soeng Saang district of Nakhon Ratchasima province, 1995/96 and 1996/97.

Treatments	1995/96			1996/97		
	Dry soil loss (t/ha)	Cassava yield (t/ha)	Net income (‘000 baht/ha)	Dry soil loss (t/ha)	Cassava yield (t/ha)	Net income (‘000 baht/ha)
1. up-down ridging	24.80	29.8	21.75	4.30	22.3	8.05
2. contour ridging	9.80	34.0	25.94	-	-	-
3. vetiver grass hedgerows	8.50	35.2	26.78	3.85	21.8	6.24
4. sugarcane hedgerows	11.80	32.2	34.71	4.23	22.2	11.03
5. mulberry barriers	16.10	40.0	32.78	-	-	-
6. peanut intercrop	13.30	28.9	30.69	-	-	-
7. sweet corn intercrop	12.60	25.5	27.76	7.02	20.5	6.96
8. pumpkin intercrop	-	-	-	5.61	21.8	9.32

Table 3. Soil erosion control treatments tested and selected by farmers in Soeng Saang district of Nakhon Ratchasima province, 1995/96 to 1998/99.

Soil erosion control treatments selected by farmers			
1995/96	1996/97	1997/98	1998/99
FPR trial plots	*FPR trial plots*	*Pilot demonstration plots*	*Production fields*
1. up-down ridging	1. up-down ridging	1. vetiver grass hedgerows	1. vetiver grass hedgerows
2. contour ridging	2. vetiver grass hedgerows	2. sugarcane alternated with vetiver grass hedgerows + pumpkin intercrop	
3. vetiver grass hedgerows	3. sugarcane hedgerows		
4. sugarcane hedgerows	4. sweet corn intercrop		
5. mulberry hedgerows	5. pumpkin intercrop		
6. peanut intercrop			
7. sweet corn intercrop			

Table 4. Average results of FPR soil erosion control trials conducted by farmers in Wang Nam Yen district of Sra Kaew province, 1995/96 and 1996/97.

Treatments	1995/96			1996/97		
	Dry soil loss (t/ha)	Cassava yield (t/ha)	Net income (‘000 baht/ha)	Dry soil loss (t/ha)	Cassava yield (t/ha)	Net income (‘000 baht/ha)
1 up-down ridging	18.12	28.7	23.69	47.79	22.1	9.60
1. contour ridging	8.22	26.9	21.28	28.27	20.7	8.17
2. vetiver grass hedgerows	14.61	23.1	17.12	10.16	18.1	4.98
3. ruzie grass barriers	4.54	31.6	30.30	-	-	-
4. wax gourd intercrop	12.30	26.4	21.07	-	-	-
5. peanut intercrop	14.66	16.5	21.68	-	-	-
6. mungbean intercrop	26.22	25.5	30.88	15.53	12.6	4.66
7. dry grass mulch	5.47	33.5	29.58	29.14	21.4	8.33

Table 5. Soil erosion control treatments selected and tested by farmers in Wang Nam Yen district of Sra Kaew province, 1995/96 to 1 998/99.

Soil erosion control treatments selected by farmers			
1995/96	1996/97	1997/98	1998/99
FPR trial plots	*FPR trial plots*	*Pilot demonstration plots*	*Production fields*
1. up-down ridging	1. up-down ridging	8. vetiver grass hedgerows	1. vetiver grass hedgerows
2. contour ridging	2. contour ridging		
3. vetiver grass hedgerows	3. vetiver grass hedgerows		
4. ruzie grass barriers	4. mungbean intercrop		
5. peanut intercrop	5. dry grass mulch		
6. mungbean intercrop			
7. wax gourd intercrop			
8. dry grass mulch			

decisions and plan next year's work; they would observe while the project staff and workers worked in the FPR trials.

10. Discussion

After the problems and constraints discussed above were identified, the project implementation was improved. Project staff explained more clearly to the farmers about the concept and the objectives of the project and encourage them to participate in every aspect, especially in the activities in the fields. The farmers were shown how to measure and set out contour lines and how to multiply and grow vetiver grass in their production fields. They and the project staff worked together in the fields. Furthermore, farmers were able to extend the practice in their own fields and teach their neighbors.

In the provinces that started the project in 1998 more effort was made to increase farmers' participation in the FPR trials.

11. Implementation Plan of Phase II

The Nippon Foundation approved a second phase (1999-2003) of the project. During this phase it is planned to extend the project to 10-15 new sites. Training courses on FPR methodologies for extension workers and farmers will also be conducted in this second phase in order to enhance farmer participatory dissemination of the selected technologies to a large number of farmers in the village and in neighboring communities. **Figure 1** shows a conceptial model of the various steps in the process.

CONCLUSIONS

By the end of the first phase the participating farmers recognized the importance of, and the need for, soil conservation in cassava fields. The farmers in the two pilot sites in Nakhon Ratchasima and in Sra Kaew provinces adopted mainly vetiver grass barriers as the best method to control erosion. Farmers in a neighboring village of the pilot site in Nakhon Ratchasima organized a group to grow vetiver grass barriers for erosion control in about 320 ha. They were supported by the project in setting out contour lines and in the multiplying of vetiver grass plants. Similarly in Sra Kaew province, farmers formed a group to grow vetiver grass as contour barriers in about 50 ha of hilly cassava production fields.

The method of participatory research, which involves farmers' participation and decision making in every step of implementation, from diagnosis of their problems to dissemination of results, and letting farmers select the methods to be tested by themselves, encouraged them to learn and to find opportunities and potential solutions to solve problems for themselves and their communities.

From our observation, farmers who participated in the first phase of the project were quite shy to express their ideas and opinions at the early stages. However, after some time, when they had met the project staff more often, they were able to discuss the advantages and disadvantages of each method and make decisions on trial implementation and give suggestions for project improvement.

The use of the farmer participatory method developed in this project is considered to be a suitable way to develop and transfer new technologies for farmers and rural communities. The use of a farmer participatory approach will make it more likely that the adoption of sustainable production practices will continue even after the project has been terminated.

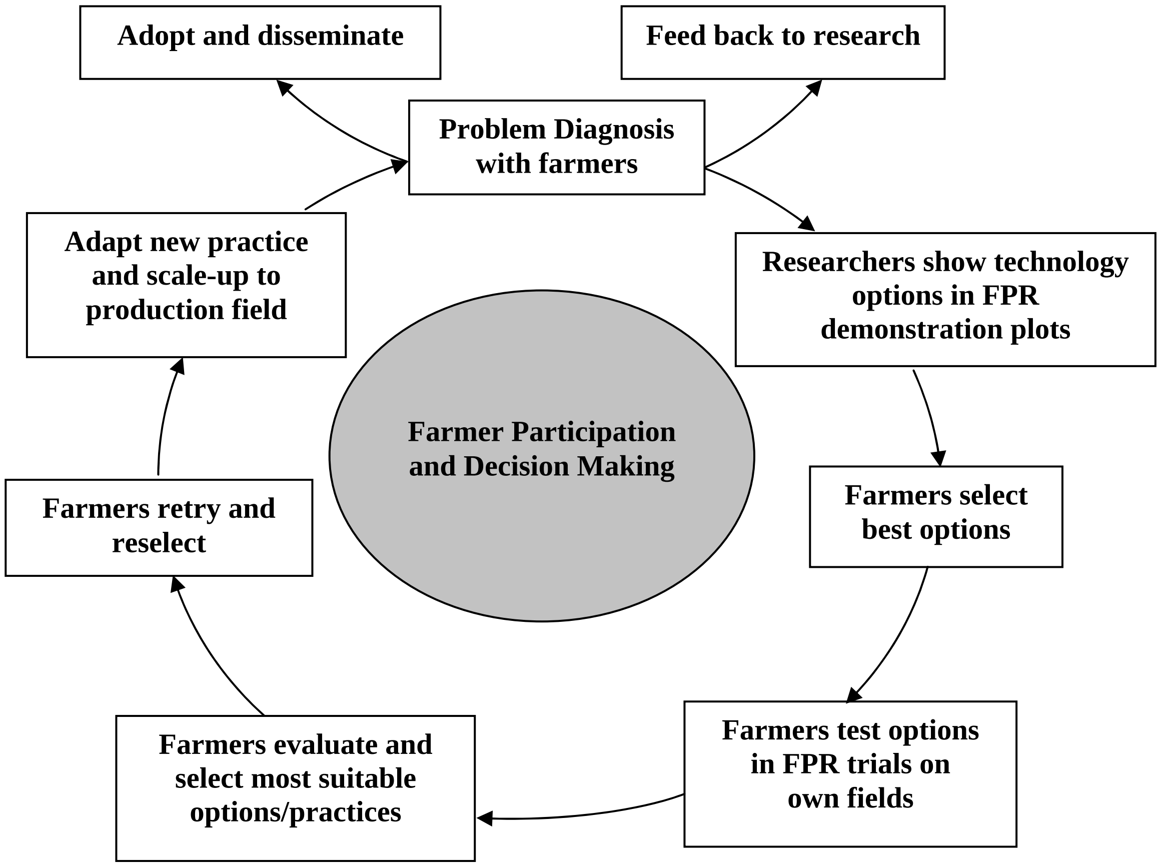

Figure 1. Farmer participatory model used for the development of sustainable cassava-based cropping systems.

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PRACTICES AND PROGRESS IN FARMER PARTICIPATORY RESEARCH IN CHINA

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ABSTRACT

The FPR project in China is a cooperative project between CIAT and CATAS, and is financially supported by the Nippon Foundation of Japan. This paper mainly describes results of the FPR trials conducted in Hainan province of China and discusses the function of FPR in the transfer of cassava technologies, existing problems and future development prospects.

The project involves the following aspects of research: variety trials, soil and water conservation and fertilizer management. Contour barriers of tropical grass and legume species, and intercropping with peanut and other legume crops have been shown to be effective in protecting the soil from erosion. Results based on trials conducted at CATAS from 1995 to 1999 indicate that hedgerows of vetiver grass, *Clitoria ternatea, Chamaecrista rotundifolia, Indigofera endecaphylla, Arachis pintoi*, *Tephrosia candida, Ananas comosus* and *Brachiaria decumbens* decreased dry soil loss (5-30 t/ha) by 65-94%, compared to the check treatment which had a dry soil loss of 85 t/ha.

FPR trials conducted by farmers in their own fields indicate that cassava intercropped with peanut and planting vetiver grass as contour barriers was the best practice: dry soil loss decreased by 28-57% compared to the check treatment, and increased income by 3,300 Yuan/ha. This practice has been widely adopted by farmers in the pilot site of Kongba village in Baisha county of Hainan, and is being disseminated to neighboring villages by farmer-to-farmer extension.

During 1995-1999, more than 41 promising clones have been tested in 38 farmers' fields; they were harvested and evaluated by farmers themselves. Results show that SC8013 and OMR33-10-4 outyielded the check variety SC205 by 13.1% and 34.4%, respectively. However, there were no significant differences among varieties in terms of soil erosion control. It is very easy for farmers to select and adopt their favorate varieties through their own participation. This approach will enhance the dissemination of new varieties and technologies.

Fertilizer trials were conducted in 14 farmers' fields using 12 treatments. The results show that all the treatments with fertilizers produced higher yields than those without fertilizers, and that application of 300 kg/ha of a special fertilizer (No. 3) increased the yield by 33% and gross income by 22%. This result will help convince farmers to apply fertilizers to their cassava fields in the future.

INTRODUCTION

Since the 1970s farmer participatory research (FPR) has been used in many agricultural areas in the world, including farmer participatory research as well as extension. Researchers and farmers conduct a participatory diagnosis, select the experiments they want to do, they participate in the selection of treatments and conduct the trials, evaluate the research results and apply the selected technologies.

As part of the FPR project, funded by the Nippon Foundation in Japan and coordinated by CIAT, CATAS has conducted farmer participatory cassava research and extension in Kongba and Dapulin villages of Baisha county in Hainan, China since 1994.

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The objectives are to accelerate the development and extension of improved varieties and efficient cassava production practices through farmer participation, to reduce erosion, maintain soil productivity and increase the income of cassava farmers in China (Zhang Weite *et al*., 1998; CATAS/CIAT, 1998; Howeler and Henry, 1998).

FPR Methodologies

A Rapid Rural Appraisal (RRA) was conducted in Hainan by CATAS and CIAT in Aug 1994. The main causes of low cassava yields in Hainan were identified to be the existence of only few and old varieties, insufficient application of fertilizers or FYM, extensive cultivation and serious erosion. From the RRA we selected Kongba and Dapulin villages in Baisha county, Hainan, to conduct farmer participatory research during 1995-1999. We organized a farmer training course and farmer fields days at CATAS, mainly to train farmers in FPR methodologies and cassava production technologies. Farmers also visited several cassava variety trials, the long-term fertilizer trial and the erosion control demonstration plots at CATAS.

Farmers selected the type of trials themselves. They were most interested in new varieties, in fertilizer application and in erosion control. CATAS provided technical assistance and supplied the basic planting materials. All trials had only one replication, and usually had the same treatments, so different farmers could be considered as replications. Not only the collaborating farmers but also other nearby farmers were invited to participate together in FPR planting and harvests, assessing the farmers' opinions about cassava yield, intercrop yield, dry soil loss etc. in the FPR trials. Farmers would then select the best improved varieties or other treatments to be included in next year's trials.

Demonstration plots on erosion control at CATAS

Tropical pastures, peanut and other legume crops have been used as barriers or intercrops for protecting the soil from erosion in demonstration plots laid out on 5-10% slope in CATAS from 1996 to 1999. **Table 1** indicates that vetiver grass, *Clitoria ternatea*, *Chamaecrista rotundifolia*, *Indigofera endecaphylla*, *Arachis pintoi*, *Tephrosia candida*, pineapple and *Brachiaria decumbens* CIAT 606 were all very effective in decreasing soil loss by erosion. Dry soil loss (5-30 t/ha) decreased by 65-94% compared to the check treatment (85-107 t/ha). Some of these treatments became more effective in controlling erosion over the years.

Vetiver grass contour barriers were found to be very effective in reducing erosion in cassava fields. However, vetiver has two limitations: it can not be used to any great extent as animal feed, and its vegetative propagation is costly and cumbersome. To overcome these problems, a preliminary trial on the use of various grasses for erosion control barriers was installed at CATAS during 1998/99 in order to evaluate the competition between cassava and the grass. Preliminary results, shown in **Table 2**, indicate that vetiver grass, lemon grass and hybrid elephant grass might be recommended for erosion control barriers.

FPR Erosion Control Trials

There were a total of 27 farmers participating in 17 erosion control trials in cassava fields during 1995-1999 (**Table 3**). Three kinds of treatments were used: 1) only intercrop,

Table 1. Demonstration plots on erosion control conducted on 5-10% slope at CATAS during 1996-1999.

	1996			1997			1998			1999			Average	
Treatments[1]	Dry soil loss (t/ha)	Root yield (t/ha)	Inter crop yield (t/ha)	Dry soil loss (t/ha)	Root yield (t/ha)	Inter crop yield (t/ha)	Dry soil loss (t/ha)	Root yield (t/ha)	Inter crop yield (t/ha)	Dry soil loss (t/ha)	Root yield (t/ha)	Inter crop yield (t/ha)	Dry soil loss (t/ha)	Root yield (t/ha)
Check, no hedgerows	106.5	24.2		85.2	30.8		85.6	25.3		97.8	19.9			
*Lablab purpureus**	83.6	14.2	1.30[2]	45.2	32.2	0.10[4]								
*Canavalia ensiformis**	42.9	11.8	1.60[2]	33.0	28.4	0.08[4]								
*Phaseolus aureus**	74.6	14.2	1.84[2]	28.5	32.6	0.08[4]								
*Crotalaria mucronata**	127.4	11.8	0[3]	50.2	17.5	0[2]								
*Indigofera endecaphylla**	77.5	13.0	0.24[4]	76.4	29.8	0.10[4]				24.4	24.0	0[2]		
*Clitoria ternatea**	83.3	10.5	0[2]	28.5	30.4	0.10[4]	15.2	26.4	0[4]	14.6	28.7	0[2]	35.4	24.0
*Chamaecrista rotundifolia**	107.6	23.0	0[3]	38.1	27.8	0.12[4]	45.4	23.1	0[4]	17.3	23.1	0[2]	52.1	24.3
*Stylosanthes guianensis**[5]	74.1	14.2	0[3]	36.9	24.3	0[2]	31.4	23.4	0[2]	18.4	21.6	0[2]	40.2	20.9
*Tephrosia candida**	158.0	15.5	0[3]	46.7	20.6	0[2]	13.0	19.4	0[2]	20.5	22.0	0[2]	59.6	19.4
*Desmodium ovalifolium**	152.8	16.7	0[3]	46.8	22.8	0[2]	44.9	21.2	0[2]	34.1	21.4	0[2]	69.7	20.5
Pineapple*	90.4	18.7	0.24[4]	43.2	24.4	0[2]	27.8	23.2	0[2]	18.1	22.9	0[2]	44.9	22.3
Vetiver grass*	129.9	15.5	0.23[4]	52.2	29.2	0[2]	18.9	24.1	0[2]	20.2	25.4	0[2]	55.3	23.6
*Brachiaria decumbens**[6]	120.0	14.2	0.24[4]	63.7	19.8	0[2]	14.3	18.6	0[2]	16.3	18.0	0[2]	53.6	17.7
*Arachis pintoi**	100.7	19.2	0[3]											
Sweetpotato*	96.1	15.5	0.25[4]											
King grass*							39.4	22.4	0[4]	12.4	19.6	0[2]		
Sugarcane*							35.0	21.4	0[2]	27.3	23.8	0[2]		
*Arachis pintoi***				12.4	30.0		5.2	18.2		5.6	13.4			
*Indigofera endecaphylla***				32.0	29.0		16.8	24.1		21.6	22.8			
Contour ridge	81.1	15.0												

[1]Check = cassava monoculture; * = cassava + intercrop+hedgerows; ** = forage species used both as hedgerow and live mulch.
[2]peanut intercrop, [3]soybean intercrop, [4]sesame intercrop, [5]CIAT 184, [6]CIAT 606.

Table 2. Preliminary trial on the use of vegetative barriers for erosion control[1] conducted on 6-8% slope at CATAS during 1998 and 1999 (Average of two years).

Hedgerow species	Cassava yield							Dry grass yield				Evaluation of hedgerows
	A	B	C	D	E	F	Total	G	H	I	Total	
	(kg/row)						(t/ha)	(kg/row)			(t/ha)	
1. Vetiver grass	43	49	30	39	53	43	36.8	19	8	11	5.4	very good
2. Dwarf elephant grass	39	30	36	25	33	18	25.9	17	14	25	8.0	very good
3. Common elephant grass	38	31	29	22	33	30	26.2	17	14	24	7.9	very good
4. King grass	33	39	24	30	44	26	28.0	45	31	42	16.9	very good
5. Sugarcane	31	32	27	30	36	36	27.5	-	-	-	-[2]	very good
6. *Brachiaria ruziziensis*	35	42	36	30	37	32	30.3	16	11	14	5.9	bad
7. *Brachiaria decumbens*	30	45	31	29	44	29	29.7	16	10	15	5.9	good
8. *Brachiaria brizantha* CIAT 26110	38	46	36	29	47	21	31.0	12	9	23	6.3	good
9. *Paspalum atratum*	47	35	36	28	46	31	31.9	10	9	16	5.0	bad
10. *Panicum maximum* TD 58	24	44	15	19	30	22	22.0	32	20	25	11.0	very good
11. Lemon grass	48	50	28	46	45	45	37.5	10	4	9	3.3	bad
12. Hybrid elephant grass	35	44	35	42	37	47	34.3	16	6	9	4.4	bad
Average	**37**	**41**	**30**	**31**	**40**	**32**	**30.1**	**19**	**12**	**19**	**7.3**	

[1] Three rows of cassava were grown between two rows of grass; 1 meter space between two cassava rows and 0.5 meter between cassava row and grass row. The six cassava rows were harvested separately (10 plants in each row). The grass species (except sugarcane) were cut back at 30 cm above the soil whenever necessary. A-F and G-I are from top row to bottom row.

[2] Sugarcane was stolen before harvest.

Table 3. Results of FPR erosion control trials conducted on 8-9% slope at Kongba and Dapulin villages, Baisha county, Hainan from 1996 to 1999.

Treatments[1]	Dry soil loss	Root yield (t/ha)	Intercrop yield	Gross income[2]	Production costs[3] (Yuan/ha)	Net income[3]
1996 Check[4]	82.4	17.0	0	5,100	0	5,100
1996 C+Stylo. CIAT184+maize[5]	61.7	20.7	0	6,210	1,350	4,860
1996 Check	124.7	13.5	0	4,050	0	4,050
1996 C+contour ridging	77.0	15.2	0	4,560	500	4,060
1996 C+*Indigofera*+soybean	96.9	16.5	0	4,950	1,350	3,600
1996 C+vetiver grass+peanut	89.6	14.0	0.63	7,350	1,350	6,000
1997 Check	114.4	20.9	0	6,270	0	6,270
1997 C+Stylo. CIAT184+peanut	131.2	19.8	0.63	9,090	1,350	7,740
1997 C+Stylo. CIAT184+sesame	73.4	18.0	0	5,400	1,350	4,050
1997 C+vetiver grass+sesame	62.5	18.8	0	5,640	1,350	4,290
1997 C+vetiver grass+peanut	59.7	21.3	0.66	9,690	1,350	8,340
1998 Check	40.9	27.2	0	8,160	0	8,160
1998 C+vetiver grass+peanut	17.4	24.7	0.07	7,790	1,350	6,440
1998 C+vetiver grass	9.6	28.8	0	8,640	360	8,280
1998 C+sugarcane+peanut	35.3	27.5	0.07	8,600	1,350	7,250
1998 C+sugarcane	32.2	26.4	0	7,920	300	7,620
1999 Check	25.7	23.7	0	7,110	0	7,110
1999 C+vetiver grass[5]	8.9	23.9	0	7,170	360	6,810

[1]C = cassava

[2]Price: cassava roots = 300 Y/t, peanut = 5000Y/t. Maize, soybean and sesame were stolen or damaged by animals.

[3]Barrier maintenance and intercrop costs only; net income is gross income minus barrier maintenance and intercrop costs.

[4]Check is cassava monoculture without any ridges, barriers or intercrops.

[5]Average of 3 replications (3 farmers); other treatments are average of 4 replications (4 farmers).

2) only hedgerows, and 3) intercrop and hedgerows together. Most of the treatments reduced soil erosion and increased cassava yields; net income was also increased due to the additional income from the intercrop. The best intercrop (without hedgerows) was peanut in 1995, which decreased soil loss (42.8 t/ha) by 35.7% compared to the check treatment (66.6 t/ha); it also increased cassava yield (46.2 t/ha) by 17.9% compared to the check (39.2 t/ha). Total net income increased 45.9% after adding the income from the sale of peanut (3300 Y/ha). This practice has spread since 1996.

In 1998 the best hedgerow (without intercrop) was vetiver grass, which decreased dry soil loss by 76.0% and increased cassava yield by 5.9% compared to the check. The best erosion control practice was to combine hedgerows and intercropping, especially using vetiver grass hedgerows and intercropping with peanut; in 1996/97 dry soil loss decreased by 28-48%, cassava yields increased by 2.4-4.5% compared with the check while there was additional income from peanut (3300 Y/ha). The effectiveness of hedgerows in erosion control increased over the years and resulted in the formation of 30 cm high terraces in cassava fields after two years; the soil just above the vetiver hedgerow became thick and soft, fertile and wet, which was beneficial for obtaining high yields.

The results of the farmers' evaluation (**Table 4**) indicate that farmers were most interested in contour barriers of vetiver grass together with intercropping with peanut. The advantages of these erosion control practices were that they reduced erosion, increased yield and added value.

Table 4. Participatory evaluation of various erosion control practices by farmers in Kongba and Dapulin villages, Baisha county, Hainan, China in 1998.

	Effective erosion control	High yield	High income	Less weeds	Others	**Total**
Cassava+vetiver grass+peanut	9.4	7.7	6.1	5.5	5.2	**33.9**
Cassava+sugarcane+peanut	4.6	5.1	5.9	4.2	5.5	**25.3**
C+vetiver grass	8.2	3.7	2.1	1.1	2.3	**17.4**
Others	6.8	5.1	4.2	3.3	4.0	**23.4**
Total	**29.0**	**21.6**	**18.3**	**14.1**	**17.0**	**100.0**

FPR Variety Trials

A total of 38 farmers participated in the testing of 41 improved varieties during 1995-1999. The results, shown in **Table 5**, indicate that most of the improved varieties produced significantly higher yields than the local check variety SC205, especially SC124, SC8013, OMR33-10-4 and ZM9244, which outyielded SC205 by 42.5%, 13.1%, 34.4% and 60.5%, respectively. Many improved varieties have now been disseminated by farmers themselves.

The results of an evaluation of improved varieties by farmers (**Table 6**) indicate that farmers were mainly interested in cassava yield, wind and drought resistance, because Hainan has often dry weather when planting and strong typhoons. Farmers were not interested in starch content because factory owners only pay by weight but do not measure starch content. The preferred varieties were SC8013, SC124 and OMR33-10-4.

FPR fertilizer trials

The results of soil analysis (**Table 7**) indicate that the Fe, Al and B contents of the soil had increased but that the contents of OM, P, K, Ca, Mg, Cu and Zn had decreased 38-54% after two years of cassava cropping, and were near or below the nutritional requirements of cassava. Continuous cropping of cassava would likely lead to a significant response to application of fertilizer or FYM.

Table 5. Results of 38 FPR cassava variety trials conducted by farmers in Kongba and Dapulin villages, Baisha county, Hainan, China during 1995-1999.

	Average cassava yield (t/ha)									
	1995		1996		1997		1998		1999	
Varieties or clones	Variety	Check*	Variety	Check*	Variety	Check*	Variety	Check*	Variety	Check*
SC8013	34.2[6)]	35.4	22.8[3)]	18.2	23.0[3)]	17.3	-	-	-	-
SC8002	27.3[4)]	36.8	16.4[3)]	18.2	20.9[1)]	14.3	-	-	-	-
OMR33-10-4	39.5[2)]	30.9	18.3[4)]	16.1	19.5[2)]	15.6	42.5[1)]	31.3	27.8[2)]	15.9
ZM8641	23.4[2)]	35.1	19.1[2)]	22.8	-	-	-	-	29.0[3)]	17.9
SC124	38.7[2)]	33.0	22.5[1)]	9.5	-	-	-	-	-	-
ZM9076	48.8[1)]	30.9	20.0[1)]	9.5	-	-	-	-	-	-
ZM9036	44.4[1)]	33.5	-	-	15.6[1)]	17.0	-	-	-	-
ZM8639	30.2[2)]	33.6	-	-	36.3[1)]	20.9	-	-	-	-
ZM9038	34.8[2)]	35.0	-	-	-	-	-	-	-	-
ZM9057	35.1[3)]	33.9	-	-	-	-	-	-	-	-
ZM9066	32.1[1)]	37.4	-	-	-	-	-	-	-	-
SM1592-3	32.0[1)]	42.9	-	-	-	-	-	-	-	-
CMR34-11-3	-	-	17.6[3)]	18.2	21.2[3)]	17.3	28.8[1)]	31.3	-	-
ZM9315	-	-	-	-	24.8[2)]	18.9	-	-	-	-
ZM9274	-	-	-	-	24.8[2)]	18.9	-	-	-	-
ZM94107	-	-	-	-	26.7[2)]	18.9	-	-	-	-
OMR35-70-7	-	-	-	-	29.3[1)]	20.9	-	-	-	-
ZM9244	-	-	-	-	47.4[1)]	20.9	32.5[3)]	27.7	26.0[4)]	17.4
CMR36-34-6	-	-	-	-	-	-	38.8[2)]	26.9	-	-
ZM94127	-	-	-	-	-	-	29.4[2)]	26.9	-	-
ZM93164	-	-	-	-	-	-	36.3[4)]	28.6	-	-
ZM9127	-	-	-	-	-	-	34.9[5)]	28.2	-	-
ZM9426	-	-	-	-	-	-	27.3[3)]	27.7	-	-
ZM93253	-	-	-	-	-	-	29.0[3)]	27.7	-	-
ZM9394	-	-	-	-	-	-	28.4[5)]	28.2	20.4[4)]	16.5
ZM93236	-	-	-	-	-	-	28.7[4)]	27.4	19.2[4)]	16.5
ZM94209	-	-	-	-	-	-	31.7[3)]	26.7	18.8[2)]	17.3
CMR36-63-6	-	-	-	-	-	-	30.0[3)]	27.7	26.9[1)]	21.9
OMR36-05-7	-	-	-	-	-	-	34.7[4)]	27.9	27.2[3)]	14.7
OMR36-05-9	-	-	-	-	-	-	32.1[5)]	26.9	21.6[3)]	15.8
35-70-6	-	-	-	-	-	-	-	-	28.4[3)]	16.1
35-70-1	-	-	-	-	-	-	-	-	22.1[3)]	20.0
36-40-9	-	-	-	-	-	-	-	-	31.5[2)]	23.4
37-102-12	-	-	-	-	-	-	-	-	45.0[1)]	30.6
93274	-	-	-	-	-	-	-	-	25.1[2)]	21.9
95125	-	-	-	-	-	-	-	-	17.6[2)]	15.9
95111	-	-	-	-	-	-	-	-	21.3[2)]	18.8
9242	-	-	-	-	-	-	-	-	20.0[2)]	17.6
95038	-	-	-	-	-	-	-	-	25.4[2)]	21.9
93252	-	-	-	-	-	-	-	-	25.7[3)]	24.8
95027	-	-	-	-	-	-	-	-	28.1[3)]	20.9

[1)] to [6)] are average cassava yields of 1 to 6 farmers, respectively.
*Check is SC205

Table 6. Evaluation of improved varieties by farmers at Kongba and Dapulin villages, Baisha county, Hainan, China in 1998.

	High yield	Typhoon tolerance	Drought tolerance	Easy to harvest	Poor soil tolerance	Good plant type	High starch	**Total**
SC8013	16.0	11.3	8.3	4.4	5.4	3.4	1.6	**50.4**
SC124	8.5	0.8	3.1	2.9	2.7	0.4	0.8	**19.2**
OMR33-10-4	2.5	1.5	1.6	2.0	0	0.7	0	**8.3**
ZM8639	2.9	1.3	0.5	1.3	0	1.5	0	**7.5**
SC205	4.4	2.0	3.4	1.8	1.8	0.5	0.7	**14.6**
Total	**34.3**	**16.9**	**16.9**	**12.4**	**9.9**	**6.5**	**3.1**	**100.0**

Table 7. Results of soil analyses at Kongba village, Baisha county, Hainan, China in 1995 and 1997.

		(%)	(ppm)	(%)	(me/100 g)			(ppm)			
	pH	OM	P	Al	K	Ca	Mg	Cu	Zn	Fe	B
Requirements	4.5-7.0	2.0-4.0	4-15	<75	0.15-0.25	1.0-5.0	0.4-1.0	0.3-1.0	1.0-5.0	10-100	0.5-1.0
January, 1995	4.55	4.8	17.6	33.2	0.28	1.44	0.72	0.24	1.51	15.7	0.33
January, 1997	4.48	2.7	9.4	56.5	0.16	0.82	0.33	0.14	0.94	33.5	0.50

A total of 14 farmers participated, conducting 13 fertilizer trials from 1995 to 1997. There was little response to fertilizer application because the soils were quite fertile in the first year in 1995 (**Table 7**). But there were responses to fertilizer application in the second and third year (**Table 8**). The combinations of two nutrients (NP, PK and NK) increased yields but decreased net incomes, while the application of complete NPK fertilizer both increased yield and net income. No. 3 special fertilizer increased cassava yields by 33.3% and increased net income by 22.2%. Some farmers also applied either compound NPK or No. 3 special fertilizer on a larger scale in their production fields in 1997. The two types of fertilizers increased cassava yields by 51-54% and increased the net income by 35-37%.

Achievements of FPR

According to statistics of Hainan province for 1999 about 1500 ha of cassava fields (about 500 farmers) benefitted directly and more than 3500 ha also benefitted indirectly from FPR during 1995-1999 (**Figure 1**), adding a total of 12,000 t of fresh cassava roots and 3.8 million Yuan for Hainan farmers. In addition, in 1999 about 800 ha of cassava production fields were planted with various improved technologies by farmers in collaboration with CATAS (**Table 9**).

FPR also seems to have a good future in Guangxi and Yunnan provinces: 80 ha of contour barriers of pineapple have been planted on steep slopes in Honghe district of

Yunnan province in 1999, and a total of 30,000 ha have now been planted with improved varieties by farmers in south China.

Table 8. Average results of four FPR cassava fertilizer trials conducted at Kongba village, Baisha county, Hainan, China in 1996 and 1997.

Treatment[1)]	Root yield 1996	1997	Avg.	Gross income[2)]	Fertilizer costs[2)]	Net income[3)]
	(t/ha)			(Yuan/ha)		
Check	13.5	22.5	18.0	5,400	0	5,400
NP	14.0	24.0	19.0	5,700	705	4,995
NK	15.8	25.5	20.7	6,210	885	5,325
PK	14.7	21.8	18.3	5,490	495	4,995
NPK	17.4	26.1	21.8	6,540	1,035	5,505
FYM	17.0	25.5	21.3	6,390	525	5,865
Compound	17.1	26.0	21.6	6,480	840	5,640
No. 3 Fertilizer	19.2	28.7	24.0	7,200	600	6,600
No. 4 Fertilizer	17.6	25.2	21.4	6,420	600	5,820

[1)] N=225 kg/ha of urea (42%N); P=225 kg/ha of SSP (16% P_2O_5); K = 225 kg/ha of KCl (60% K_2O); FYM = 15 t/ha of farm-yard manure; Compound = 300 kg/ha of 15:15:15; No 3. Fertilizer =300 kg/ha of special fertilizer consisting of 78% compound 10:5:15, 1% Zn and 21% chicken manure; No 4. Fertilizer = 300 kg/ha of special fertilizer consisting of 86% compound 10:5:20, 1% Zn and 13% chicken manure.

[2)] Prices:

cassava	Y 300/tonne	KCl	Y 1.5/kg	No. 3 Fertilizer	Y 2.0/kg
urea	2.4/kg	Compound	2.8/kg	No. 4 Fertilizer	2.0/kg
SSP	0.7/kg	FYM	35/tonne		

[3)]Net income is gross income minus fertilizer costs.

Table 9. Extent of adoption of various improved practices selected through FPR in Hainan in 1999.

Variety/practice	Area of adoption (ha)
SC124	200
SC8013	150
OMR33-10-4	80
Other improved varieties	170
Cassava special fertilizer	15
Contour barriers of vetiver grass	2
Contour barriers of sugarcane	3
Improved practices	180
Total	**800**

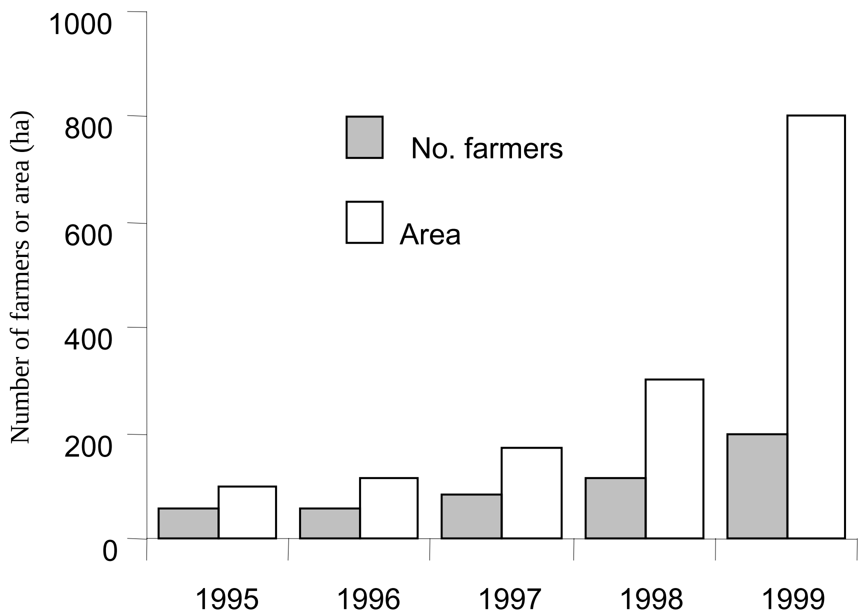

Figure 1. Number of farmers and planted area in Hainan that benefitted from FPR during 1995-1999.

CONCLUSIONS

Farmer Participatory Research (FPR) has promoted friendship between researchers and farmers, and combined the theoretical knowledge of researchers with the rich experience of farmers. This has stimulated the participatory development and extension of improved varieties and efficient cassava production practices. But there are some problems:

1. Farmers liked planting the improved varieties, but they generally ignored controlling erosion and applying manures or fertilizers.
2. The local governments did not always support FPR because they did not recognize the importance of it. Local officials should be directly involved in FPR so they gain a better understanding of the process.
3. Experimental plots were scattered over a wide area and farmers always changed the treatments, uniform standards were difficult to maintain and data were easily lost. It needs more guidance and management from researchers and collaborating technicians.

We will organize an FPR network in China and train more people in FPR methodologies in the future, accelerating the dissemination of improved varieties, special cassava fertilizers and erosion control practices.

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IMPLEMENTATION OF FARMER PARTICIPATORY RESEARCH (FPR) IN THE TRANSFER OF CASSAVA TECHNOLOGIES IN INDONESIA

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ABSTRACT

A Farmer Participatory Research (FPR) approach has been used in two pilot sites located in Malang and Blitar districts of East Java. The objective of the work, which was executed since l994, was to enchance the development and adoption of efficient cassava production technologies that are able to maintain soil productivity, reduce erosion, and increase the income of cassava farmers.

To achieve this objective, a Rapid Rural Appraisal method was employed. The involvement of farmers started from the identification of the problems and discussion of possible solutions. The results show that most farmers in the pilot site had been aware of soil degradation problems in their fields, as well as some technologies to overcome the problems. However, they hardly practiced the technologies on their field, because they thought that the technologies were too complicated and costly. After discussion with the project staff, they realized that some cassava production technologies are not as difficult and costly as they had earlier thought. They decided to establish demonstration plots to test their ideas. The technologies tested in the demonstration plots included erosion control practices, fertilizer application and the introduction of new cassava varieties.

After the experiences obtained in the demonstration plots during the first year, collaborating farmers decided to test some promising technologies in their own fields during the following years. The number of collaborating farmers, as well as the farmers doing FPR trials in their own fields, increased in the third year. In addition, some farmers at the Wates site in Blitar district started to adopt the preferred technologies in their whole field. The numbers of farmers adopting soil conservation practices increased significantly in the following year (1998/99). In the Dampit site in Malang district, the adoption process started in 1999/2000.

Farmers in Wates and Dampit are happy with the FPR approach. This approach increased the ability of farmers to try new technologies that they thought might increase their income, although the results were not yet sure. This approach also motivated farmers to actively obtain new knowledge by discussing their problems and ideas with extension personnel and others.

INTRODUCTION

Cassava is the most important root crop in Indonesia, but is less important than rice, maize and soybean. It is grown extensively throughout Indonesia with a harvested area of about 1.2 million ha/year and a yearly production between 15 and 17 million tonnes. Most of the production is used for human consumption (about 71% of total production), and the rest is used for industrial purposes (about 13%), for export (about 6.5%), and for animal feed (about 2%) and waste (about 7.5%) (CBS, 1998).

Most cassava is planted on marginal land in relatively dry areas, such as in the central and eastern parts of Java and in Nusa Tenggara. Cassava is also found in transmigration areas of Sumatra, Kalimantan and other islands. In these areas cassava is

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grown by small-scale farmers with limited land, capital, technology, and labor. Therefore the crop is usually grown with traditional technologies. Farmers grow the locally available varieties with no or insufficient application of fertilizer and improper land management. As a result, the yield is low (about 13 t/ha), and soil fertility tends to deteriorate.

On the other hand, the government and researchers have developed many new technologies to increase crop yields and to reduce soil degradation. Researchers have developed technologies that are capable of obtaining cassava yields as high as 30-40 t/ha, and at the same time decrease the rate of soil degradation and maintain soil productivity.

So far, most of these technologies have been developed based on the ideas of the government or researchers. The technologies are usually developed on experiment stations, or, if the experiment is conducted on farmer's land, the experiment is largely managed by researchers. Then, if the technologies seem useful, the government disseminates them through conventional methods used by the extension services. With this approach, a lot of technologies are developed that are technically sound but are hardly adopted by the farmers, or if there is any adoption it will last a short time. Soon after the project ends, farmers will go back practicing the old traditional technology.

Farmers may agree that the technology is good, but they may think that the technology is too expensive, too complicated, too laborious and often does not yield immediate benefits. Oftentimes, the technologies developed by researchers do not meet their needs and may not be suitable for their conditions.

Lately, some sociologists and anthrophologists (e.g. Fujisaka, 1989; Saragih and Tampubolon, 1991) suggested a more farmer oriented approach in developing crop production technologies. It is expected that the technologies thus developed would be more appropriate for the farmer's needs and conditions. Hence, the farmers would be happy to adopt them. A lot of approaches have been developed and tested. These include On-farm Research, Farming Systems Research and Farmer Participatory Research. The differences among these approaches is mainly in the degree of involvement of the farmers in the planning and implementation.

The success of the application of Farmer Participatory Research in the development and transfer of soil conservation technologies has been shown by Fujisaka (1989). Henry and Hernandez (1994) have also successfully used this approach for the development and dissemination of new cassava varieties in Colombia. This approach was also used to improve the soil fertility status in Africa by Defour *et al*. (1998), and was extensively used for watershed management in India (Chennamaneni, 1998). The strengths, weaknesses and prospective future of the participatory approach for the development and dissemination of soil management technologies has been extensively discussed by Fujisaka (1991).

The work reported here discusses the experiences of the application of Farmer Participatory Research to develop and transfer cassava production technologies in Blitar and Dampit districts of East Java, Indonesia. The work was started in 1994/95 and executed for five years.

LOCATION OF PILOT SITES

The study was conducted in two pilot sites: Ringinrejo village, Wates sub-district of Blitar district; and in Sumbersuko village, Dampit sub-district of Malang district, both in

East Java province. Farmers in Ringinrejo grow cassava intercropped with maize, and the cassava is mainly used for human consumption as a security food. Farmers in Dampit grow cassava mostly in monoculture as a cash crop, selling the fresh roots to factories.

The cassava fields in Wates are dominated by very poor and shallow Alfisols with many limestone outcroppings. The soil in Dampit is an acid Inceptisol with a relatively better fertility status. The general biophysical conditions in the two sties and farmers characteristics in the study area have been reported by Utomo *et al*. (1998).

FPR METHODOLOGY

The project started with a Rapid Rural Appraisal (RRA) in the pilot sites to identify the cassava farmers' problems, and to understand the perception of the farmers to their problems and the possible technologies to overcome these problems. After this initial discussion we asked the farmers to select the most appropriate technologies and then let them test these in demonstration plots. All activities in the demonstration plots were done by the farmers, and the project staff helped only with the design and lay-out of the experiment.

Field days were organized to let the farmers (collaborating farmers and surrounding non-collaborating farmers) see and discuss the performance and the results of the technologies tested in the demonstration plots. Several farmers in Ringinrejo were pleased with some technologies shown in the demonstration plots, so in the second year they tested these preferred technologies in FPR trials on their own fields.

In the following year, in addition to continuing the previous activities, the project facilitated the adoption process and farmer-to-farmer extension. These activities were done in Wates. In Sumbersuko village farmers still concentrated on various types of demonstrations and on-farm trials, while they also started to do FPR trials in their own fields.

RESULTS AND DISCUSSION

1. Awareness of Farmers of their Problems

As reported in the first part of the project (Utomo *et al*., 1998), most farmers in the study area were well aware of the problems they encountered. The farmers know well that their land is in a very poor condition, and that a lot of work and capital must be expanded to get a reasonable yield. They are also well aware that soil degradation due to soil erosion is occurring very rapidly. Hence, soil conservation practices, which would result in a decrease in erosion and improvement in soil fertility, should be implemented.

The problem is that due to the fact that farmers own a very small land area, their income is too low to manage their land properly. Actually, the farmers are very eager to practice better soil management in their fields. However, based on their experiences with previous extension activities, they think that the recommended management practices are expensive, complicated and need a lot of labor, either for establishment or maintenance.

2. FPR Demonstration Plots

The results of the first year demonstration plots have been reported by Utomo *et al*. (1998). After this first year, the land for the demonstration plots in Wates district were used for other purposes; therefore, a new demonstration plot was established. The results are presented in **Table 1**. In general, the various treatments produced lower levels of erosion than the traditional farmer's practice. Except for Taiwan grass hedgerows in the first year (1997/98), the soil losses in all hedgerow treatments were lower than that of the no-hedgerow treatment. In contrast with the soil loss, there were no great differences in the yield of cassava and maize among treatments. In the second year after hedgerow establishment, these treatments again did not have any effect on crop yields. The lower yield of cassava in the no-hedgerow treatment shown in **Table 1** could not be attributed to the treatment effect; this was merely due to experimental variability.

Table 1. Crop yield and dry soil loss due to erosion in the FPR demonstration plots conducted on 5-10% slope in Ringinrejo, Wates, in 1997/98 and 1998/99.

Treatment (hedgerows)	Crop yield (t/ha) Cassava 97/98	98/99	Maize 97/98	98/99	Soil loss (t/ha) 97/98	98/99
Farmers' practice (no hedgerows)	19.41	24.40	1.55	1.76	49.11	36.24
Vetiver grass	28.73	28.16	1.63	2.04	26.79	24.56
Elephant grass	24.97	22.48	1.03	1.96	35.71	22.19
Taiwan grass	23.11	24.17	1.29	2.10	49.11	28.65
Gliricidia sepium	30.36	27.16	1.80	2.24	41.07	25.16
Leucaena leucocephala	25.80	24.18	2.15	1.98	39.29	28.17

Similar results were obtained in the Dampit demonstration plot (**Table 2**). The average results for three years in Dampit (**Table 3**) show that some very simple erosion control technologies, consisting of making ridges across the slope or in-line mounds, were able to reduce erosion rates by 40 to 50% as compared to that of the farmer's practice. Again, there were no significant differences in cassava and maize yields, except that treatment 6 (intercropping with peanut and cowpea in addition to maize) resulted in lower cassava and maize yields; this latter treatment, however, produced the highest gross and net income, but had also a very high soil loss due to erosion. Farmers will need to decide whether the higher income is justified by the higher level of soil degradation.

The average results of two on-farm variety trials conducted in Dampit (**Table 4**) indicate that the introduced varieties produced a lower yield compared to the local Caspro variety. Actually, Caspro and Sembung are not real local varieties. These are high yield national varieties which have been cultivated by Indonesian cassava farmers for many years; nevertheless, farmers consider these as local varieties. Among the introduced varieties, UB ½, a variety developed by Brawijaya University, produced the highest root yield; however, the widely grown industrial variety, Adira 4, had by far the highest starch content, which resulted in a higher starch yield.

It is interesting to note the results of the on-farm fertilizer experiment conducted in Dampit (**Table 5**). Application of manure and/or fertilizer did not increase cassava yields. Considering the high yield obtained without fertilizers (42.3 t/ha) this is not surprising. A cassava yield of 40 t/ha is already very high and approaching the maximum yield. Therefore, application of fertilizers is unlikely to further increase the yield. There may even be a decrease in the yield due to a nutrient imbalance or excess.

Table 2. Results of FPR Demonstration plots conducted in Sumbersuko village, Dampit, Malang, East Java, Indonesia, in 1997/98 (4th cycle).

Treatments[1)	Yield (t/ha) Cassava	Maize	Gross income[3)	Production costs[4)	Net income	Dry soil loss (t/ha)
			('000 Rp/ha)			
1. C+M, farmer's practice, up-down ridging	17.10	1.25	5,617	2,247	3,370	24.45
2. C+M, recom. practices, contour ridging, vetiver HR	14.60	1.30	4,982	2,399	2,583	3.00
3. C+M, recom. practices, staggered mounds	17.60	1.40	5,845	2,399	3,446	10.44
4. C+M, recom. practices, contour ridging, lemon grass HR	15.20	1.25	5,104	2,399	2,705	7.83
5. C+M, recom. practices, in-line mounds	12.50	1.25	4,375	2,399	1,976	6.92
6. C+M+P-Cp[2), recom. practices, contour ridging of cassava rows	5.55	0.95	7,723	3,051	4,672	13.13
7. C+M, recom. practices, contour ridging	14.60	1.35	5,022	2,399	2,623	9.93
8. C+M, recom. practices, contour ridging, *Gliricidia* HR	12.30	1.30	4,361	2,399	1,962	6.27
9. C+M, recom. practices, contour ridging, *Flemingia* HR	15.00	1.30	5,090	2,399	2,691	9.45
10. C+M, recom. practices, contour ridging, *Leucaena* HR	14.55	1.25	4,928	2,399	2,529	7.50
11. C+M, recom. practices, contour ridging, *Calliandra* HR	16.25	1.35	5,467	2,399	3,068	3.69
12. C+M, recom. practices, contour ridging, elephant grass HR	16.45	1.30	5,481	2,399	3,082	2.28

[1) C = cassava, M = maize, P = peanut, Cp = cowpea; HR = contour hedgerows

[2) Yields of peanut: 850kg/ha; cowpea: 410 kg/ha

[3) Prices:

cassava	Rp 270/kg fresh roots	seed maize	Rp 2,500/kg	urea	Rp 1,200/kg
maize	800/kg dry grain	seed peanut	4,500/kg	SP-36	1,500/kg
peanut	4,500/kg dry grain	seed cowpea	4,000/kg	KCl	1,700/kg
cowpea	4,000/kg dry grain			FYM	20/kg

[4) Cost of production ('000 Rp/ha):

	T_1	T_{2-5}, T_{7-12}	T_6
seed	87	87	190
fertilizers	1,035	1,130	1,350
pesticides	-	57	111
labor	1,125	1,125	1,400
	2,247	2,399	3,051

[5) 1US $ = Rp 8,000 in 1997/98.

Table 3. Crop yield and dry soil loss in the FPR demonstration plots conducted on 12% slope in Sumbersuko village, Dampit, Malang. Data are average values for 1996/97, 1997/98 and 1998/99.

Treatments[1)]		Soil loss (t/ha)	Yield (t/ha) Cassava	Maize	Net income ('000 Rp/ha)
1. C+M	Farmers' practices; up and down ridging	19.22	16.54	1.21	1,724
2. C+M	recom. practice; contour ridging; vetiver hedgerows	4.37	13.82	1.16	1,228
3. C+M	recom. practice; staggered mounds	11.02	14.95	1.22	1,577
4. C+M	recom. practice; contour ridging; lemongrass hedgerows	7.92	13.78	1.17	1,294
5. C+M	recom. practice; in-line mounds	7.19	13.60	1.16	1,079
6. C+M+P-Cp[2)]	recom. practice; contour ridging on cassava line	15.41	5.09	0.98	2,771
7. C+M	recom. practice; contour ridging	9.22	12.67	1.21	1,158
8. C+M	recom. practice; contour ridging; *Gliricidia* hedgerows	7.10	12.71	1.25	1,004
9. C+M	recom. practice; contour ridging; *Flemingia* hedgerows	9.39	14.14	1.14	1,283
10. C+M	recom. practice; contour ridging; *Leucaena* hedgerows	8.02	13.31	1.16	1,178
11. C+M	recom. practice; contour ridging; *Calliandra* hedgerows	4.93	12.55	1.20	1,277
12. C+M	recom. practice; contour ridging; elephant grass hedgerows	3.21	14.75	1.17	1,463

[1)]C=cassava; M=maize, P=peanut, Cp=cowpea

Table 4. Average results of two on-farm variety trials of cassava intercropped with maize conducted in Sumbersuko village, Dampit, Malang, E. Java, in 1997/98 and 1998/99.

Variety/clone	Plant height (cm)	Cassava yield (t/ha)	Starch content[1)] (%)	Starch yield (t/ha)
1. Local Caspro	336	46.1	20.0	9.22
2. Local Sembung[2)]	294	36.4	19.0	6.92
3. OMM 90-6-89	363	30.9	16.5	5.10
4. OMM 90-6-72	315	38.5	19.5	7.51
5. OMM 90-5-42	297	31.9	15.5	4.94
6. Adira 4	317	37.6	24.0	9.02
7. Malang 2	286	33.1	21.5	7.12
8. UB 1/2	309	40.6	19.5	7.92
9. UB 881-5	289	37.9	18.5	7.01
10. UB 477-2	292	37.4	19.0	7.11
11. OMM 90-2-66	278	32.9	16.5	5.43

[1)] Measured by Reihmann scale
[2)]=Faroka

Table 5. Crop yield and gross and net income in the on-farm fertilizer trial conducted in Sumbersuko village Dampit, Malang, E. Java, in 1997/98.

Treatments[1)]	Cassava yield (t/ha)	Maize yield (t/ha)	Gross income	Cost fert+ manure	Net income
			(‘000 Rp/ha)		
1. No fertilizer or manure	42.3	1.44	12,573	0	11,303
2. 10 t FYM/ha	41.5	1.39	12,317	200	10,847
3. 200 kg Urea/ha	46.2	1.53	13,698	240	12,188
4. 200 kg Urea+10 t FYM/ha	40.5	1.39	12,047	440	10,337
5. 200 kg Urea+10 t ash/ha	45.7	1.76	13,747	240	12,237
6. 200 kg Urea+100 kg KCl/ha	42.4	1.38	12,552	410	10,872
7. 200 kg Urea+100 kg SP-36/ha	45.0	1.20	13,110	390	11,450
8. 200 kg Urea+100 kg SP-36+100 kg KCl/ha	50.2	1.16	14,482	560	12,652
9. 200 kg Urea+100 kg SP-36+200 kg KCl/ha	49.6	1.25	14,392	730	12,392
10. 200 kg Urea+200 kg RP+200 kg KCl/ha	50.0	1.30	14,540	NA	NA
11. 200 kg Urea+100 kg SP-36+10 t ash/ha	44.5	1.39	13,127	590	11,467
12. 200 kg Urea+100 kg SP-36+100 kg KCl+ 10 t FYM/ha	48.4	1.53	14,292	760	12,262
LSD (P=0.05)	NS				
CV (%)	14.7				

[1)]FYM = Farm-yard manure; RP = Rock phosphate; SP-36 = Superphosphate (36% P_2O_5)
NA = data not available; NS = not significant.

3. Participating Farmer’s Experiments (FPR trials)

In the third year, 21 farmers in Wates participated in the project; of these, 12 farmers did FPR trials on their own fields, six practiced the hedgerow system on their whole fields, and three others joined in the execution of the demonstration plots. Similar to the results obtained in the demonstration plots, the practice of planting contour hedgerows decreased soil loss (**Table 6**). The local variety Ijo (Ijo is a term in Javanese meaning green) was generally superior to the introduced varieties (**Table 7**).

In Dampit, in addition to conducting more demonstration plots, farmers did experiments in their own fields. In 1997/98 and 1998/99, five and ten farmers, respectively, conducted FPR erosion control and fertilizer experiments. The results of the experiments conducted on farmers’ fields are presented in **Tables 8** to **11**. Highest gross incomes were generally obtained with applications of both farmyard manure (FYM) and NPK fertilizers. However, applications of only urea or urea with KCl (or ash) is likely to produce higher net incomes. In the FPR variety trials the local variety Caspro again produced the highest yield and gross income.

Table 6. Results of FPR trials on the use of hedgerows conducted in Ringinrejo village, Wates, Blitar, E. Java in 1997/98 and 1998/99.

Treatments (hedgerows)	Crop yield (t/ha) Cassava 97/98	Cassava 98/99	Maize 97/98	Maize 98/99	Soil loss (t/ha) 98/99
No hedgerows	45.15	16.62	0.78	0.88	38.76
Calliandra calothyrsus	33.81	18.76	0.78	1.04	36.82
Gliricidia sepium	25.97	20.17	0.75	1.15	29.74
Leucaena leucocephala	35.94	16.54	0.79	0.98	-
Elephant grass	-	14.16	-	0.78	24.15
Vetiver grass	-	16.17	-	1.04	27.18

Table 7. Results of an FPR variety trial conducted by Mr. Hardy in Ringinrejo village, Wates, Blitar, E. Java, in 97/98.

Cassava varieties/clones	Cassava root yield (t/ha)	Gross income ('000 Rp/ha)	Production costs ('000 Rp/ha)	Net income ('000 Rp/ha)
Ijo (local variety)	42.55	7,233	2,430	4,803
SM 4772	41.99	7,138	2,430	4,708
UB 15/10	35.04	5,957	2,430	3,527

Table 8. Average results of ten FPR erosion control trials conducted for two years on farmers' fields in Sumbersuko village, Dampit, Malang, E. Java, in 1997/98 and 1998/99.

Treatments[1]		Dry soil loss (t/ha)	Yield (t/ha) Cassava	Yield (t/ha) Maize	Gross income ('000 Rp/ha)	Prod. costs ('000 Rp/ha)	Net income ('000 Rp/ha)
1. C+M	: farmers' practices; in-line mounds followed by up/ down ridging	17.4	17.80	1.15	4,641	1,200	3,441
2. C+M	: recom. practices; contour ridging; vetiver grass hedgerows	5.7	20.67	1.32	5,392	1,900	3,492
3. C+M+P+Cp[2]	: recom. practices; contour ridging on cassava line	14.1	7.10	0.82	6,436	2,370	4,066
4. C+M	: recom. practices; contour ridging; lemon grass hedgerows	8.6	19.30	1.25	5,086	1,900	3,186

[1] C = Cassava; M = Maize; P = Peanut; Cp = Cowpea

[2] Yield of peanut = 620 kg/ha; cowpea = 360 kg/ha in1997/98, and 750 and 400 kg/ha, resp. in 1998/99.

Table 9. Average results of five FPR fertilizer trials conducted by farmers in Sumbersuko village, Dampit, Malang, E. Java in 1997/98.

Treatments[1)]	Yield (t/ha) Cassava	Yield (t/ha) Maize	Gross income[2)] ('000 Rp/ha)	Fertilizer costs[2)] ('000 Rp/ha)	Net income ('000 Rp/ha)
1. Farmers' practice: 200 kg Urea/ha	22.60	1.50	7,302	240	7,062
2. 200 kg Urea+10 t ash/ha	25.40	1.15	7,778	440	7,338
3. 200 kg Urea+100 kg SP-36+10 t FYM/ha	26.20	1.60	8,354	590	7,764
4. 200 kg Urea+100 kg KCl+10 t FYM/ha	23.50	1.35	7,425	610	6,815
5. 200 kg Urea+100 kg SP-36+100 kg KCl+10 t FYM/ha	27.15	1.60	8,610	760	7,850

1)Cassava variety: Caspro

2)Prices: cassava Rp 270/kg fresh roots; maize 800/kg dry grain; FYM or ash 20/kg; urea Rp 1,200/kg; SP-36 1,500/kg; KCl 1,700/kg

Table 10. Average results of ten FPR fertilizer trials conducted by farmers in Sumbersuko village, Dampit, Malang, E. Java in 1998/99.

Treatments[1)]	Yield (t/ha) Cassava	Yield (t/ha) Maize	Gross income[2)] ('000 Rp/ha)	Fertilizer costs[2)] ('000 Rp/ha)	Net income ('000 Rp/ha)
1. 200 kg urea/ha	21.7	1.2	4,035	200	3,835
2. 200 kg urea +100 kg SP-36+10 t FYM/ha	24.2	1.5	4,605	530	4,075
3. 200 kg urea +100 kg SP-36+10 t ash/ha	22.5	1.0	4,025	530	3,495
4. 200 kg urea +100 kg KCl/ha	25.0	1.1	4,465	330	4,135
5. 200 kg urea +100 kg Sulphomag[3)]/ha	22.4	1.3	4,205	NA	NA

1)Cassava variety: Caspro

2)Prices: cassava Rp 150/kg fresh roots; maize 650/kg dry grain; FYM or ash 20/kg; urea Rp 1,000/kg; SP-36 1,300/kg; KCl 1,300/kg

3)Potasium-magnesium-sulfate: 22% K_2O, 11% Mg, 22% S

Table 11. Average results of ten FPR variety trials conducted by farmers in Sumbersuko village, Dampit, Malang, E. Java in 1998/99.

Variety	Yield (t/ha) Cassava	Yield (t/ha) Maize	Gross income[1)] ('000 Rp/ha)
1. Sembung (Faroka)	29.0	1.6	5,390
2. Caspro	35.0	1.4	6,166
3. OMM 90-6-72	31.0	1.3	5,495

1)Prices: cassava Rp 150/kg fresh roots; maize 650/kg dry grain

4. Technology Adoption

In the third year, there were six farmers in Wates adopting some technologies on their land. Four farmers planted *Gliricidia* hedgerows and two planted *Leucaena* hedgerows. As discussed before, until this year none of the suggested technologies increased crop yields. Thus, no direct benefits were obtained by the farmers. They adopted the technologies because they saw that these decreased soil erosion, and the application of the technologies was not so difficult and expensive as they had thought before. These results indicate that at least some farmers in Wates have a good perception of sustainable crop production. Thus, if they practice any land management technology, they do not only think about a direct benefit; indirect benefits, such as reducing soil erosion, has also become a consideration.

The reason that farmers prefer *Gliricidia* hedgerows are: the hedgerows help decrease soil erosion, it is easy to find planting material, the plants are easy to grow, leaves can be used for animal feeding and the stems for fire wood, and they are sure (based on what they saw during the field day at Jatikerto Experiment station) that the technology will eventually increase crop yields.

In the fourth year, the number of farmers in Wates adopting the technologies increased to 15 with a total land area of about 9.0 ha. The technologies adopted and the reason for the adoption are given in **Table 12**. Adoption of the technologies in Dampit started in 1999, with four farmers planting *Gliricidia* hedgerows on part of their land.

Table 12. Soil management technologies adopted by farmers in the 4th year in Ringinrejo village, Wates, Blitar, E. Java.

Technologies/Hedgerows	Number of farmers	Reasons
Gliricidia sepium	8	Decrease soil erosion Easy to find planting material Easy to grow for animal feeding and fire wood Improved crop performance Increase in crop yield
Leucaena leucocephala	4	Easy to find planting material Decrease soil erosion Animal feeding
Elephant grass (Pennisetum purpureum)	2	Animal feeding Decrease soil erosion
Calliandra calothyrsus	1	Decrease soil erosion Animal feeding

5. Farmer's Perception of the FPR Methodology

The use of the FPR methodology was evaluated by asking the collaborating farmers in Wates to answer a short questionnaire. Basically, they were happy with the FPR methodology because they obtained a better understanding about the difficulties, cost, and advantages of the technologies they developed. Soon after the technologies showed a good prospect, they already had the skill to implement the technologies. Hence the FPR method facilitated the adoption process.

Some farmers are proud that they are capable of developing by themselves new technologies for increasing crop yield and conserving their soil. Since they were involved in the development of the technologies, they consider that the technologies belong to them or their group. Therefore, they say that they have the responsibility for the success of the technologies.

The FPR method also increased the self-confidence and motivation of farmers to obtain any information concerning new technologies. They do not hestitate to come and discuss with any person, especially the extension services, when they have problems or difficulties; they will ask if there are any new technologies. The method also increases their willingness and ability to try new technologies.

CONCLUSIONS

The use of Farmer Participatory Research methodologies to develop and transfer better soil management practices for cassava farmers in Wates and Dampit has shown that:

1. Most farmers in the study area, actually have a good understanding that the low productivity of their crops is partially due to improper land management. They know that their soil is in a very poor condition and that soil degradation due to erosion has occurred.
2. Most farmers realize the importance of proper land management to both obtain a reasonable yield and to maintain or increase soil productivity. To some extent, farmers already knew how to implement soil conservation practices but they did not adopt the technology properly.
3. The reason farmers do not adopt soil conservation practices is that they think that the technology is very complicated, expensive, need a lot of labor, and does not give direct benefits.
4. Participation of the farmers in the identification of the problems and in the development of the technologies made the farmers think that the technologies belong to them, so they feel responsible for the success of the technologies. With this approach, farmers know that the use of proper land management technologies is not so complicated and costly as they had thought before.
5. The FPR approach increases the self-confidence of the farmers. The farmers do not hesitate to come and discuss their problems with other persons, especially extension personnel, and ask for information about their problems and about new technologies.

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CASSAVA TECHNOLOGY ASSESSMENT AND TRANSFER THROUGH USERS PARTICIPATION IN INDIA

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ABSTRACT

Cassava plays a major role in the food security of a large but weaker sector of the population, operating under complex, diverse and risk-prone farming systems. As the crop generally received low priority in the extension agenda of Government policies, direct intervention in the technology assessment and transfer by CTCRI in India was considered necessary. Over the past three decades the transfer of technology (TOT) program has undergone changes in concept and methodology according to changing farmers' needs and socio-economic conditions, presently culminating in the concern for the users rather than the crop.

CTCRI has implemented a series of "Users Participatory Programmes" in assessing and transferring the cassava technology. The assessment of cassava technology was done in various production systems, including hill agriculture, as well as users' categories, including hill tribes. Agro-ecosystem analyses were conducted prior to the assessment of the cassava technologies; these were carried out in stages involving different categories of users. There were differential preferences observed in the various production systems as well as in the users' categories. Trials conducted in the lowland production system indicated that the cassava varieties CI-649 and CI-731 were preferred, while farmers of upland production systems rated CI-732 and CI-649 as the best ones. Differences were also observed in the varietal preferences by various tribal people. The trials clearly indicate that there is a need to develop location-specific as well as user-specific technologies. The TOT programs excuted by CTCRI during the past three decades, namely the National Demonstrations, the Operational Research Project, and the Lab-to-Land Programme, and the impact of these programs are briefly described in the paper. The technology assessment and refinement through the Institution-Village-Linkage Programme (IVLP), a novel concept using a holistic approach, and the current testing and popularizing of cassava varieties in Tamil Nadu are detailed in the paper. The technology transfer is also enhanced through human resources development in participatory training courses and seminars.

The issue of concern is who makes the choices of technology. Normally those least affected by the choice are the ones responsible for determining that choice, while those who are forced to live with the technology have least say in the matter.

- *Hoyzer, N.*

INTRODUCTION

Cassava is a secondary crop, extending the primary functions of food security and livelihood to a large majority of the weaker sections of the population, operating under complex, diverse, and risk-prone areas(CDR) in many developing countries. In India, more than 90% of the cassava area is in the states of Kerala, Tamil Nadu and Andhra Pradesh (in order of importance) (Lakshmi *et al*., 2000). Cassava is cultivated in various types of production systems, namely, lowland rainfed, upland rainfed and hill agriculture rainfed (by tribals) in Kerala; under rainfed and irrigated conditions in the plains, and rainfed in hill agriculture (by tribals) in Tamil Nadu; in Andhra Pradesh it is grown under rainfed conditions in the plains as well as hill agriculture (by tribals) – indicating a wide range in

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production systems and thereby in the user systems too. While the end-use of roots are for direct consumption in Kerala (> 75% of the production), cassava occupies a different status in terms of value addition in the form of starch and sago in the neighboring states of Tamil Nadu and Andhra Pradesh (Ghosh *et al*., 1988).

Agricultural technology breakthroughs and the resulting success of the green revolution has been restricted to priority crops and privileged farmers growing them in the more favorable areas with well endowed production systems, but did not benefit the less privileged crops like cassava cultivated by less privileged farmers in peripheral/CDR areas. This clearly shows that agricultural technologies are not neutral to the production systems as well as farmer categories. This situation emerges mainly due to a mismatch between the scientist's assumptions and the farmer's expectations on technology requirements. Rural communities have a vast reservoir of expertise in the management of complex agro-ecologies and their associated agricultural and aquatic systems (Farrington and Martin, 1987). Applied agricultural research cannot begin in isolation on an experimental station, out of touch with farmers' conditions (Rhoades and Booth, 1982).

Similarly, transfer of technologies (TOT) cannot isolate the farmers from the extension system. In fact, crops are not automatically transformed into food unless a series of users, i.e. farmers, laborers, farm women, traders and processors, make the product. In practice, this means obtaining information on the production system's complexities, and achieving an understanding of the user's perception of the value of the technology to be assessed and refined; in other words, emphasizing user participation in research and technology assessment and transfer.

CTCRI provides the leadership in user participatory research in cassava technology generation in India. As a crop not appropriately prioritized in the extension agenda of government polices, cassava also requires the direct intervention in the transfer of technology. This paper describes the CTCRI methodology and some of the salient results in the assessment of cassava technology and transfer.

TECHNOLOGY ASSESSMENT

Technology assessment is carried out both on the production and processing fronts adopting User Participatory Research (UPR). UPR is similar to Farmer Participatory Research (FPR) in the concept and procedures, except that it covers a wide range of persons apart from farmers who are involved in an particular enterprise like cassava. FPR is defined by Ashby (1990) as a set of methods designed to enable the farmers to make an active contribution as decision makers in the planning and execution for agricultural technology generation. As far as the production front is concerned, CTCRI concentrates on varietal evaluation, as crop improvement is considered to be the kingpin of agricultural research, and has a direct bearing on productivity improvement. On the processing front, technologies meant for farm, home and cottage-level industries were subjected to assessment by the users. The methodology followed by CTCRI in assessing cassava technology is shown in **Table 1**. The participatory varietal evaluation is done mainly through on-farm trials (OFT), adopting consultative participation of farmers which emphasizes researcher-managed and farmer-implemented trials (Ashby, 1986). The cassava varietal evaluations are undertaken in Kerala, Tamil Nadu and Andhra Pradesh states, covering all the production systems as indicated in **Table 1**. The utilization technologies which are meant for home, farm and cottage-level industries, comprise value-added products and post-harvest equipment. These technologies are assessed using consumer testing and field testing methods, respectively.

Table. 1. Cassava Technology Assessment - CTCRI Methodology.

I	**Production Technology**		
	a) Varietal evaluation		
	1. Mode: On farm trials - Consultative participation of farmers		
	2. Production systems		
		a. Kerala	1. Lowland, Rainfed
			2. Upland, Rainfed
			3. Hill Agriculture, Rainfed
		b. Tamil Nadu	1. Plains, Irrigated
			2. Hill Agriculture, Rainfed
		c. Andhra Pradesh	1. Plains, Rainfed
			2. Hill Agriculture, Rainfed
II	**Utilization Technology**		
	a) Value-added products		
	Mode: Consumer testing		
	b) Postharvest equipment		
	Mode: Field-testing		

Production Technology

1. User participatory cassava varietal evaluation

The steps followed by CTCRI in the user participatory cassava varietal evaluation are shown schematically in **Figure 1**.

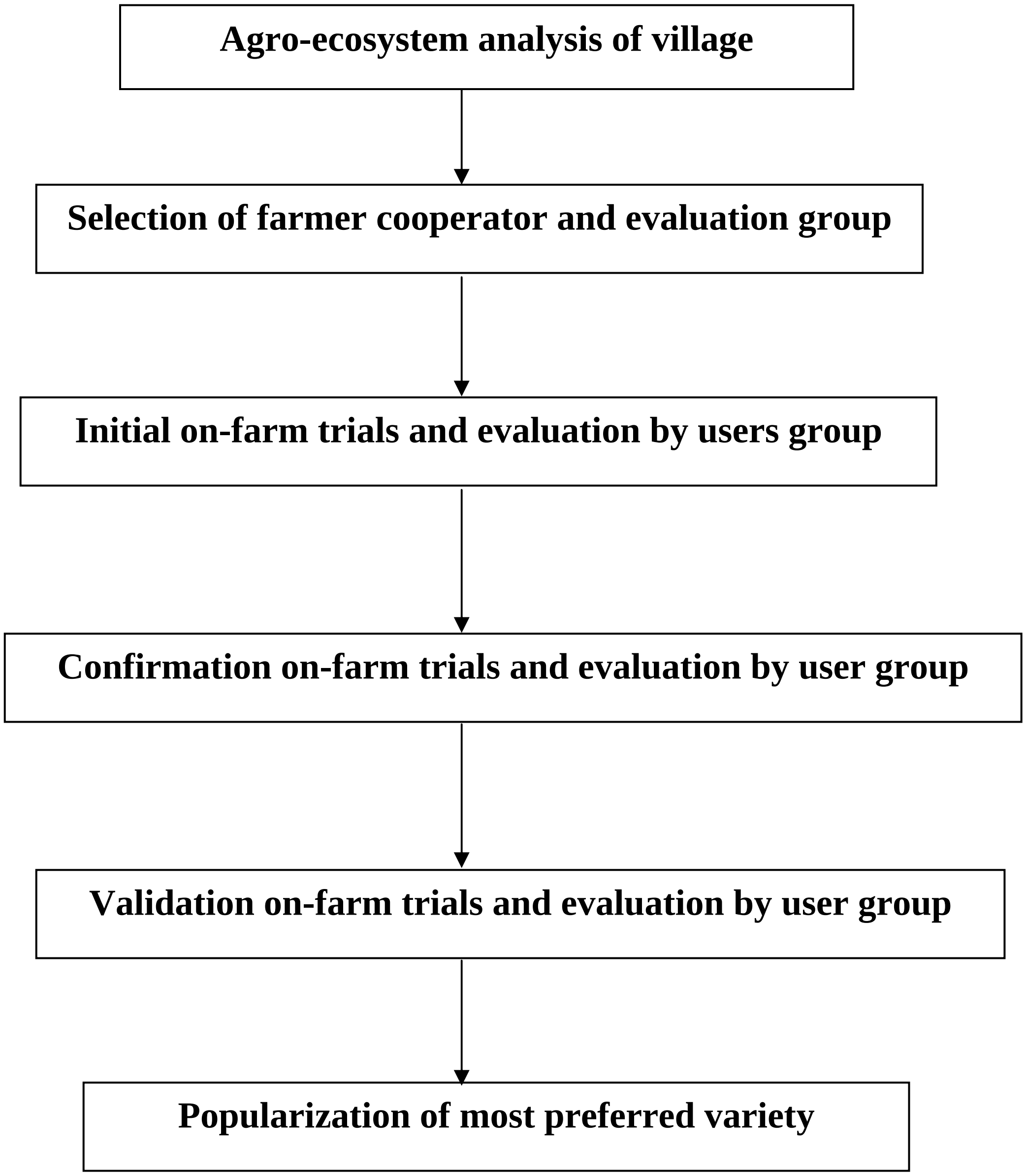


Figure 1. User participatory cassava varietal evaluation.

1.1 Agro-ecosystem analysis

Agro-ecosystem analysis is a technique to analyze an ecological system partially modified by man to produce food, fiber or other agricultural products (Conway *et al*., 1987). Using pattern analysis as a tool, the agro-ecosystem analysis was carried out in a selected village for varietal evaluation. Space, time, flow and decision were considered the major patterns in describing the agro-ecosystem, and were determined using Participatory

Rural Appraisal (PRA) techniques. Results of some of these are presented for the various villages selected in the ensuing pages.

1.2 Selection of cooperator farmers and evaluation groups

One cooperator farmer in each of the villages, selected by the criteria laid out by Ashby (1990), was chosen to conduct an OFT in each of the production systems listed. It was not possible to establish a large number of trials to be used as replications due to the paucity of planting materials and other resources. Instead, groups of various user evaluation categories, such as farmers, farm women and traders, were formed to evaluate a single trial. Each member of the group was considered to be a replication/observation for the purpose of analyzing and interpreting the outcome of the trials.

1.3 Laying out and management of OFT and user's evaluation

Farmer/user evaluation is a subset of these participatory methods. The evaluation methods can be applied at different points (Ashby, 1990). Farmers are involved at three stages of varietal evaluation, namely regional trials, exploratory trials and farmer-managed trials according to Ashby (1987), while Sperling (1995) adopted two stages of evaluation, i.e. on-station and on-farm trials. CTCRI in its varietal evaluation adopted three stages, i.e. initial on-farm trials (IOFT), confirmation on-farm trials (COFT) and validation on-farm trials (VOFT). Considering the ability of the farmers to comprehend as well as their familiarity with the trials, laying out the OFT using a typical design was felt to be difficult under actual field conditions. Hence, a modified completely randomized design was followed to test the cassava varieties in two replications in the IOFT. However, replications were not adopted in hill agriculture production systems in view of the fact that the farmers are tribal, and the terrain highly undulating. The nature and number of varieties in the IOFT were based on the combined decisions of farmers and scientists. The varieties evaluated in the IOFT were screened down to roughly half the number, and carried over to the COFT. The VOFT tested only the best 1 or 2 varieties screened from the COFT. At each stage, the varieties selected and passed on to subsequent trials were left to the discretion of the farmers, based on group consensus. The data were collected using PRA techniques and analyzed using content analysis, ranking, mean scores and analysis of variance.

1.4 Popularization of selected cassava varieties

Both the farmer cooperator and the evaluation group were used for popularizing the varieties based on their own personal experience. They also acted as seed producers *cum* distributors. The spread of the varieties was also studied using PRA techniques.

Following the above-mentioned steps, UPR was undertaken in the various production systems of Kerala, Tamil Nadu and Andhra Pradesh states in India. OFT laid out in Andhra Pradesh are yet to be harvested; hence these results are not presented.

Kerala

1. Lowland rainfed production system

1.1 Agro-ecosystem analysis

Ayanimoodu (Pallichal), a village in the Thiruvananthapuram district, was selected and the agro-ecosystem analysis was conducted. The agro-ecosystem transect of the village is given in **Figure 2**. Cassava is a predominant crop in the lowland production system. The matrix ranking of crops conducted by farmers (**Table 2**) indicates that food security, profitability, risk aversion and marketability are the principal parameters considered by the farmers for crop selection and ranking. It may be observed that cassava was ranked highest for risk aversion and second for food security.

1.2 On-farm trials

The IOFT was conducted on 11 varieties (**Table 3**). The varieties with serial numbers 2, 9 and 10 are landraces, while 1, 4, 8 and 11 are released varieties, and the remaining ones are pre-released ones. The yield performance of the varieties is given in the table. Analysis of variance revealed that there were significant differences in yield among the varieties. The varieties, CI-731, CI-732, CI-649 and H-1687, had significantly higher yields than the other varieties. The roots were evaluated by the users, namely farmers, traders and farm women, and their preferential ranking is also presented in **Table 3**. The Spearman rank correlation indicates that the rank order of varieties between two of the three groups was significant, revealing that there existed concordance among all the three groups. The varieties preferred by the users and selected based on group consensus, namely CI-731, CI-649, CI-732, and CI-664, were forwarded to the COFT. The results of this trial for yield and rank order by the farmers and farm women are presented in **Table 4**. Two varieties, CI-731 and CI-649, clearly emerged as most preferred. It may be noted that CI-731, in spite of its lower yield was preferred because of its other favorable traits like taste, cooking quality and marketability, as is evident from the matrix ranking of varieties by the farmers (**Table 5**). In the VOFT (**Table 6**) which tested two varieties, namely CI-649 and CI-731, the latter was preferred for its root size, shape, uniformity and number.

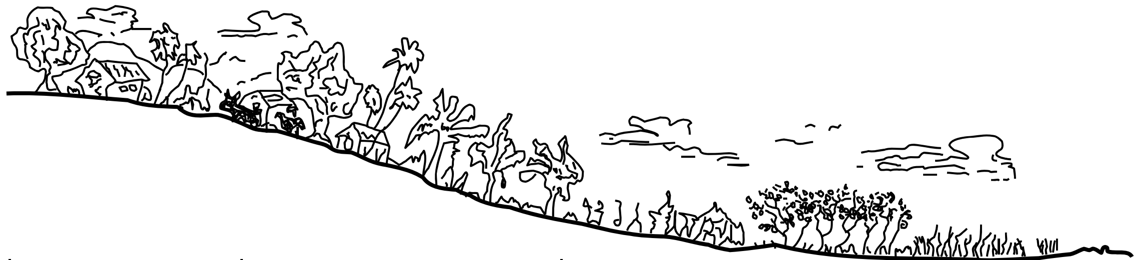
Table 2. Matrix ranking of crops by farmers of Ayanimoodu (Pallichal) village in a lowland rainfed production system in Kerala, India, in 1995.

Character	Paddy	Cassava	Coconut	Banana	Vegetables
Food security	1	2	5	3	4
Profitability	5	4	3	2	1
Risk aversion	4	1	2	3	5
Marketability	4	5	3	2	1

Source: *Anantharaman et al., 1995.*

1.3 Popularization of the most preferred variety

The dissemination effect of the variety CI-731 was assessed in the village. It was estimated from a link source that the variety went from ten farmers after the first year of the IOFT to 30 farmers in the second year. Key informant interviews and direct observation also indicated that nearly 70% of the farmers were cultivating the variety CI-731 in 50% of the area by the third year.



Land type	Upland	Lowland
Soil type	Red laterite	Clayey loam
Trees	Mango, jack fruit, tamarind	-
Crops	Coconut, pepper, cassava, banana	Banana, vegetables (cowpea, bitter gourd, snake gourd, greens, cucumber), paddy, cassava, Colocasia
Irrigation	Rainfed	Tanks, canals
Livestock	Cows, buffaloes, goats, poultry	-
Pests and diseases	CMD, coconut mites	CMD, rice bug, stemboror, aphids, fruit flies, pod-borer, pseudostem weevil, rhizome weevil

Figure 2. Agro-ecosystem transect of Ayanimoodu (Pallichal), village, Thiruvananthapuram district, Kerala, India.

Table 3. Initial on-farm trials on varieties at Ayanimoodu village, Kerala, India, in 1995.

Variety	Yield (t/ha)	User evaluation rank order		
		Farmers	Traders	Farm women
1. H-1687	32.00a	7	8.5	10
2. Karunkannan	26.52b	4.5	7	7
3. CI -664	23.64c	6	4.5	2.5
4. S-856	26.57b	9	10.5	9
5. CI-731	32.73a	1	1.5	1
6. CI-649	32.15a	2	4.5	4.5
7. CI-732	32.51a	3	1.5	2.5
8. M-4	22.65c	10	8.5	4.5
9. Mankozhunthan	23.65c	8	4.5	8
10.Kariyilaporiyan	20.88c	4.5	4.5	6
11.H-2304	17.73d	11	10.5	11
Analysis of variance	**			
F value	108.56	-	-	-
CD	2.55	-	-	-

Degree of agreement: Farmers and Traders 0.86**
Farmers and Farm women 0.76**
Traders and Farm women 0.83**

Varietal yield performance based on CD: values followed by the same better are statistically not significantly different.

Source: *Anantharaman et al., 1995.*

Table.4. Confirmation on-farm trials on varieties at Ayanimoodu village, Kerala, India, in 1996.

Variety	Yield (t/ha)	Rank order	
		Farmers	Farm women
CI-664	24.14	2	3
CI-649	28.93	3.5	2
CI-731	23.14	1	1
CI-732	26.04	3.5	4

Source: *Anantharaman et al., 1996.*

Table. 5. Matrix ranking of varieties by farmers at Ayanimoodu village, Kerala, India, in 1996.

Character	Variety			
	CI-664	CI-649	CI-731	CI-732
Yield	3	1	4	2
Taste	2	3	1	4
Cooking	3	2	1	4
Marketing	3	2	1	4
Starch	3	2	4	4

Source: *Anantharaman et al., 1996.*

Table 6. Validation on-farm trials on two selected varieties at Ayanimoodu village, Kerala, India, in 1997.

Evaluation criterion	Variety	
	CI-649	CI-731
Yield (t/ha)	34.5	29.5
Root size	2	1
Root shape	2	1
Root number uniformity	2	1
Starch content	1	2
Overall preference	2	1

Source: *Anantharaman et al., 1997.*

2. Upland rainfed production system

The farmer participatory cassava varietal evaluation was done in Kodankara village of Thiruvananthapuram district.

Ten varieties were tested in the IOFT. Yields and farmer preferential ranking are presented in **Table 7**. CI-732 gave the highest yield of 28 t/ha. The analysis of variance showed significant differences in yield due to varieties. Varieties CI-732, CI-731, S-856, CI-664, Mankozhunthan, H-1687, and CI-649 were significantly superior in yield to the others. The preferential ranking by the farmers indicate that CI-732 was preferred most, followed by CI-731, CI-649, and CI-664. All the four were carried forward to the COFT. The farmer participatory evaluation of the COFT revealed that CI-732 was again the most preferred variety, followed by CI-664, CI-649 and CI-731 (**Table 8**). However, the highest yield was produced by CI-649 at 28.5 t/ha. Farmers considered eight characters in arriving at the preferential ranking of varieties as is evident from **Table 9**. They are root size, shape, uniformity, number, color, starch content, taste and marketability. CI-732 secured first rank for size, starch and marketability. As there were four varieties, paired ranking was also used to pinpoint the most preferred variety (**Table 10**); CI-732 outranked the remaining varieties. Three varieties, namely CI-732, CI-649 and CI-731, were tested in the

VOFT, and the user evaluation indicated high preference for CI-732 for its starch content and root size (**Table 11**). Key informant sources showed that CI-732 had been adopted by 30% of the farmers in the village.

Table 7. Initial on-farm trials on varieties at Kodankara village in an upland rainfed production system in Kerala, India, in 1996.

Variety no.	Variety	Yield (t/ha)	Farmers' preferential ranking
1	H-1687	23.25abcde	7
2.	Karunkannan	20.15cdefg	9
3.	CI-664	27.90ab	4
4.	S-856	26.67abc	8
5.	CI-731	18.21defg	2
6.	CI-649	22.32abcdef	3
7.	CI-732	29.45a	1
8.	M-4	13.07g	10
9.	Mankozhunthan	24.80abcd	6
10	Kariyilaporiyan	18.60defg	5

F Value: 11.55^{**} CD: 7.39

Varietal performance based on CD: values followed by the same letter are statistically not significantly different

Source: *Anantharaman et al., 1996.*

Table 8. Confirmation on-farm trials on varieties at Kodankara village, Kerala, India, in 1997.

Variety no.	Variety	Yield (t/ha)	Farmers'preferential ranking
1.	CI-664	26.66	2
2.	CI-731	21.70	4
3.	CI-732	24.80	1
4.	CI-649	28.52	3

Source: *Anantharaman et al., 1997.*

Table 9. Matrix ranking of varieties in confirmation on-farm trials at Kodankara village, Kerala, India, in 1997.

Variety	Size	Shape	Uniformity	Root no.	Color	Starch content	Taste	Marketing
1.CI-731	3	1	1	1	2	4	1	2
2.CI-664	4	4	1	1	3	3	3	4
3.CI-732	1	2	3	3	4	1	1	1
4.CI-648	2	3	4	4	1	2	4	3

Source: *Anantharaman et al., 1997.*

Table 10. Paired ranking for varieties in confirmation on-farm trials at Kodankara village, Kerala, India, in 1997.

Varieties paired	Preferred	Rank
731 and 664	731	732 (1)
731 and 732	732	731 (2)
731 and 649	731	649 (3)
664 and 732	732	664 (4)
664 and 649	649	-
732 and 649	732	-

Source: *Anantharaman et al., 1997.*

Table 11. Results on yield and character preference of three varieties by farmers in validation on-farm trials at Kodangara village, Kerala, India in 1998.

Character no.	Evaluation criteria	Variety		
		CI-732	CI-649	CI-731
1.	Yield (t/ha)	27.15	29.76	23.86
2.	Root size	2	1	3
3.	Root shape	1	3	2
4.	Root number	2	3	1
5.	Root uniformity	3	2	1
6.	Starch content	1	2	3
7.	Overall preference	1	2	3

Source: *Anantharaman et al., 1998.*

3. Rainfed hill agriculture production system

Chinnaparakudi, a tribal settlement in Idukki district, known for its tribal population and hill eco-system was selected to assess cassava varieties suitable for hill agriculture. Mannan, the dominant tribe in these hills, is tradition-bound and one of the oldest tribal groups inhabiting this settlement. Even though cassava was introduced to this settlement as recently as four decades ago, it plays a significant role in the livelihood of the tribe. An agro-ecosystem analysis showed that this settlement is rich in cassava varietal diversity. More than ten cultivars were found to be cultivated in this small settlement (**Table 12**).

The IOFT was conducted with ten cassava varieties. High variability was observed in the yield of the different varieties, ranging from 6 to 33 t/ha (**Table 13**). This may be due to the undulating terrain and losses by damage from wild pigs. Preferential ranking of the varieties on root characteristics and taste was made by a group of tribals. There were differences observed in the ranking of varieties in relation to root characteristics and taste. However, S-856, CI-649, CI-731 did not exhibit much difference in rank for these traits. The varieties selected, based on group consensus for forwarding to the COFT, were S-856, H-165, H-97, CI-649 and CI-731. The COFT has yet to be carried out.

Table 12. Special characteristics of local cassava varieties grown by farmers of the tribal settlement of Chinnaparakudi, Kerala under a rainfed hill agriculture production system.

No.	Local name of variety	Special characteristics
1.	Ceylon Kappa	Good taste, non-bitter, suitable for raw consumption
2.	Kanthari Padappan	Non-bitter, suitable for raw consumption
3.	Arimanian	Non-bitter, suitable for raw consumption
4.	Ambakadan	Good yield, suitable for raw consumption
5.	Raman Thalai	Good yield, high starch, suitable for raw consumption and for parboiling
6.	Malabar Kattan	Bitter, high starch, used in large-scale parboiling, less susceptible to wild pig damage
7.	Vella Thundan	Non-bitter
8.	Pathinettu	High starch, suitable for parboiling
9.	Mullan Thalayan	Good taste
10.	Etha Kappa	Non-bitter, good cooking quality

Source: *Anantharaman and Ramanathan, 1996.*

Table 13. Yield, root and taste preference of cassava varieties in initial on-farm trials at Chinnaparakudi tribal settlement, Kerala, India, in 1997.

No.	Variety	Preferential rank		Yield (t/ha)
		Root (yield)	Taste	
1.	H-165	2	8	21
2.	S-856	1	1	33
3.	CI-649	3	6	6
4.	CI731	3	4	9
5.	H-1687	5	2	7
6.	H-226	3	7	13
7.	H-2304	6	5	13
8.	H-97	4	3	6
9.	M-4	4	3	6
10.	Local (Kattan)	3	10	13

Group consensus: S-856>H-165>H-97 >CI-649>CI-731

Source: *Anantharaman and Ramanathan, 1997.*

Tamil Nadu

1. Irrigated production system

Cassava under an irrigated production system is very prevalent in Salem, Namakal, Erode, Dharmapuri and Cuddlore districts of Tamil Nadu. Kalichettipatti village of Namakal district was selected for evaluation under the irrigated production system. Six varieties were tried in the IOFT, of which H-165 and H-226 were found to be most popular in the locality (**Table 14**). H-165 gave the highest yield of 38 t/ha. The farmer evaluators selected all the varieties except H-2304 to evaluate in the COFT which was in progress at the time of this report.

Table 14. Initial on-farm trials on varieties in an irrigated production system at Kalichettipatti village, Tamil Nadu, India, in 1999.

No.	Variety	Yield (t/ha)
1.	H-165	38.0
2.	CI-649	35.5
3.	H-226	28.7
4.	H-2304	16.7
5.	H-97	32.2
6.	CI-731	23.0

Source: *Edison et al., 2000.*

2. Rainfed hill agriculture production system

Kolli hills, also located in Namakal district, are of historical importance and are rich in medicinal herbs and in traditional medical practitioners. It was selected as representative of the rainfed hill agriculture production system in Tamil Nadu. These beautiful hills are situated at an altitude of 1,200 m. The brilliant greenery from its vast stretches of cassava fields on Kolli hills bestows a gratifying experience to any cassava researcher. Cassava, a crop introduced during the early eighties, dominates Kolli hills in terms of cultivated area, and is a major socio-economic determinant in the livelihood of the Malai Gounder tribes (**Figures 3** and **4**). Almost the entire cassava area (of 8,000 ha) in Kolli hills is occupied by a single variety from CTCRI, namely, H-165. Thengottupatti village was selected for the cassava varietal evaluation. The agro-ecosystem transect is given in **Figure 5**. The IOFT was carried out with four varieties, including the popular variety H-165 (**Table 15**). S-856 gave the highest yield, but not much different from that of H-165. Both these varieties were ranked the same by the group of farmers, and were followed by CI-649 and CI-731. The positive and negative aspects of the varieties as evaluated by the tribal farmers are given in **Table 16**. H-165 has many positive traits, whereas S-856 was rated high for starch, yield and shape, but had negative aspects such as knots and fiber in the roots. Farmers selected S-856 and H-165 for inclusion in the COFT.

UTILIZATION TECHNOLOGIES

The UPR on processing technologies was primarily conducted for those technologies to be considered for transfer to the home, farm and cottage-level industries. The technologies assessed may be broadly classified as value-added food products and small pre- and post-harvest equipment.

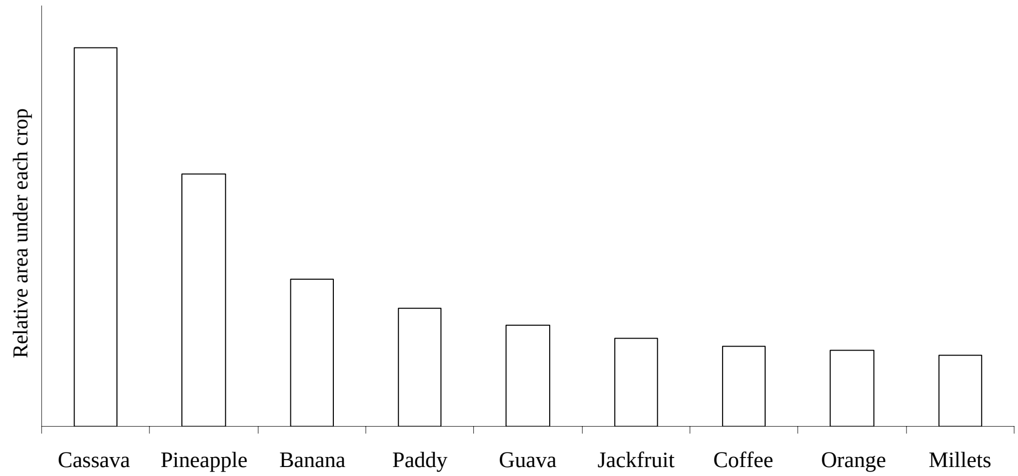


Figure 3. Area under crops (farmers' relative perception diagram) in a rainfed hill agriculture production system at the Thengottupatti village, Kolli Hills, Tamil Nadu, India, in 1997.

Table 15. Preferential ranking and yield of varieties in initial on-farm trials at Thengottupatti village, Tamil Nadu, India, in 1997.

Variety	Rank	Yield t/ha
H-165	1.5	30.0
S-856	1.5	31.0
CI-649	3	27.0
CI-731	4	24.0

Source: *Anantharaman and Ramanathan, 1997.*

Table 16. Positive and negative aspects of varieties as perceived by tribal farmers at Thengottupatti village, Tamil Nadu, India, in 1997.

Variety	Positive characters	Negative characters
H-165	Size, Shape, Starch, Uniformity, Number, Market value, Yield, Non- fibrous, Hardy stems	Nil
H-856	Starch, Yield, Shape, Size, Color	Knots, Fiber
CI-649	Size, Starch, Color	Yield, Number, Fiber, Short
CI-731	Size, Shape	Yield, Color, Knots, Fiber, Less market

Source: *Anantharaman and Ramanathan, 1997.*

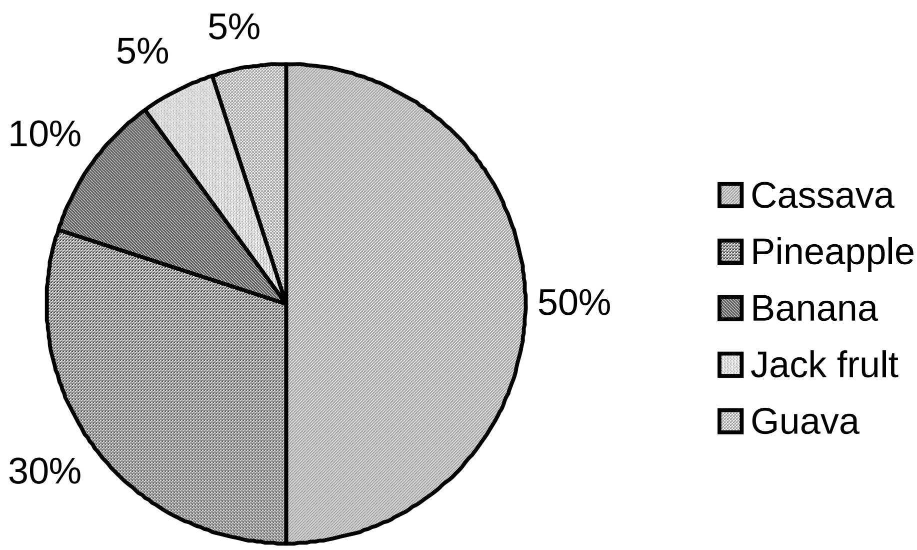


Figure 4. Livelihood income from various crop enterprises in Thengottupatti village, Kolli Hills, Tamil Nadu, India. (farmers' perception)

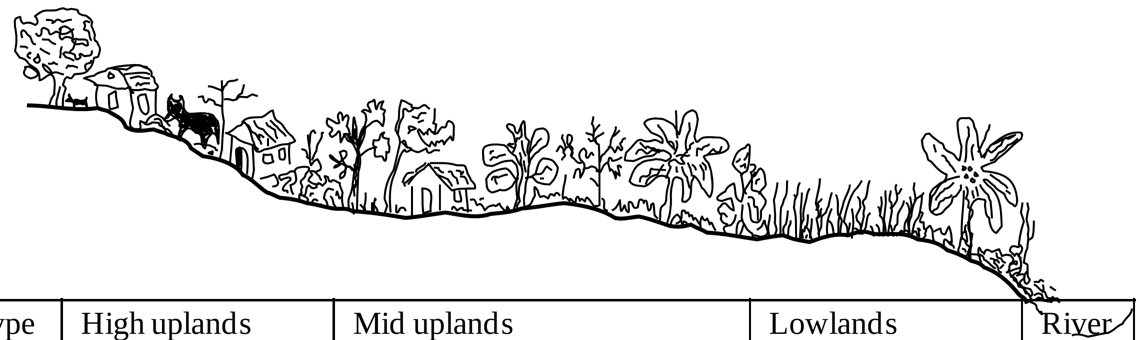
Value-added Products

1. Cassava semolina

Consumer testing was done with randomly selected respondents from among consumers who purchased cassava semolina from the CTCRI exhibition stalls. Data were collected by means of a structured mailed questionnaire on selected testing criteria using a Hedonic scale. The method of preparation of the recipes from semolina was demonstrated at the stall as well as described on the packets and distributed printed folders (Anantharaman and Balagopalan, 1996). Results are presented in **Table 17**. The majority of the consumers expressed an overall satisfaction with the product, showing their acceptance of such parameters as color, consistency, ease in cooking and taste. As far as inclination to purchase was concerned, 53% of the consumers expressed an interest to buy the product in the open market. The step-wise regression carried out indicated that comparative assessment, consistency and taste significantly explained the variation in the overall satisfaction, whereas comparative assessment, taste and ease in cooking influenced the purchase inclination of the consumers. Marketing depends very much on a competitive price of this product.

2. Cassava porridge

The method of consumer testing followed was that of cassava semolina. Ease in cooking, color, comparative assessment and aroma of the cassava porridge were rated



Land type	High uplands	Mid uplands	Lowlands	River
Soil type	Red, Rocky	Red, loamy	Black, clayey	
Water resources	Springs	Rainfed	Rainfed, flood depressions	River
Crops	Coffee, citrus, pepper, guava, pineapple	Cassava, pineapple, banana, millet, sweetpotato	Paddy, banana	-
Trees	Jackfruit, mango, orange, silver oak, konnai	Jackfruit, mango	-	-
Livestock	Sheep, cows, buffaloes, poultry	Sheep, cows, buffaloes, poultry	-	-
Pest and diseases	-	Wilt, bunchy top	Hoppers, rice bug	-
Problems	-	Lack of irrigation, middle man problem in cassava, yield decrease in cassava	-	-

Figure 5. Agro-ecosystem transect of Thengottupatti village, Kolli Hills, Tamil Nadu, India.

higher than the other parameters, and it was observed that more than 80% of the consumers expressed their satisfaction over the product (**Table 17**). However, a relatively lower proportion (56%) had an inclination to purchase the product.

Table 17. Distribution of consumers for acceptance/satisfaction (%) and purchase orientation in consumer testing of value-added products (cassava semolina and cassava porridge).

Parameter	Semolina			Porridge		
	Acceptance/ satisfaction	MS*	Rank	Acceptance/ satisfaction	MS	Rank
1. Color	89.04	3.98	1	84.21	4.05	2
2. Taste	72.73	3.78	4	84.21	3.73	5
3. Aroma	49.09	3.47	5	78.17	3.80	4
4. Consistency	86.45	3.94	2	72.53	3.58	7
5. Ease in cooking	81.82	3.90	3	100.00	4.47	1
6. Fuel consumption	10.91	3.05	7	51.12	3.63	6
7. Comparative assessment	50.90	3.27	6	76.38	3.92	3
Overall satisfaction	54.55	3.43	-	82.97	3.89	-
Purchase orientation	52.73	2.41	-	56.00	3.25	-

*MS = Mean Score

Source: *Anantharaman and Balagopalan, 1996.*

Pre- and Post-harvest Small Equipment

1. Hand-operated chipping machine

The machine was field tested in five villages in Kerala and Tamil Nadu where cassava roots are converted to chips. Evaluation of the machine was done by keeping the machine in each village to allow the users to operate it. Responses were collected on 17 characters categorized under four factors, namely, operation, productivity, cost and maintenance (Nanda, 1987). The machine was well received by the farmers with an average rate of adaptability of 81.2%. The characters found favorable to acceptance were overall skill required for operation, convenience in loading, operating cost and method of removal and refitting of blades, whereas the characters initial cost, broken produce and inclination to purchase were deemed unfavorable. It may be noted that this technology, although a mechanical contrivance, was kept simple to transfer and easy to manage.

2. Pedal-operated chipping machine

The machine was assessed in six villages in Kerala and Tamil Nadu, by using a structured interview schedule with a five-point rating scale for 30 characters (Sheriff and Kurup, 1997). The field-testing indicated that the items favorable were convenience in loading, thickness, shape and uniformity of chips and trimming facility. The characters which were not favored by the farmers were initial cost, broken produce and inclination to purchase.

3. Cassava harvesting tool

The harvesting tool was field evaluated in six villages in Kerala and Tamil Nadu with a five-point rating scale for 20 characters. The results showed that the characters appropriateness to socio-economic status and superiority over traditional pulling were highly correlated with overall performance, farmers' liking and willingness to purchase (Sheriff and Kurup, 1997). Effort in lifting the tool, breakdown of the tool and cost of purchase were negatively associated with willingness to purchase. The mean values of quality of the roots and quantity left in the soil were rated favorable for the harvester.

TECHNOLOGY TRANSFER

TOT is a process by which viable technologies developed and perfected at research institutes are transmitted to the farming community and other users through strategic programs and appropriate methods. CTCRI has taken the lead in formulating and implementing TOT strategies for cassava in India. The TOT model followed by CTCRI is depicted in **Figure 6**. CTCRI transfers technologies directly to the user system through on-farm research mainly on cassava varieties, field-oriented outreach programs, and by various extension methods, such as training, exhibitions, demonstrations, etc., and indirectly through close liaison with the Departments of Agriculture/Horticulture of various states, and with NGOs. The linkage with the various departments and NGOs are through training programs organized for extension personnel, seminars, workshops and seed multiplication programs. The department in turn transfers the technologies through training programs for the farmers, demonstrations, mass media, etc. to the user system.

Outreach Programs of CTCRI

CTCRI has adopted various field-oriented outreach programs to transfer cassava technologies (**Table 18**).

1. National demonstrations (ND)

National demonstration (ND) on cassava was the pioneering attempt to transfer cassava technologies on a specific program basis during the early seventies (1970-74). The main concept under ND was unless scientists demonstrate the technologies in the farmers' fields their advice may not be accepted by the farmers. Also, the demonstration plot should be sufficiently large so that the feasibility of raising a good crop can be strikingly and unquestionably demonstrated. In total, 27 NDs were conducted on 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 demonstrations have convinced farmers that high-yielding cassava varieties were able to produce as much as 40 t/ha. As a result of the proven potentialities, there was a great demand for planting material, especially in Tamil Nadu. A beginning on the dissemination of high-yielding cassava varieties was made due to ND.

2. Operational research projects (ORP)

This program was in operation during 1976-1980 in a village called Vattiyoorkavu in Thiruvananthapuram district of Kerala. The main theme of the program was to

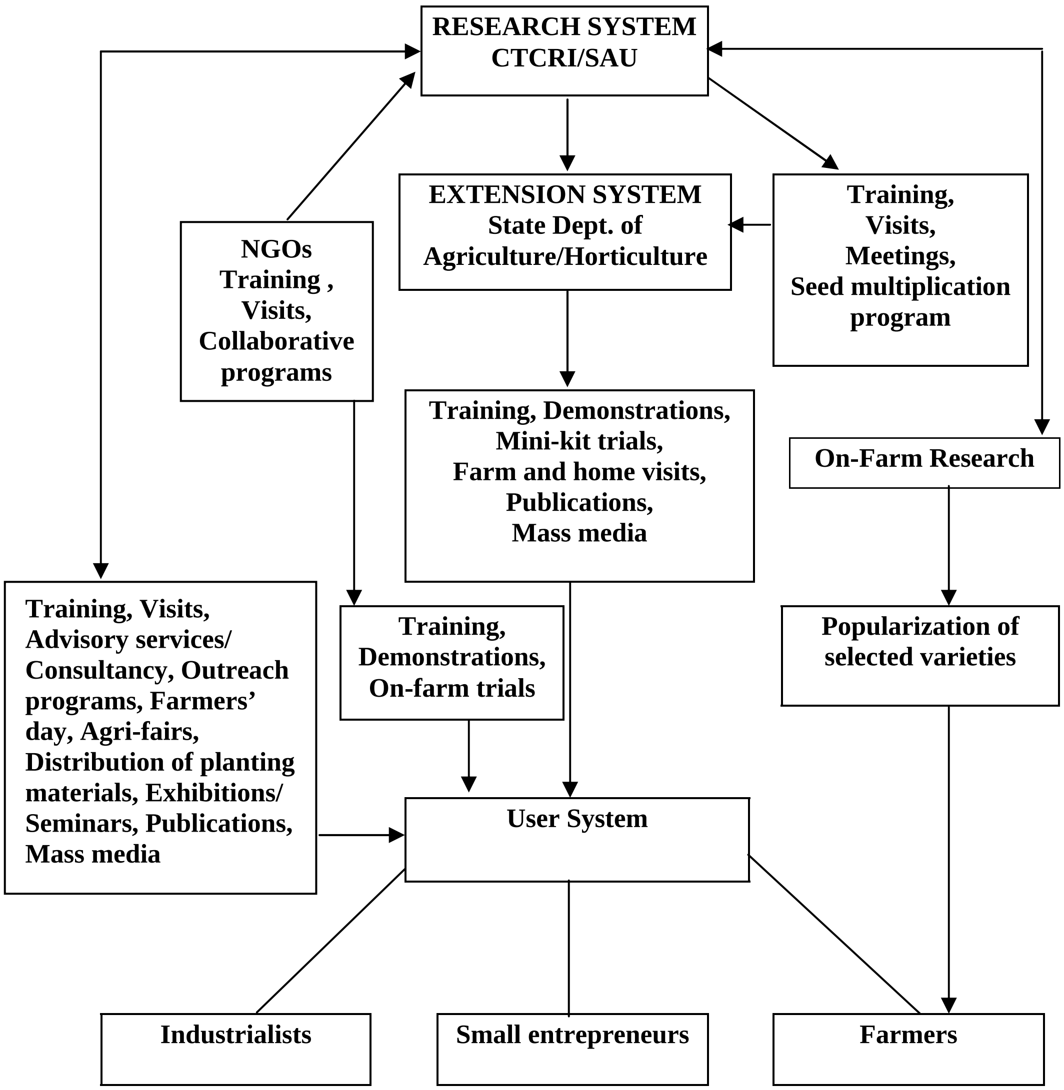


Figure 6. Technology transfer system for cassava in India.

Table 18. Types of outreach programs in India since 1970.

1.	National Demonstrations	1970-1974
2.	Operational Research Project	1976-1981
3.	Lab to Land Program	1978-1996
4.	Institution-Village Linkage Program	since 1996
5.	Testing and popularization of cassava varieties in Tamil Nadu	since 1998

demonstrate the proven technology, and concurrently to study the constraints in adoption. The major technologies promoted in ORP were: 1) two high-yielding cassava varieties, H-2304 and H-1687, together with improved management, and 2) cassava mosaic disease (CMD) eradication. In total, 268 demonstrations were laid out in the selected village. Eradication of CMD in an area of 200 ha was achieved through method demonstration and campaigns. The experience on the ORP revealed that the root quality of introduced cultivars was not comparable to that of landraces, there was poor market demand for high-yielding cassava varieties, and that farmers were reluctant to adopt recommended practices in view of the required additional expenditure.

3. Lab-to-land program (LLP)

The lab-to-land program (LLP) is a massive TOT program initiated by the Indian Council of Agricultural Research (ICAR) targeting small and marginal farmers for socio-economic upliftment. The program emphasized direct participation of a multidisciplinary team of scientists and a multi-mix extension approach. The technologies transferred with respect to cassava were: 1) high-yielding cassava varieties, i.e. H-226, H-2304 and H-1687; 2) improved methods of cultivation; and 3) intercropping cassava with groundnut and cowpea. The CTCRI LLP has passed through eight phases from 1978 till 1996, during which sixteen villages from three states, i.e. Kerala, Tamil Nadu and Orissa, were adopted, benefiting directly more than 1700 families (**Table 19**).

Table 19. Lab-to-Land Program on cassava. (1978-1996)

State	No. of villages covered	No. of beneficiaries
Kerala	12	1600
Tamil Nadu	4	165
Orissa	1	25

Source: *Balagopalan and Anantharaman, 1995.*

An impact study conducted clearly indicates that the technologies introduced could double farmer income from high-yielding cassava varieties, apart from additional income from the intercrop (Balagopalan and Anantharaman, 1995). The adoption behavior of the beneficiary farmers significantly improved due to the program, especially for high-yielding cassava varieties and fertilizer adoption (Anantharaman *et al*., 1993). The impact of the program was also felt in the spread of technologies to non-beneficiaries.

4. Institution-village linkage program (IVLP)

Over the years, TOT has focused on those technologies which have been standardized based on the criterion of increasing productivity. Initially, non-adoption of technologies by resource-poor farmers was attributed to inadequate support systems like extension, and then attributed to attitudinal constraints. This perception is largely the product of the basic assumption that technologies are good and are resource- and scale-neutral. This perception is untrue as is evident from the failure of technologies in many complex, diverse and risk-prone (CDR) systems. This has led to the thinking that technologies must be evaluated in terms of both its technical performance under the environmental conditions prevailing on small farms and also in conformity to the goals and socio-economic organization of a small-farm production system. A more holistic approach through the process of diagnosis of problems, identification of technologies based on farmers' knowledge and from the research institute system, and assessment of these identified technologies for suiting various production systems of a social system is envisaged in IVLP. The operation of IVLP has the following steps: 1) selection of the operation area; 2) forming a multidisciplinary team; 3) characterizing 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.

The IVLP includes as many as six production systems. In the cassava production system, three types of interventions have been made, namely, on-farm trials on new high-yielding cassava varieties, on nutrient management in cassava, and on intercropping in cassava. The treatments and replication parameters for assessment, and the results of each intervention are presented in **Table 20**.

5. Testing and popularizing of cassava varieties in Tamil Nadu

Tamil Nadu, known for its irrigated cassava production system, high cassava yields and cassava-based starch factories, is the largest producer of cassava in India, although it ranks second in area. H-226 and H-165 have been the predominant varieties for two decades. There has been a long-pending agenda of identifying new high-yielding cassava varieties and popularizing them. With this concept in mind, cassava varietal evaluation was undertaken in an irrigated production system. The varieties were evaluated by district, and the results are given in **Table 21**. It was observed that varieties seldom exhibited consistency in yield: some of the varieties (TCH-1 and TCH-3) had poor establishment and growth, while CI-649 and CI-731 were susceptible to CMD. The trials are being continued for a second year for confirmation. From the experience on yield variability among varieties, it was concluded that instead of trying only a few new varieties which had been evaluated and released elsewhere, it is better to evaluate a large number of varieties of both released and non-released status to select for varieties appropriate for the test region.

Table 20. Institution-village linkage program implemented in an upland cassava-based production system in Chengal village, Thiruvanthapuram district, Kerala.

Technology intervention	Variety	Yield (t/ha)	Parameter	Result
1. On-farm trials on new high-yielding cassava varieties(6 replications)	M-4	24.96	Root number	TCH-1 and TCH-2 were accepted due to high yield and good culinary characters
	Sree Visakham	25.92	Root weight	
	Sree Jaya	26.09	Cooking quality	
	Sree Vijaya	28.25	Taste	
	TCH-1	46.74	Incidence of CMD	
	TCH-2	45.92	Marketability	
	TCH-3	29.63		
	TCH-4	39.20		
	Local	24.44		
2. On-field trials on nutrient management (10 replications)	1. Farmers practice 40 N: 40 P_2O_5: 40 K_2O (kg/ha)	25.50	Yield Incidence of CMD	VAM[1)] increased yield slightly, and could replace 25 kg of P_2O_5
	2. Recommended practice 100 N: 50 P_2O_5: 100 K_2O (kg/ha)	30.20		
	3. VAM* + 100 N: 25 P_2O_5: 100 K_2O (kg/ha)	32.80		
3. Intercropping in cassava	Peanut varieties:		Yield	Peanut variety JL-24 found to be suitable as an intercrop. Crop loss of cowpea due to mosaic.
	TMV-2	0.650	Pest and disease incidence	
	JL-24	0.827		
	Cowpea, variety C-252	0.300	Marketability	

[1)] VAM = mycorrhizal inoculation

Source: *CTCRI, 1999.*

Table 21. Cassava fresh root yields (t/ha) from the testing and popularizing of cassava varieties in on-farm trials in various districts of Tamil Nadu, India, in 1999/2000.

Variety	District				
	Salem*		Namakkal*	Erode*	Tirunelveli**
	Village-1	Village-2			
H-97	24.0	40.9	33.4	15.0	26.7
H-165	31.0	37.5	37.0	29.5	34.0
H-226	28.0	48.3	29.7	20.8	-
H-2304	41.0	44.0	14.8	27.7	17.0
CI-649	27.7	40.0	39.5	8.6	17.0
CI-731	20.0	44.0	26.0	32.0	34.0
TCH-1	-	29	-	6.9	-
TCH-2	-	37	-	24.3	-
TCH-3	-	40.9	-	8.6	-
TCH-4	-	33.4	-	29.5	-
H-1687	-	-	-	-	19.0
S-856	-	-	-	-	37.0
M-4	-	-	-	-	29.7
Local	H-226 Popular variety	H-226 Popular variety	H-165 Popular variety	Mulluvadi 35.0	Narukku 19.3

* irrigated ** rainfed

Observations:
1. Varieties do not exhibit stability in yield over locations
2. TCH varieties have generally poor growth/establishment
3. CI-649 and CI-731 showed CMD infection.

Source: *Edison et al., 2000.*

Consultancy

CTCRI offers consultancies to large-scale farmers and entrepreneurs, thereby transferring both production and processing technologies. Project UPTECH is one by which CTCRI gives consultancy on a contract basis.

1. Project UPTECH

Project UPTECH, set up by the State Bank of India in 1988, is an extension of the management of consultancy services for supporting a client's efforts in modernization. Its mission is to catalyze technology upgrading in selected industries, following a cluster of industries approach. UPTECH, for the first time, has entered into the improvement of agriculture and processing of resultant produce, by selecting cassava as the crop and cassava-based sago industries in Samalkot of the East Godavari district in Andhra Pradesh. Through a memorandum of understanding, CTCRI offers technical support on production and processing by providing consultancies since 1998.

CTCRI transfers technology by providing consultancies on:

- refinement of agro-techniques to improve yield and quality,
- evaluation of high-starch medium-duration genotypes,
- preservation of planting materials,
- soil fertility management, and
- modernization of sago industries to increase starch recovery and quality, and to reduce the cost of production,

CTCRI also participates in training courses, seminars, exhibitions and farmers' days organized under UPTECH.

2. Training programs and other TOT activities

Apart from outreach programs, cassava technologies are transferred by organizing training programs for extension personnel, farmers and students. Other TOT activities undertaken by CTCRI are participation in mass media, both electronic and print, exhibitions, popular articles, video production and presentation, and distribution of planting materials.

CONCLUSIONS

FPR, which had a humble beginning in the form of pilot projects by international research institutes, has taken up the magnitude of a movement in many national agricultural research systems, especially for privileged crops. Cassava also needs to be addressed in the form of an intensified UPR. The relevancy of UPR is felt more in cassava, in view of the gravity of micro-niche influences. While FPR has been attempted on a extensive scale, care needs to be given to the main concept of FPR and its procedures, without much dilution, to encourage the participation of users in a real sense. In view of the high variability observed in cassava, the area of on-farm trials has to be large, but then this faces problems of resources in terms of planting material availability and limited land holding of cassava farmers. It may be necessary to develop suitable farmer-friendly field designs, especially for hill agriculture systems. UPR is mostly attempted in the area of varietal evaluation in India, and the time is ripe to intensify FPR in production practices with special reference to soil conservation, nutrient and water management and cropping systems. Cassava is cultivated in a wide range of production systems, and by different categories of farmers. This calls for documentation of farmer practices by region, production system and farmer category. Hitherto, UPR in the case of processed product development and transfer has been passive. UPR methodology for processed products demands a different approach from that of production. Action research is more wanting in this aspect. The low priority of cassava in policy making, as well as inadequate extension programs and information systems, have been the weaknesses of cassava TOT. Linkage and coordination with state development departments need to be strengthened. Development of an appropriate information system also becomes the need of the hour for effective TOT.

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THE USE OF FARMER PARTICIPATORY RESEARCH (FPR) IN THE NIPPON FOUNDATION PROJECT: IMPROVING THE SUSTAINABILITY OF CASSAVA-BASED CROPPING SYSTEMS IN ASIA

Reinhardt H. Howeler[1]

ABSTRACT

The Nippon Foundation Project entitled "Enhancing the Sustainability of Cassava-based Cropping Systems in Asia" started in 1994 and has as its main objective to develop, together with farmers, crop/soil management practices that will increase yields and farm income while also protecting the soil and water resources from degradation. To attain this objective a farmer participatory research (FPR) methodology was developed that will help diagnose the principal problems in the farm community, make farmers aware of the extent and importance of soil erosion and fertility degradation, test various ways to overcome these problems, and after selecting the most suitable practices to enhance adoption and dissemination of those practices to other farmers and other communities.

The project was implemented by CIAT in collaboration with research and extension organizations in China, Indonesia, Thailand and Vietnam. In each country, "FPR teams" were formed and in mid-1994 an FPR training course was held in Rayong, Thailand, to familiarize team members with the FPR approach and discuss and develop a suitable methodology. The principle behind the approach is to encourage farmers to diagnose their own problems, consider various possible solutions and test those ideas on their own fields, in order to select the best ones for adoption. The basic steps of the FPR methodology used in the four countries included:

1. Select 2-3 pilot sites (villages or subdistricts) where cassava is an important crop and erosion is a serious problem.
2. Show farmers a wide range of options to reduce erosion and soil degradation in demonstration plots with many treatments, and let farmers discuss, score and then select the most suitable options.
3. Help farmers test the selected options on their own fields; the options tested usually involved new varieties, intercropping systems, fertilization practices and methods to control erosion.
4. Together with farmers harvest the trials, evaluate the results, select the best treatments, to be either tested again in the following year or tried on small areas of their production fields.
5. Encourage adoption and dissemination of the best practices.

During the first phase of the project (1994-1998), about 76 FPR trials were conducted in Thailand, 216 in Vietnam, 77 in China and 101 in Indonesia. In addition, some farmers in Vietnam started testing new varieties completely on their own. After 2-3 years of testing and evaluating, many of the participating farmers started adopting some of the most promising practices on larger areas of their fields. Besides planting new varieties and using improved fertilization practices, many farmers adopted some form of erosion control practices: in Thailand and China mainly contour hedgerows of vetiver grass or sugarcane, in Vietnam mainly hedgerows of *Tephrosia candida* or vetiver grass combined with intercropping with peanuts, and in Indonesia mainly contour ridging (Malang) and hedgerows of *Gliricidia sepium* or *Leucaena leucocephala* (Blitar).

The paper also describes some valuable lessons learned during the implementation of the project and concludes that farmer participation in technology development, especially in the case of soil conservation, is absolutely essential for attaining widespread adoption of these technologies.

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INTRODUCTION

In Asia most cassava is grown on rather acid and very infertile Ultisols (55%), followed by slightly more fertile Inceptisols (18%) and Alfisols (11%) (Howeler, 1992). Most of these soils have a sandy or sandy loam texture - especially in Thailand, Vietnam and on Sumatra island of Indonesia - and have an undulating topography. Cassava soils in southern China and on Java island of Indonesia tend to have a heavier texture, but are located on steeper slopes.

Farmers know that if they grow cassava for many years on the same land without application of fertilizers or manures, their yields will decrease and the soil may become so degraded that no other crops will grow. This is not because cassava extracts excessive amounts of nutrients from the soil; if only roots are harvested and removed from the field, nutrient removal by cassava is actually less than that of most other crops, with a possible exception of K (Howeler, 2001). However, soils can seriously degrade due to erosion. When cassava is grown on slopes, especially in light-textured and low organic matter (OM) soils, erosion can be a serious problem due to the wide plant spacing used and the slow initial growth of the crop (Quintiliano *et al*., 1961; Margolis and Campo Filho, 1981; Puthacharoen *et al*., 1998).

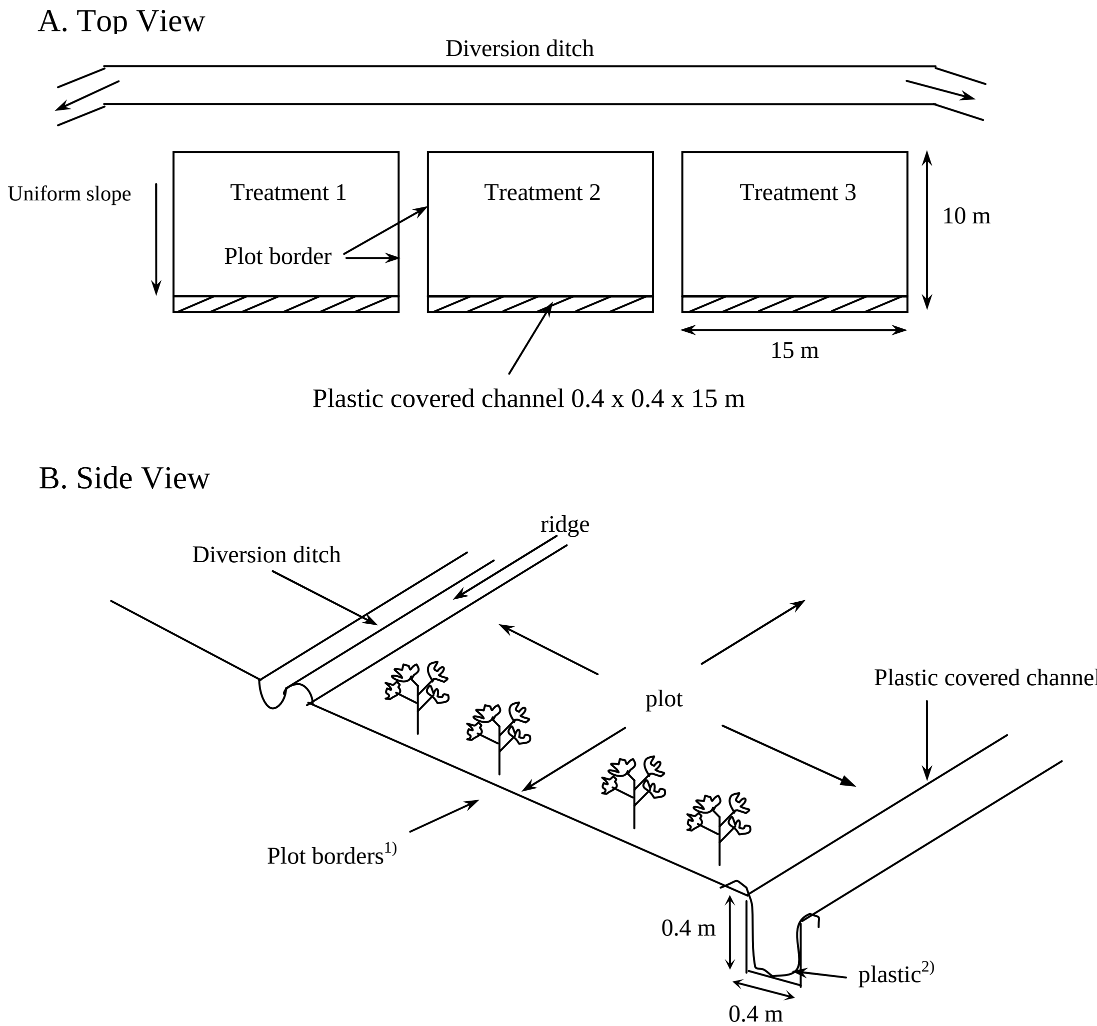
Research on erosion control practices has shown that soil losses due to erosion can be markedly reduced by simple agronomic practices combined with soil conservation practices. This includes agronomic practices such as minimum or zero tillage, mulching, contour ridging, intercropping, fertilizer and/or manure application, and planting at higher density; and soil conservation practices such as terracing, hillside ditches and planting contour hedgerows of grasses or legumes. But these practices are seldom adopted by farmers because they were not appropriate for the specific circumstances of the farmers, either from an agronomic or socio-economic standpoint (Ashby, 1985; Barbier, 1990; Fujisaka, 1991; Napier *et al*., 1991).

CIAT has developed a simple methodology for measuring the effect of soil/crop management treatments on erosion, using plastic-covered ditches dug along the lower edge of each plot to trap eroded sediments (**Figure 1**); this allows research on erosion control to be carried out on-farm. Using this simplified methodology, many soil/crop management and erosion control practices can be compared in terms of yield, gross and net income, as well as soil losses due to erosion. This allows farmers to be directly involved in the development and dissemination of more sustainable practices; the practices selected by farmers are likely to be effective in controlling erosion and appropriate for the local conditions, and also provide substantial short-term economic benefits. It was decided to use a farmer participatory approach in seeking solutions, and to enhance the dissemination and adoption of these practices.

A. FARMER PARTICIPATORY RESEARCH (FPR)

Methodology and Principal Activities

An outstanding feature of farmer participatory research (FPR), which sets it apart from "on-farm" research, is that farmers themselves make all major decisions. They evaluate and select the most appropriate technology options available, select treatments in the trials, evaluate the results and decide what practices, if any, to adopt. The researchers and extensionists merely facilitate the decision making process and provide new technological options as well as materials, such as seeds or planting material of new varieties or crops etc. This bottom-up



[1]Plot border of sheet metal, wood or soil ridge to prevent water, entering or leaving plots.
[2]polyethylene or PVC plastic sheet with small holes in bottom to catch eroded soil sediments but allow run-off water to seep away, Sediments are collected and weighed once a month.

Figure 1. Experimental lay-out of simple trials to determine the effect of soil/crop management practices on soil erosion.

approach is completely different from the traditional top-down approach used by most research and extension organizations; some initial persuasion and much hands-on experience is necessary for people to feel comfortable with this new approach.

The project was initiated in early 1994 by contacting potential collaborating institutions in the four countries participating in the project, i.e. Thailand, Indonesia, China and Vietnam. Participating institutions are shown in **Table 1**. They usually include a research institute or university involved in cassava research as well as an extension organization. Within the collaborating institutes the most suitable persons were identified, ideally including agronomists/soil scientists knowledgeable about cassava, as well as socio-economists. These formed the "FPR teams" in each of the four countries.

Table 1. Institutions collaborating with CIAT in the first phase of the Nippon Foundation Project on Improving Agricultural Sustainability in Asia, 1994-1998.

Country/Province	Institution	FPR project	Research
China-Hainan	Chinese Acad. Tropical Agric. Sciences (CATAS)	✓	✓
China-Guangxi	Guangxi Subtropical Crops Research Institute (GSCRI)		✓
China-Guangdong	Upland Crops Research Institute (UCRI)		✓
Indonesia-E.Java	Brawijaya University (UNIBRAW)	✓	✓
Indonesia-E.Java	Research Institute for Legumes and Tuber Crops (RILET)	✓	✓
Indonesia-W.Java	Central Research Institute for Food Crops (CRIFC)		✓
Philippines-Leyte	Phil. Root Crops Research and Training Center (PRCRTC)		✓
Philippines-Bohol	Bohol Experiment Station (BES)		✓
Thailand-Rayong	Field Crops Research Institute (FCRI) of Dept. of Agriculture	✓	✓
Thailand-Bangkok	Field Crops Promotion Division of Dept. Agric. Extension	✓	
Thailand-Korat	Thai Tapioca Development Institute	✓	
Thailand-Bangkok	Kasetsart University		✓
Vietnam-Thai Nguyen	Agro-Forestry College of Thai Nguyen University	✓	✓
Vietnam-Hanoi	National Inst. for Soils and Fertilizers (NISF)	✓	
Vietnam-Ho Chi Minh	Institute of Agric. Sciences (IAS)		✓

In June 1994 a one-week Workshop was held in Thailand to acquaint the FPR team members of the four countries with the objectives and principles of FPR, and train them in the use of FPR methodologies, including various surveying techniques, such as Rapid Rural Appraisal (RRA) and formal socio-agronomic surveys. After discussing the general methodology proposed for the project, each team worked out and presented a specific workplan for implementing the project in their country.

To implement the FPR component of the project a relatively standardized methodology was used, but modifications could be made to adapt to local institutional arrangements and socio-economic conditions. The general proposed methodology included the following steps:

1. Establishment of demonstration plots which compare a wide range (usually 15-25) of management options to increase cassava yields (or income) and reduce erosion. The plots were established on a uniform slope and a plastic-covered channel below each plot allowed the collection of eroded sediments, in order to measure the effect of each treatment on soil erosion (**Figure 1**).
2. The conducting of Rapid Rural Appraisals (RRAs) in preselected pilot sites to obtain basic information about soil, climate, topography, cropping systems, cultural practices and socio-economic conditions in each site, in order to select the most suitable pilot sites for the project. In each country, at least two pilot sites were selected for the FPR project, based on the criteria that cassava is an important crop in the area, cassava is grown on slopes, erosion is a serious problem and is as such perceived by the farmers. The principal characteristics of the selected pilot sites in the four countries are shown in **Table 2**, and one example of a more detailed RRA conducted in Vietnam is shown in **Table 3**. **Figure 2** shows the location of the selected pilot sites.
3. The organization of farmers' field days to explain the objectives and activities of the project to farmers of the selected pilot sites, and to visit and discuss with these farmers the demonstration plots. In the demonstration field, farmers are asked to score the various treatments in terms of their general usefulness. After a discussion of the *pros* and *cons* of each treatment, farmers select those treatments that they think are most useful for their own particular conditions. The field day may also include training, to familiarize farmers with the newest cassava varieties and production practices.
4. A meeting at each pilot site between farmers and FPR team members, to further diagnose the farmers' production problems, to decide on the type of FPR experiments to be conducted, the treatments to be included, and who will do what and when. In general, farmers volunteer to participate in the project, but if too many farmers volunteer, some form of selection of participating farmers is used. While the project focuses on management practices to control erosion by conducting FPR erosion control trials, farmers may also want to conduct trials on new varieties, as well as on fertilization and intercropping practices. These latter trials are usually done by farmers having mainly flat land.
5. Farmers conduct FPR trials on their own fields. FPR team members and local extension agents provide the basic planting materials and help farmers to select the most suitable sites for the trials, set out contour lines and plot borders, plant cassava and establish the selected treatments. Farmers manage the trials on their own fields. FPR team members visit the trials several times during the cropping cycle to make observations or take data (such as the harvest of intercrops or the weighing of eroded sediments) and to discuss the progress or problems with the farmers.

At time of cassava harvest the FPR team members and farmers together harvest the trials, determine cassava root yield, intercrop yields, and erosion losses. These data are quickly tabulated and presented to the farmers. The results are discussed and evaluated, and farmers indicate which treatments they prefer and for what reason.

6. The best treatments or other alternative treatments are tested again in similar FPR trials during the next and following crop years in a reiterative process of testing, evaluating, selecting and adapting, in order to develop the best practices for the farmer's particular bio-physical and socio-economic conditions.

Table 2. Characteristics of eight pilot sites for the Farmer Participatory Research (FPR) trials in Asia in 1994/95.

	Thailand		Vietnam			China	Indonesia	
	Soeng Saang	Wang Nam Yen	Pho Yen	Thanh Ba	Luong Son	Kongba	Malang	Blitar
Mean temp. (^{o}C)	26-28	26-28	16-29	25-28	16-29	17-27	25-27	25-27
Rainfall (mm)	950	1400	2000	~1800	~1700	~1800	>2000	~1500
Rainy season	Apr-Oct	Apr-Nov	Apr-Oct	Apr-Nov	May-Oct	May-Oct	Oct-Aug	Oct-June
Slope (%)	5-10	10-20	3-10	30-40	10-40	10-30	20-30	10-30
Soil	± fertile loamy Paleustult	± fertile clayey Haplustult	infertile sandy loam Ultisol	very infertile clayey Ultisol	± fertile clayey Paleustult	± fertile sandycl.l. Paleudult	infertile clay loam Mollisol	infertile clay loam Alfisol
Main crops	cassava rice fruit trees	maize soybean cassava	rice sweet pot. maize	rice cassava tea	rice cassava taro	rubber cassava sugarcane	cassava maize rice	maize cassava rice
Cropping system[1)]	C monocrop	C monocrop	C monocrop	C monocrop	C+T	C monocrop	C+M	C+M
Cassava yield (t/ha)	17	17	10	4-6	15-20	20-21	12	11
Farm size (ha)	4-24	3-22	0.7-1.1	0.2-1.5	0.5-1.5	2.7-3.3	0.2-0.5	0.3-0.6
Cassava (ha/hh)	2.4-3.2	1.6-9.6	0.07-0.1	0.15-0.2	0.3-0.5	2.0-2.7	0.1-0.2	0.1-0.2

[1)] C = cassava, T = taro, M = maize

Table 3. Cropping systems, varieties and agronomic practices, as determined from RRAs conducted in four FPR pilot sites in Vietnam in 1996/97.

Province	Hoa Binh	Phu Tho	Thai Nguyen	
District	Luong Son	Thanh Ba	Pho Yen	
Village		Phuong Linh		
Hamlet	Dong Rang	Kieu Tung	Tien Phong	Dac Son
Cropping system[1)]				
-upland	tea C+T C monoculture peanut, maize	C monoculture C+P tea, peanut maize	C+P or C+B or 2 yr C rotated with 2 yr fallow sweet potato	C monocult. or C-P rotation or C-B, C-SP sweet potato
Varieties				
-rice	CR 203, hybrids from China	DT 10, DT 13, CR 203	DT 10, DT 13 CR 203	CR 203 DT 10, DT 13
-cassava	Vinh Phu, local	Vinh Phu, local	Vinh Phu Du, Canh Ng	Vinh Phu
Cassava practices				
-planting time	early March	early March	Feb/March	Feb/March
-harvest time	Nov/Dec	Nov/Dec	Nov/Dec	Nov/Dec
-plant spacing (cm)	100x80	80x80; 80x60	100x50	100x50
-planting method	horiz./inclined	horizontal	horiz./inclined	horizontal
-land preparation	buffalo/cattle	by hand/cattle	buffalo	buffalo
-weeding	2 times	2 times	2 times	2 times
-fertilization	basal	basal+side[2)]	basal+side[3)]	basal+side[4)]
-ridging	mounding	flat	flat	flat
-mulching	rice straw	peanut residues	peanut residues	peanut residues
-root chipping	hand chipper	knife	small grater	small grater
-drying	3-5 days	3-5 days	2-4 days	2-4 days
Fertilization				
-cassava				
-pig manure (t/ha)	5	5	3-5	8-11
-urea (kg/ha)	0	50-135	83	83-110
-SSP (18% P_2O_5) (kg/ha)	50-100	0	140	0-280
-KCl (kg/ha)	0	0	55	0-280
-rice				
-pig/buffalo manure (t/ha)	5	0	-	-
-urea (kg/ha)	120-150	80	-	-
Yield (t/ha)				
-cassava	11-12	8-15	8.5	8.7
-rice (per crop)	3.3-4.2	4.2	3.0-3.1	2.7-3.0
-taro	1.9-2.2	-	-	-
-sweet potato	-	-	8.0	3.3
-peanut	0.8-1.2	0.5-1.1	1.4	1.3
pigs (kg live weight/year)	100-120	-	-	-

1) C=cassava, P=peanut, B=black bean, T=taro, M=maize
C+P=cassava and peanut intercropped; C-P=cassava and peanut in rotation
2) urea at 2 MAP
3) urea when 5-10 cm tall; NPK+FYM when 20 cm tall
4) NPK when 30 cm tall; hill up

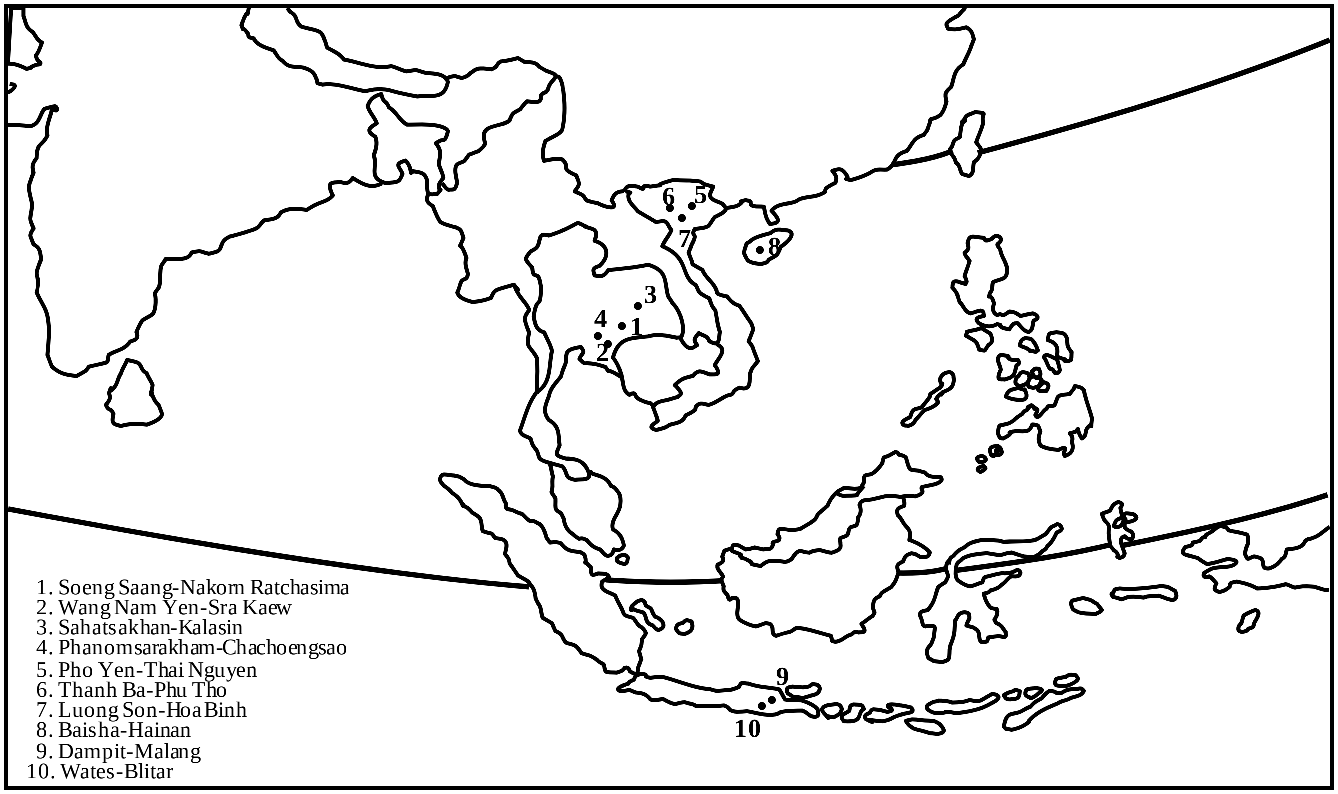


Figure 2. Location of pilot sites in the Nippon Foundation FPR project on Improving the Sustainability of Cassava-based Cropping Systems in Asia, 1994-1998.

7. Farmers make further adaptations, if necessary, and try out the best of the available options on small areas of their regular production fields
8. Neighboring farmers or those from neighboring villages are invited to participate in the field days, to visit the trials or to conduct their own trials. Once suitable technologies have been selected these may spead to neighbors who may also decide to adopt them.

By working directly with farmers, FPR team members learn about real farming conditions, about the farmers' selection criteria as well as the farmers' needs and limitations. When certain production problems arise, these are fed back to the research stations to conduct further adaptive or applied research (see below) to try to solve the problems. The conceptional model of this FPR methodology is shown in **Figure 3**.

In the subtropical regions of north Vietnam and southern China, cassava is generally planted in early spring (Feb-April); in the tropical regions of Thailand and Indonesia the crop is planted mainly at the beginning of the rainy season, which in Thailand is generally in March-May and in Indonesia in Oct-Nov. Thus, in Indonesia all activities tend to be about six months behind those in the other three countries, due to a different pattern of rainfall distribution. A schedule of the specific activities conducted in each country during the course of the 5-year project is shown in **Table 4**.

Table 5 shows the type and number of FPR trials conducted by farmers in the nine pilot sites in four countries during the four cropping cycles of the project. In Vietnam the number of trials increased over the years as more and more farmers wanted to participate in the project. In the other three countries the number of trials tended to decrease when farmers felt that they had tested adequately the available new technologies and started to adopt some selected soil erosion control practices in small "demonstration fields" of their regular production areas.

In Thailand, a new pilot site in Sahatsakhan district of Kalasin province was selected in 1997, demonstration plots were established and about 30 farmers initiated FPR trials on erosion control, varieties and fertilization practices in 1998. Farmers in a second new pilot site in Phanom Sarakham district of Chachoengsao province also started FPR trials in late 1998.

Results and Discussion

1. *Selection of Options from the Demonstration Plots*

When farmers visited the demonstration plots they were asked to score each treatment. After discussing the merits of the various treatments they selected 3-4 treatments that were considered most suitable for their own conditions. Various examples of results of these demonstration plots were reported by Nguyen The Dang *et al*. (1998; 2001), Vongkasem *et al*. (1998), Zhang Weite *et al*. (1998), Huang Jie *et al*. (2001) and Utomo *et al*. (1998; 2001). Farmers generally select those treatments that produce high cassava and/or intercrop yields, a high net income and low levels of erosion, and that fit well in their current production system. In Vietnam this included intercropping cassava with peanut and using either hedgerows of *Tephrosia candida* and vetiver grass or contour ridges to reduce erosion. In Indonesia, farmers generally preferred intercropping with maize and planting either elephant grass or *Gliricidia sepium* as contour hedgerows to reduce erosion and supply animal feed during the dry season.

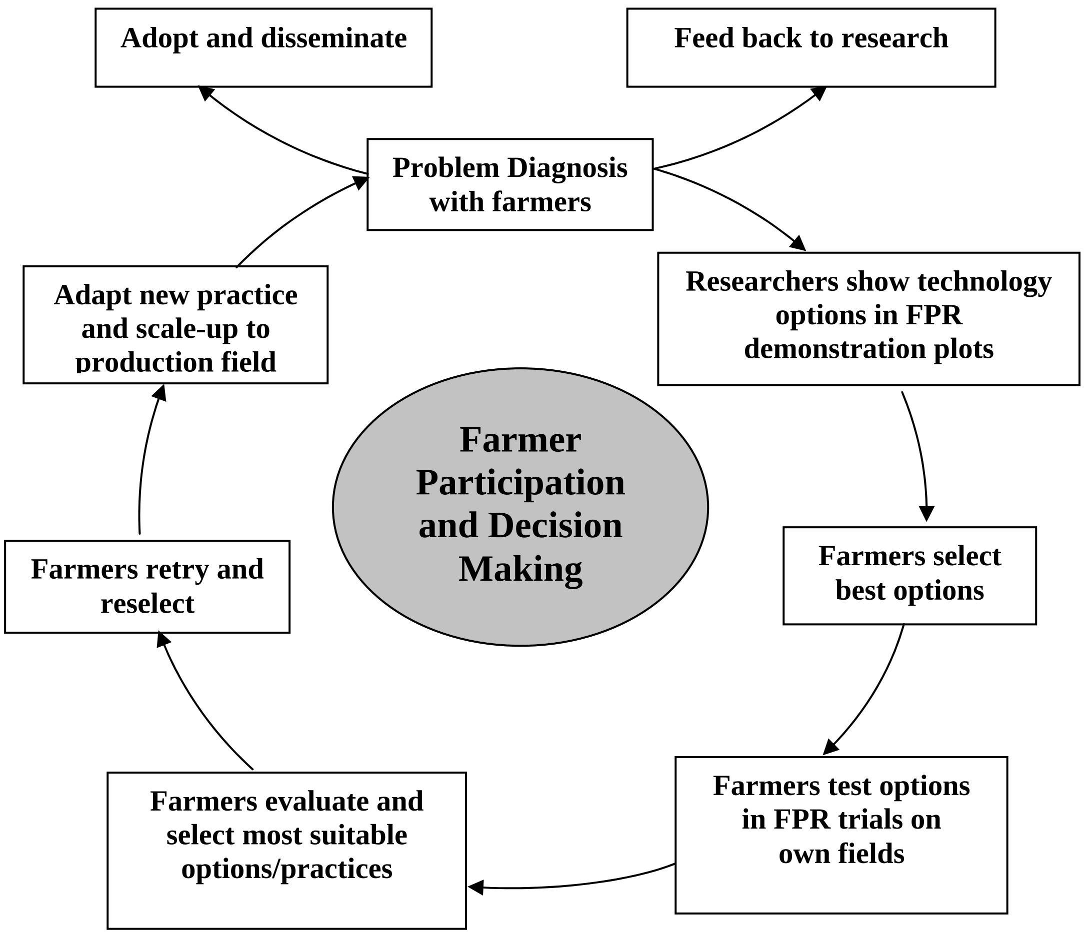


Figure 3. Farmer participatory model used for the development of sustainable cassava-based cropping systems in Asia.

Table 4. Schedule of activities in the Nippon Foundation Project in the four participating countries.

Activity	China	Indonesia	Thailand	Vietnam
Institutional arrangements	early'94	mid'94	early'94	early'94
FPR training workshop	July'94	July'94	July'94	July'94
Plant demonstration plots	March'94	Nov'94	Aug'94	Feb'94
RRA	Aug'94	Jan-May'95	Dec'94-Jan'95	Oct-Nov'94
Farmers' field day	Jan'95	March'95	Jan'95	Nov'94
Install FPR trials-1st cycle	May'95	Nov'95	April-May'95	Feb'95
Second farmers' field day	Oct'95	Sept'95	Aug-Sept'95	-
Third farmers' field day	Jan'96	July-Aug'96	Jan'96	Nov'95
Install FPR trials-2d cycle	April'96	Nov'96	April'96	Feb'96
5th Regional Cassava Workshop	Nov'96	Nov'96	Nov'96	Nov'96
Fourth farmers' field day	Jan'97	Aug'97	Feb'97	Dec'96
Install FPR trials-3d cycle	March'97	Oct'97	April'97	Feb'97
Training-of-Trainers in FPR	June'98	May'98	Sept'97	Sept'97
Fifth farmers' field day	Dec'97	Aug'98	Feb'98	Dec'97
Install FPR trials-4th cycle	March'98	Oct'98	April'98	Feb'98
Sixth farmers' field day	Dec'98	Aug'99	Febr'99	Dec'98
Project evaluation	← June-July 1998 →			
Final Project Report	← Oct 1998 →			

Table 6 shows the ranking of treatments by farmers in seven pilot sites in 1995. It is clear that farmers in different countries, and even within the same country, select very different options, depending on the local conditions and their traditional cropping patterns. Thus, in Thailand, where labor tends to be scarce, intercropping treatments are seldom preferred options, while in those parts of Indonesia where land is very scarce (Java), intercropping is a highly preferred option. Vetiver grass contour hedgerows were shown to be quite effective in reducing erosion in the demonstration plots in Thailand and Vietnam, and farmers from both pilot sites in these two countries selected this as one of the treatments they wanted to try on their own fields. In China, vetiver grass was initially not considered a preferred option, and in Indonesia this treatment was not included in the demonstration plots on the assumption that farmers would prefer hedgerows of a grass or legume species that can also be used as animal feed. When vetiver grass was later included as a treatment in either demonstration plots or FPR erosion control trials, farmers in both China and Indonesia considered it as a useful option that they wanted to test further in their FPR trials.

2. *Selection of Treatments for FPR Trials*

During the first year of FPR trials (1995) farmers generally selected some of the preferred options from the demonstration plots as treatments for their FPR erosion control trials. In some cases, however, farmers made their own adaptations. Thus, in one site in Thailand, farmers decided to try contour hedgerows of sugarcane instead of king grass that they had seen used in the demonstration plots, since the sugarcane stalks (for chewing) can be sold at the local market, while king grass is of little use to them.

Table 5. Types and number of Farmer Participatory Research (FPR) trials with cassava conducted in four countries in Asia from 1995 to 1998.

	Thailand		Vietnam			China		Indonesia	
Type of trial	Soeng Saang Nakorn Ratchasima	Wang Nam Yen Sra Kaew	Pho Yen Thai Nguyen	Thanh Ba Phu Tho	Luong Son Hoa Bin	Baisha Hainan	Tunchang Hainan	Dampit Malang	Wates Blitar
1995/96									
Erosion control	9	6	6	7	3	12	-	10	7
Varieties	5	7	6	-	1	15	-	-	8
Fertilization	5	-	4	-	1	10	-	-	-
Intercropping	-	-	8	-	-	-	-	-	
Total	**19**	**13**	**24**	**7**	**5**	**37**	**-**	**10**	**15**
1996/97									
Erosion control	8	7	5	7	3	4	1	10	9
Varieties	3	6	11	3	3	4	1	1	5
Fertilization	8	-	6	4	3	4	1	1	-
Intercropping	-	-	11	-	-	-	-	-	-
Total	**19**	**13**	**33**	**14**	**9**	**12**	**3**	**12**	**14**
1997/98									
Erosion control	2	1	5	7	3	4	-	5	6
Varieties	4	5	15	8	2	4	-	-	-
Fertilization	-	-	5	5	3	4	-	5	4
Intercropping	-	-	8	-	-	-	-	-	-
Total	***6***	***6***	***33***	***20***	***8***	***12***	***-***	***10***	***10***
1998/99									
Erosion control	-	-	5	7	3	5	-	10	-
Varieties	-	-	18	1	3	8	-	10	-
Fertilization	-	-	5	5	5	-	-	10	-
Intercropping	-	-	8	-	-	-	-	-	-
Total	***-***	***-***	***39***	***13***	***11***	***13***	***-***	***30***	***-***

Note: During 1997/98 and 1998/99 the number of FPR trials in Thailand decreased as farmers in the two pilot sites adopted some erosion control measures in large "demonstration fields" in their cassava production areas. In addition, a new pilot site was initiated in Sahatsakhan district of Kalasin province in 1997 and in Sanaam Chaikhet district of Chachoengsao province in 1998.

Table 6. Ranking of conservation farming practices selected from demonstration plots as most useful by cassava farmers from several pilot sites in Asia in 1995/96.

Practice	Thailand		Vietnam		China	Indonesia	
	Soeng Saang	Wang Nam Yen	Pho Yen	Thanh Hoa	Baisha	Blitar	Dampit
Farm yard manure (FYM)				2			
Medium NPK	5						
High NPK					2		
FYM+NPK				1			
Cassava residues incorporated			5				
Reduced tillage	4						
Contour ridging		2					
Up-and-down ridging					5		
Maize intercropping	2					1	1
Peanut intercropping		5			4		2
Mungbean intercropping					3		
Black bean intercrop+*Tephrosia* hedgerows			1	4			
Tephrosia green manure			3	5			
Tephrosia hedgerows			4				
Gliricidia sepium hedgerows						2	4
Vetiver grass barriers	1	1	2	3			
Brachiaria ruziziensis barriers	3	4					
Elephant grass barriers						3	3
Lemon grass barriers		3					
Stylosanthes barriers					1		

In the second and subsequent cycles of FPR trials, farmers selected those treatments that had shown promise and eliminated others that were found to be less useful, replacing these with other alternative options, either observed in the demonstration plots or adaptations from previously tried treatments.

While initially in some sites each farmer selected their own preferred treatments, it was found that it is better if farmers as a group decide on the 3-4 treatments to be tested (in comparison with their own "traditional practice"), so that average yields and erosion losses can be calculated for each treatment from data of several trials, and more definite conclusions can be drawn. In case of FPR variety trials, there was sometimes not enough planting material of each variety for each farmer, so different farmers compared 1-3 new but different varieties with their own traditional variety. This is an alternative way of screening and multiplying a large number of new materials, while the best materials can then be further tested with replication in subsequent years.

3. *Results of FPR Trials*

Tables 7 to **10** show examples of FPR trials conducted in 1997/98 on erosion control, varieties, intercropping and fertilization. After discussing the results of the trials during the farmers' field day at harvest time, farmers ranked or scored the treatments, indicating which they preferred most. In an FPR erosion control trial conducted in Kieu Tung village in Vietnam

(**Table 7**) the practice of intercropping cassava with peanut, applying a balanced fertilizer (both chemical fertilizers and pig manure) and growing hedgerows of vetiver grass was the most preferred option, as this treatment nearly doubled the net income and reduced to one third soil loss due to erosion, as compared to the traditional farmers' practice of planting cassava in monoculture and applying only animal manure. Farmers in this village indicated that the new erosion control practices they had developed through FPR trials not only increased their income, improved their soil (through incorporation of peanut residues and less soil and nutrient losses), but also saved them the hard work of having to dig the acid and infertile soil, eroded from surrounding uplands, out of their rice paddies every year.

Table 8 indicates that farmers in Kongba village on Hainan island of China clearly preferred the new variety SC8013, not only for its higher yield but also for its typhoon resistance.

Table 9 shows that in Pho Yen district of Vietnam intercropping with one row of peanut between cassava rows increased net income, and this practice has now been widely adopted by farmers. In the same site, the FPR fertilizer trials (**Table 10**) indicate that a balanced application of a moderate amount of pig manure with chemical fertilizers that are high in N and K could almost double the net come in comparison with farmers' traditional practices.

Table 11 summarizes the results of three years of FPR erosion control trials conducted in the various pilot sites in the four countries, comparing the best farmer-selected practice with the traditional farmers' practice. In most cases, the new practice selected by farmers markedly reduced soil losses due to erosion while also increasing the gross or net income.

4. *Adoption of Technologies*

After several years of testing new varieties and more sustainable management practices in their FPR trials, farmers in the pilot sites started to adopt some technology components they had tested in their production fields (**Table 12**). In general, farmers were most interested in the testing and multiplication of new varieties, and this was the first component to be adopted. In both pilot sites in Thailand new varieties have now completely replaced the traditional variety Rayong 1, while in Vietnam and China participating farmers have now largely replaced their traditional varieties, Vin Phu and SC205, respectively, with new higher yielding varieties. Adoption, however, has been much slower in Indonesia, since the new varieties were only marginally higher yielding than the local varieties, which are well adapted to ecological niches and have been selected over the years for local taste preferences.

FPR fertilizer trials generally showed that a balanced application of farmyard manure (FYM) and chemical fertilizers that are high in N and K but low in P produces the highest net income. The greater use of chemical fertilizer was readily adopted by participating farmers as long as these fertilizers are available at a reasonable cost.

Intercropping with peanut was readily adopted in Vietnam because it increased total net income, improved the soil, and reduced weeds and soil losses by erosion. Intercropping was less successful in China and Thailand, mainly because of drought or excessive rain, or due to rat damage of the intercropped peanut in China. In Indonesia, intercropping with maize, upland rice and various grain legumes is already a traditional practice, which could be further improved, however, by introducing higher yielding varieties of the intercrops.

Table 7. Effect of various crop management treatments on the yield of cassava and intercropped peanut, as well as the gross and net income and soil loss due to erosion in an FPR erosion control trial conducted by six farmers on about 40% slope in Kieu Tung village of Thanh Ba district, Phu Tho province, Vietnam in 1997.

Treatments[1)]	Dry soil loss (t/ha)	Yield (t/ha) cassava	Yield (t/ha) peanut	Gross income[2)] (mil.dong/ha)	Product. costs (mil.dong/ha)	Net income (mil.dong/ha)	Farmers' ranking
1. C monoculture, no fertilizers, no hedgerows (TP)	106.1	19.17	-	9.58	3.72	5.86	6
2. Cassava+peanut, no fertilizers, no hedgerows	103.9	13.08	0.70	10.04	5.13	4.91	5
3. C+P, with fertilizers, no hedgerows	64.8	19.23	0.97	14.47	5.95	8.52	-
4. C+P, with fertilizers, *Tephrosia* hedgerows	40.1	14.67	0.85	11.58	5.95	5.63	3
5. C+P, with fertilizers, pineapple hedgerows	32.2	19.39	0.97	14.55	5.95	8.60	2
6. C+P, with fertilizers, vetiver hedgerows	32.0	23.71	0.85	16.10	5.95	10.15	1
7. C monoculture, with fertilizers, *Tephrosia* hedgerows	32.5	23.33	-	11.66	4.54	7.12	4

[1)]Fertilizers=60 N+40 P_2O_5+120 K_2O; all plots received 10 t pig manure/ha
TP=farmer traditional practice
[2)]Prices: cassava: d 500/kg fresh roots
peanut: 5,000/kg dry pods
1US $ = approx. 13,000 dong

Table 8. Results of four FPR variety trials conducted by farmers in Kongba village, Baisha county, Hainan, China in 1997.

	<---Cassava yield (t/ha)---> A[1]	B	C	D	Av.	Farmers' preference[2]
SC 205	-	16.93	14.32	20.83	17.36	9
SC 8002	-	-	20.83	-	20.83	0
SC 8013	36.46	21.48	19.53	27.99	26.36	14
SC 8639	28.65	-	-	36.46	32.55	14
ZM 9036	-	15.62	-	-	15.62	0
ZM 9244	27.02	-	-	47.53	37.27	10
ZM 9247	-	23.44	-	26.04	24.74	13
ZM 9315	-	18.23	-	31.25	24.74	10
ZM 94107	19.53	19.53	-	33.85	24.30	0
OMR 33-10-4	26.69	18.23	20.83	-	21.92	5
OMR 34-11-3	25.06	16.93	18.23	28.65	22.22	4
OMR 35-70-7	29.95	-	-	29.30	29.62	13

[1] A = Mr. Lu Huan Cheng
B = Mr. Zhou Yong Ming
C = Mr. Tan Yin Chai
D = Mr. Fu Yong Quan
[2] Number of farmers liking variety (out of 14 farmers)

Table 9. Average results of ten FPR trials on planting arrangement in intercropping cassava with peanut conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam in 1997.

	Yield (t/ha)		Gross income[1]	Production costs[2]	Net income	Farmers' preference
	cassava	peanut	<----------(mil.dong/ha)		---------->	(%)
1. Farmer's practice[3]	20.87	0.64	13.64	3.82	9.82	10
2. Cassava+1 row of peanut[4]	27.23	0.32	15.22	3.34	11.88	55
3. Cassava+2 rows of peanut[5]	21.64	0.49	13.27	3.52	9.75	52
4. Cassava+3 rows of peanut[6]	19.02	0.58	12.41	3.70	8.71	0

[1]Prices: cassava: d 500/kg fresh roots
peanut: 5000/kg dry pods
peanut seed: 6000/kg dry pods
1 US $ = approx. 13,000 dong
[2]Peanut seed requirements: T_1=120, T_2=40, T_3=70, T_4=100 kg/ha
[3]Cassava on ridges spaced at 1.0-1.2m between ridges, peanut planted cross-wise on ridge in short rows, 0.6-0.8m between rows (to reduce excess moisture)
[4]Cassava at 1x0.6m; peanut between cassava rows at 0.1m between plants
[5]Cassava at 1x0.8m; 2 rows of peanut at 0.35x0.1m
[6]Cassava at 1.2x0.8m; 3 rows of peanut at 0.35x0.1m

Table 10. Average results of five FPR fertilizer trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen district, Thai Nguyen province, Vietnam in 1997.

Treatments	Cassava yield (t/ha)	Gross income[1)]	Fertilizer costs[1)]	Net income	Farmers' preference (%)
		<----------(mil. dong/ha)---------->			
1. Farmer's practice[2)]	18.50	9.25	3.31	5.94	0
2. 10 t/ha FYM+40N+40K_2O	19.87	9.44	2.43	7.01	32
3. 10 t/ha FYM+80N+40P_2O_5+80K_2O	22.37	11.19	3.10	8.09	64
4. 10 t/ha FYM+120N+40P_2O_5+120K_2O	28.00	14.00	3.54	10.46	61

[1)]Prices: cassava: d 500/kg fresh roots
pig manure: 200/kg
urea (45%N): 3000/kg
SSP (17%P_2O_5): 1000/kg
KCl (50%$K_2$0): 2600/kg
1 US $ = approx. 13,000 dong

[2)]Average farmer application: 12.8 t/ha of FYM+58 kg N+31 P_2O_5+34 K_2O/ha

Table 11. Effect of farmer selected soil conservation practices on dry soil loss and gross and net income as compared to the traditional farmers' practice in FPR trials conducted in eight pilot sites in Asia from 1995-1998.

FPR pilot sites	Year	No. of farmers	Dry soil loss(t/ha)	Income ($/ha)	
				Gross	Net
China - Hainan, Baisha, Kongba					
Farmers' practice (C monoculture)	1995	11	47	1220	-
Various intercropping/hedgerows			32	1391	-
Farmers' practice (C monoculture)	1996	4	125	371	-
C+peanut , vetiver hedgerows			89	736	-
Farmers' practice (C monoculture)	1997	4	114	523	-
C+peanut, vetiver hedgerows			60	941	-
Indonesia - E. Java, Malang, Dampit					
Farmer's practice (C monocult, up/down ridge, N)	94/95	D[1)]	72	578	545[2)]
C+maize, elephant grass hedgerows, NPK			48	1069	993[2)]
Farmer's practice (C monoculture, N)	95/96	D[1)]	145	317	155[4)]
C+maize, elephant grass hedgerows, NPK			134	346	37[4)]
Farmer's practice (C+maize, N)	96/97	9	8	615	-
C+maize, vetiver hedgerows, NPK			8	603	-
Indonesia - E. Java, Blitar, Ringinrejo					
Farmers' practice (C monoculture)	94/95	D[1)]	27	312	211[2)]
C+maize, *Gliricidia* hedgerows			28	588	509[2)]
Farmers' practice (C+maize)	95/96	D[1)]	28	307	157[4)]
C+maize, *Gliricidia* hedgerows			23	247	97[4)]
Farmers' practice (C+maize)	96/97	2	55	697	597[2)]
C+maize, *Gliricidia* hedgerows		2	57	40	641[2)]

Table 11. continued

FPR pilot sites	Year	No. of farmers	Dry soil loss(t/ha)	Income ($/ha) Gross	Net
Thailand - Nakorn Ratchasima, Soeng Saang					
Farmers' practice (up/down ridging)	95/96	9	25	1254	870[4)]
Vetiver hedgerows, no ridging			8	1480	1071[4)]
Farmers' practice (up/down ridging)	96/97	7	4	893	322[4)]
Vetiver hedgerows, no ridging			4	871	250[4)]
Farmers' practice (up/down ridging)	97/98	1	24	644	-
Vetiver hedgerows, no ridging			8	521	-
Thailand - Sra Kaew, Wang Nam Yen					
Farmers' practice (up/down ridging)	95/96	6	18	1378	948[4)]
Vetiver hedgerows, no ridging			15	1110	685[4)]
Farmers' practice (up/down ridging)	96/97	6	48	884	384[4)]
Vetiver hedgerows, no ridging			10	724	199[4)]
Farmers' practice (up/down ridging)	97/98	1	17	815	-
Vetiver hedgerows, no ridging			1	496	-
Vietnam - Thai Nguyen, Pho Yen					
Farmers' practice (C monoculture, no fertilizers)	1995	6	30	1024	753[3)]
C+peanut, vetiver hedgerows, NPK			19	1047	892[3)]
Farmers' practice (C monoculture, no fertilizers)	1996	5	8	629	424[3)]
C+peanut , *Tephrosia* hedge., contour ridg., NPK			5	815	606[3)]
Farmers' practice (C monoculture, no fertilizers)	1997	5	8	535	336[3)]
C+peanut, *Tephrosia* hedge., contour ridg., NPK			3	1041	817[3)]
Vietnam - Phu Tho, Thanh Ba, Kieu Tung					
Farmers' practice (C+peanut, no hedge., no fert.)	1995	6	54	1347	921[3)]
C+peanut, vetiver hedgerows, NPK			43	1653	1129[3)]
Farmers' practice (C monocult., no hedge., no fert.)	1996	6	28	695	459[3)]
C+peanut , vetiver hedgerows, NPK			25	1525	1187[3)]
Farmers' practice (C monocult., no hedge., no fert.)	1997	6	106	871	533[3)]
C+peanut, vetiver hedgerows, NPK			32	1464	923[3)]
Vietnam - Hoa Binh, Luong Son, Dong Rang					
Farmers' practice (C monocult., no hedge., no fert.)	1995	1	10	481	139[4)]
C+peanut, *Tephrosia* hedgerows, NPK			1	978	49[4)]
Farmers' practice (C+taro, no hedge., no fert.)	1996	3	43	635	568[2)]
C+peanut , vetiver hedgerows, NPK			2	1012	873[2)]
Farmers' practice (C+taro, no hedge., no fert.)	1997	1	3	522	20[4)]
C+peanut, *Tephrosia* hedgrows, NPK			0	698	99[4)]

[1)] D = demonstration plots
[2)] Gross income minus fertilizer and manure costs
[3)] Gross income minus all material costs
[4)] Gross income minus labor and material costs

Table 12. Technological components selected and adopted by participating farmers from their FPR trials conducted from 1994 to 1998 in four countries in Asia.

Technology	China	Indonesia	Thailand	Vietnam
Varieties	SC8013***[1)] SC8634* ZM9247* OMR35-70-7*	Faroka*** 15/10* OMM90-6-72*	Kasetsart 50*** Rayong 5*** Rayong 90**	KM60*** KM94* KM95-3*** SM1717-12*
Fertilizer practices	FYM 10 t/ha (TP)+ +chicken manure 300kg/ha*	15-5-20+Zn 90 N+36 P_2O_5+ 100 K_2O**	FYM 10 t/ha (T)+ 156 kg/ha***	15-15-15 80 N+40 P_2O_5+ 80 K_2O**
Intercropping	monoculture(TP) C+peanut*	C+maize(TP)	monoculture(TP) C+pumpkin* C+mungbean*	monoculture(TP) C+taro(TP) C+peanut***
Soil conservation barrier***	sugarcane barrier*** vetiver barrier*	*Gliricidia* barrier** *Leucaena* barrier* contour ridging**	vetiver barrier*** sugarcane barrier**	*Tephrosia* vetiver barrier* pineapple barrier*

[1)] * = some adoption
** = considerable adoption
*** = widespread adoption
TP = traditional practice; FYM=farm yard manure.

Adoption of soil conservation practices has been slower and not as widespread as that of the other three components. There are several reasons for this:

a. In some pilot sites, erosion was not perceived as a serious problem because slopes were not so steep, or much of the land was already terraced (Pho Yen district of Vietnam and Blitar district of Indonesia).

b. The various contour barriers used to control erosion require additional labor for planting and maintenance; they also occupy part of the land and may compete with neighboring crop plants, thus reducing crop yields. **Table 13** shows that when contour hedgerows of vetiver or sugarcane were planted for erosion control on 1 rai (1600 m^2) plots of farmers' production fields in Thailand, cassava yields were on average 18% lower than without these hedgerows, mainly due to the space occupied by the hedgerows (about 10%). By using sugarcane instead of vetiver as a hedgerow, the reduction of income from a lower cassava yield was offset by the additional income from the sale of sugarcane stalks (see Mrs. Champaa in **Table 13**). It is expected that in the second and subsequent years, the yield reduction will decrease due to improved soil fertility and water conservation as a result of the hedgerows. When contour hedgerows have secondary uses for the farmer, such as sugarcane, *Tephrosia candida* or elephant grass, or when hedgerows are combined with intercropping or better fertilization practices, the initial income reduction due to lower cassava yields can often be compensated by the additional income from the hedgerows, or from the associated soil/crop management practices, such as intercropping, fertilization, improved varieties etc. (see net income data for Vietnam in **Table 11**).

Table 13. Efect of contour hedgerows of vetiver and/or sugarcane on cassava yield and gross income when planted in production fields of 1600m^2 of five farmers in Soeng Saang and Wang Nam Yen districts in Thailand in 1997/98.

		Cassava yield (t/ha)		Gross income ('000B/ha)[1)]	
Farmer	Hedgerows species	With hedgerows	Without hedgerows	With hedgerows	Without hedgerows
Mrs. Naakaew[2)]	vetiver	25.72	31.31	38.58	46.96
Mrs. Champaa[2)]	sugarcane and vetiver	9.26	12.45	18.71	18.67
Mr. Sawing[3)]	vetiver	15.99	19.05	23.98	28.57
Mr. Somkhit[3)]	vetiver	16.39	21.66	24.58	32.49
Mr. Phuem[3)]	vetiver	23.81	26.25	35.71	39.37
Average		**18.23**	**22.14**	**28.31**	**33.21**

[1)] Prices: cassava: B 1.50/kg fresh roots
sugarcane: 3.0/stalk (for chewing)
[2)] In Soeng Saang district of Nakorn Ratchasima province.
[3)] In Wang Nam Yen district of Sra Kaew province.

c. In some cases contour hedgerows interfere with other production practices, such as mechanized land preparation, weed control or harvesting, which is more conveniently done in straight lines parallel to the longest side of the field. In Thailand, some contour hedgerows of vetiver planted by participating farmers were subsequently destroyed by tractor drivers contracted to do the land preparation. Also, curved contour lines prevent the planting of cassava in straight lines using tight strings as guides, as is often used in Thailand. These are practical problems farmers face when management practices that seem promising in small experimental plots are scaled up to production fields. This is one reason why some recommended practices are never adopted by farmers, and why farmer participation in technology development is essential for the development of truly useful and effective technologies that will be adopted.

d. Lack of planting material. Planting material of some hedgerow species, such as vetiver, are difficult to obtain and slow to multiply. Other species like *Tephrosia candida* can be planted from seed, but production of good quality seed is presently beyond the farmers' capacity as it requires regular spraying of insecticides.

5. *Farmers' Perception of FPR*

During the final evaluation of the project in June/July 1998, the evaluators often asked participating farmers what they had learned from the project, what they were doing differently now than before, and what aspects they appreciated most in the project. Farmers almost invariably expressed the following sentiments (Lynam and Ingram, 2001):

1. Farmers at all pilot sites expressed great appreciation for the project.
2. They particularly liked the close interaction with researchers and extensionists.
3. They liked being able to see the performance of new technologies on their own fields.
4. They particularly liked having access to planting material of new varieties, which they could test and multiply on their own fields.
5. They learned about the importance of a balanced fertilizer application, about improved fertilizer management through split applications, about the benefits of a wider plant

spacing that increases root size and permits intercropping, and they obtained new varieties of intercrops. They indicated that this had resulted in increases in their productivity and income.

6. They became more aware of the amounts of soil lost from their fields due to erosion by seeing the trapped sediments in the plastic-covered channels, and realized the importance of soil conservation. They learned that many management practices, such as intercropping, ridging, fertilization, hedgerows, and planting distance have an effect on erosion and can be optimized to enhance soil and water conservation and maintain high yields.
7. The lack of planting material of vetiver grass or seed of *Tephrosia candida* are the main obstacles to a wider adoption of these technologies (especially in Vietnam and China).
8. They would like to continue experimentation with new varieties, intercropping and fertilization practices, but need financial and technical assistance mainly with erosion control trials.

6. *Institutionalization of FPR*

As indicated before, farmer participation in technology development is a new concept in most research and extension organizations in Asia, and it took time and first-hand experience for people and institutions to feel comfortable with, and be convinced of the effectiveness of, this new approach. In fact, it was a learning experience for all involved.

Interest in, and acceptance of, the new approach varied between countries and between institutions. Probably most enthusiastic about this approach are the Departments of Agriculture (DOA) and Agric. Extension (DOAE) in Thailand, which have already committed substantial amounts of their own budget to extend the FPR cassava project to other sites in the country. In addition, the use of FPR will be initiated in other crops and programs, such as maize and grain legumes. In Vietnam, researchers have always had good contact with the local extension service and with innovative farmers, but this project moved beyond on-farm trials to include farmer participation in decision making. The value of that approach and the need for farmer feedback in technology development is now well recognized in the various participating institutions. In China and Indonesia the FPR teams were relatively small, and their institutions are still strongly rooted in a top-down approach. Still, most people involved in the project participated with great enthusiasm, and a keen interest in the approach was expressed by institute administrators during the FPR training courses (see below). However, it will probably take time for these institutions to fully accept a participatory approach in technology development and dissemination.

B. Strategic and Applied Research on Soil/Crop Management Alternatives

During the 5-year project, strategic and applied research was conducted in many universities and research institutes in five countries (**Table 14**) in collaboration with CIAT. This research was mainly aimed at improving our basic knowledge of the crop as well as providing alternative technology options for farmers to test in their FPR trials.

Some experiments were also designed to solve specific problems identified in the FPR trials, such as finding a more suitable alternative to vetiver grass as an erosion control measure. Detailed results of this research have been reported in papers presented at the 5th and the 6th

Table 14. Collaborative research projects on sustainable cassava production systems conducted in various Asian countries in 1998.

Country	Project	Collaborating Institute	Site
Thailand	a. green manure/mulch trial	Field Crops Research Inst.	Rayong
	b. live barrier trial	Kasetsart University	Khaw Hin Sorn
Indonesia	a. long-term fertility trial	Central Res. Inst. Food Crops	Lampung
	b. erosion control trial	Central Res. Inst. Food Crops	Lampung
	c. fert.x soybean variety trial	Central Res. Inst. Food Crops	Yogyakarta
	d. cassava variety trial	Central Res. Inst. Food Crops	Yogyakarta
	e. erosion control trial	Central Res. Inst. Food Crops	Yogyakarta
	f. erosion control trial	Brawijaya University	Malang
Vietnam	a. long-term fertility trial	Agro-forestry College	Thai Nguyen
	b. erosion control trial	Agro-forestry College	Thai Nguyen
	c. Mg trial	Agro-forestry College	Thai Nguyen
	d. long-term fertility trial	Inst. Agric. Science of S. Vietnam	Hung Loc
	e. soil improvement trial	Inst. Agric. Science of S. Vietnam	Hung Loc
	f. weed control trial	Inst. Agric. Science of S. Vietnam	Hung Loc
	g. erosion control trial	Inst. Agric. Science of S. Vietnam	Hung Loc
China	a. long-term fertility trial	Chinese Acad. Trop. Agric. Science	Danzhou
	b. live barrier trial	Chinese Acad. Trop. Agric. Science	Danzhou
	c. erosion control trial	Guangxi Subtrop. Crops Research Institute	Nanning
	d. on-farm fertilizer trials	Upland Crops Research Inst.	Guangdong
Philippines	a. on-farm fertilizer trials	Bohol Exp. Station	Bohol

Regional Cassava Workshops, held in Hainan, China in Nov 1996 and in Ho Chi Minh city, Vietnam in Feb 2000, respectively, as well as in CIAT's Annual Reports for 1994 through 2000.

The highlights of this research can be summarized as follows:

1. Long-term Fertility Maintenance with Chemical Fertilizers

Results of 11 long-term NPK trials conducted in four countries in Asia (Howeler, 2001) indicate that after continuous cropping for four to ten years, there was a significant or highly significant response mainly to the application of N and K indicating the importance of N and K and the relatively less importance of P for cassava nutrition. These trials are presently being continued in four sites. By relating the relative response to each nutrient to the content of that nutrient in the soil or in cassava indicator leaves, "critical" nutrient concentrations in soil and plant tissue were determined, using the combined data from many of these trials (Howeler, 1998). These critical levels are essential for being able to diagnose nutritional problems from soil or plant tissue analyses.

2. Fertility Maintenance with Green Manures

Soil fertility can be improved by incorporating or mulching green manures, intercrop residues, and prunings of hedgerow species (also called alley cropping). However, green manures occupy the land unproductively during part of the rainy reason, intercrops generally compete with the main crop, and hedgerows also occupy permanently a part of the cropping area; these practices are therefore not readily adopted by farmers. An exception to this is the use of intercrops, since the value of the intercrop usually compensates for the reduction of cassava yield; and the use of *Tephrosia candida* hedgerows in Vietnam where the hedgerows have a dual function of fertility maintenance and erosion control.

An experiment conducted in south Vietnam for nine consecutive years showed no significant improvement in cassava yields through various intercropping and alley cropping practices during the first six years. However, in the 7th and subsequent years, cassava yields increased significantly by alley cropping with *Leucaena leucocephala* or *Gliricidia sepium*. A similar experiment conducted in Rayong Research Center in Thailand showed that mulching of green manures such as *Crotalaria juncea* or *Canavalia ensiformis*, grown intercropped with cassava during the first two months of the cropping cycle, increased cassava yields compared with the check without green manures, but that these yields were still significantly lower than the yields obtained with a higher rate of chemical fertilizers (Howeler, 1998; Tongglum *et al*., 2001). In areas where labor is scarce or expensive, such as Thailand, farmers will generally prefer to buy the chemical fertilizers.

3. Erosion Control

Experiments to develop more effective practices to control erosion have been conducted in eight sites in four countries. It was found that cassava generally causes more erosion than other upland crops like maize, upland rice, peanut or soybean (Wargiono *et al*., 1998; 2001; Howeler, 1998), but that various management practices, such as contour ridging (Zhang Weite *et al*., 1998; Nguyen Huu Hy *et al*., 1998), intercropping (Zhang Weite *et al*., 1998; Tongglum *et al*., 1998), hedgerows of *Gliricidia sepium* or *Flemingia congesta* (Wargiono *et al*., 1998), *Tephrosia candida* and vetiver grass (Nguyen Huu Hy *et al*., 1998), mulching and fertilizer applications (Wargiono *et al.*, 1998; Zhang Weite *et al*., 1998) are all very effective in reducing erosion. Among all these practices, the planting of contour hedgerows of vetiver grass is generally the most effective in reducing soil losses. These hedgerows assist in natural terrace formation, with terrace risers of 40-60 cm height being formed in a relatively short time of 3-4 years. These terraces in turn reduce runoff and erosion and help conserve soil moisture. However, as mentioned above, vetiver grass also has some important limitations, which constrain its adoption.

4. Alternatives to Vetiver Grass

Since vetiver grass hedgerows are very effective in reducing erosion, but are difficult and expensive to establish, alternative grass species are being tested as erosion control barriers in Khaw Hin Sorn in Thailand and at CATAS in China. Experience has shown that an ideal species for erosion control hedgerows should have the following characteristics:

a. an erect but not too tall growth habit, with strong tiller formation to trap soil sediments (similar to vetiver grass).
b. A deep and vertical root system that causes little competition with neighboring crop plants.
c. Drought tolerant and well-adapted to acid and infertile soils.
d. Has other uses, such as animal feed, green manure etc., or has direct commercial value.
e. Can be propagated both from vegetative material and seed, but the seed must not easily spread and create a weed problem.

From four years of testing many grass species in Thailand, it appears that the species *Paspalum atratum* shows the most promise as it fulfils nearly all the above criteria: it is an excellent animal feed, is rather drought tolerant, is less competitive than any of the other grasses tested and can be planted either from seed or vegetative material. If the initial promise of this species holds up in future experiments, it could become an important hedgerow species without some of the limitations of vetiver grass.

C. Training in FPR Methodologies

In addition to the initial training course, aimed at familiarizing the selected FPR team members with FPR methodologies in general and with the proposed project methodologies in particular, four in-country Training-of-Trainers Courses in FPR Methodologies were held in the four participating countries in year 4 and 5 of the project. In Sept 1997 one course was held in Thailand and one in Vietnam, and in May/June of 1998 similar courses were held in Indonesia and China. About 25 to 30 people, mainly researchers and extensionists, participated in each course. Since many participants were not proficient in English, most lectures were either given directly in the native language or were translated from English to that language.

During the first day of each training course, “decision-makers’, i.e. high-level administrators of research and extension organizations, were invited along with the course participants. This was done to introduce the new concept of “participatory technology development and dissemination” to the trainees and their bosses alike, so that the latter would understand and be supportive of this new approach, and may eventually decide to institutionalize this concept in their own organizations. The curriculum of the training courses included classroom lectures, but emphasized excercises on various FPR methodologies such as diagnostic tools, like village mapping, transects, rainfall and crop calenders, problem ranking and diagramming; and evaluation tools, like matrix ranking. These methodologies were than practiced with farmers at the pilot sites during 2-3 field days. While many participants were initially doubtful of the usefulness of the participatory approach, most participated in the course with enthusiasm and returned home with a desire to apply this approach in their own work.

The reason for organizing these courses towards the end of the project was to gain first experience and confidence with the FPR methodologies used in the project, and to develop an effective farmer participatory model for enhancing sustainable cassava production systems. Once these methodologies were used and adapted to fit the requirements of the project, they could be taught to others, who might either set up their own FPR projects, teach other FPR training courses, or participate in the proposed second phase of this project. As indicated in **Table 15**, a total of 127 researchers and extensionists from five countries were trained in the various FPR training courses, while 155 farmers participated in the conducting of FPR trials. This large pool of trained and enthusiastic individuals will be a valuable resource in helping to conduct FPR trials in a much larger number of sites, and to disseminate the results to thousands of other farmers, as proposed in the second phase of the project.

Table 15. Number of researchers/extensionists who participated in FPR training courses and number of farmers who participated in FPR trials from 1994 to 1998.

	Researchers/ Extensionists	Farmers
China	28	40
Indonesia	32	27
Philippines	2	-
Thailand	35	32
Vietnam	30	56
Total	**127**	**155**

D. Lessons Learned

To be successful in promoting soil conservation the following issues should be taken into account:

1. *Economic profitability is necessary but not sufficient for adoption to occur, and the time horizon for profitability should be as short as possible.* In the trials discribed above, higher net incomes in the "improved" practices were obtained not so much from the soil conservation practices, but from other innovations in the "package", such as higher yielding varieties, fertilization and intercropping. By testing and adopting the whole integrated system, farmers can obtain economic benefits while significantly reducing erosion (**Table 11**). Improved cultural practices such as closer spacing, reduced tillage, intercropping and fertilization will all contribute to reducing erosion while they may also increase yield and income. The "right" combination of cost-effective cultural practices and soil conservation practices (hedgerows, agro-forestry) is highly site-specific and must be developed locally in a cooperative effort between farmers, extensionists and researchers. Only those combinations of practices that are profitable in the short-term and effective in erosion control will be adopted. The Nippon Foundation project was able to achieve profitability and raise farmers' interest in the project by the introduction of new varieties, fertilization, intercropping and various new hedgerow species that had previously been developed in on-station research, and that were "on the shelf" for on-farm testing and dissemination. If no good technologies are available for introduction, farmers soon loose interest in participating. The planting of new higher-yielding varieties was the main incentive for farmers to participate in the project and was a very important "entry point" for getting farmers interested in testing methods of soil conservation. For that reason, FPR trials were never limited to only erosion control, but included varieties, intercropping, fertilization, weed control etc.
2. *Some incentives may be necessary.* Since soil conservation structures may be too expensive for farmers to establish on their own, governments should provide some assistance, as society as a whole also benefits from less flooding, more and better quality water, and lower costs of dredging and maintenance of irrigation and hydro-electric generating systems.

   Thus, in Thailand vetiver grass contour hedgerows are being adopted because farmers have seen their effectiveness in reducing erosion; in addition, the government supplies free planting material, helps farmers in setting out contour lines, teaches about multiplication and management of vetiver plants, as well as the use of vetiver leaves in the making of handicrafts as an additional source of income. In Vietnam, adoption of *Tephrosia candida* hedgerows is being facilitated by supplying farmers with good quality seed; similarly, in Indonesia farmers adopted *Gliricidia sepium* contour hedgerows after they received good quality seed from the project.

Financial incentives should be kept to a minimum, as this will not be sustainable in the long run, but some incentives in kind may be useful and necessary to allow farmers to adopt the new technology.

3. *Farmers must be aware of soil erosion and its impact on soil productivity before they will be interested in soil conservation.* Severe soil erosion is usually associated with steep slopes and its impact on soil productivity is most pronounced in shallow soils or in soils having a thin topsoil underlain by a highly infertile subsoil. In that case farmers can clearly see the negative impact of erosion on soil productivity and know that yields will decline unless they protect their soil from erosion. But even in areas with gentle slopes (2-10%) and deep soils, the accumulation of large amounts of runoff water in natural drainage ways can cause severe gulley erosion, break contour ridges and wash away young plants and fertilizers, while the eroded sediments may obstruct roads and irrigation and drainage systems below. By conducting erosion control trials on their own fields and seeing the large amounts of eroded sediments in the plastic-covered ditches, farmers start to appreciate how much soil they are losing each year.

   To be convincing, however, and to be able to obtain accurate data on soil losses, these FPR erosion control trials must be laid out exactly on the contour, and care must be taken that no water runs onto the plots from above or from the sides, and no water leaves the plots across side borders. This is not an easy task, especially if the slope is not uniform; it requires much care and experience at the time these plots are laid out and treatments are established. Researchers and farmers generally like rectangular plots, preferably parallel to roads or field borders, while this type of trial may require trapezoidal or irregularly shaped plots to maintain the sediment-collection ditches along the contour and perpendicular to the natural flow of runoff water.
4. *Give farmers freedom to experiment.* In conducting the trials, farmers should be allowed to not only select the treatments but also their location within the trial, as farmers' fields are not necessarily uniform. Some of this disuniformity can be exploited and much can be learned from letting the farmer select the right treatment for each particular condition. On the other hand, having farmers as a group decide on a set of the same treatments, to be tested by all farmers participating in the trials, facilitates the taking of data and allows the calculation of averages (see **Tables 7-10**) across trials within the site, which makes it possible to compare treatments over a range of conditions. Alternatively, some treatments may be common to all trials in the village, while other treatments may be selected by each farmer individually.
5. *Yield calculations must be accurate and based on total cropped area.* To be believable, yield data must be accurate and must reflect the real on-farm conditions. In treatments with intercrops or hedgerows the yield of each crop should be calculated based on the total area of the plot, or of a subplot that includes all crop components. Calculating yields from "effective" plots that exclude border rows and hedgerows will inevitably overestimate the yield of those treatments, and thus mislead farmers into

attributing non-existing benefits to those treatments. Also, treatments of "farmers' traditional practices" should be managed as much as possible like the farmer's production fields; the yields of those plots should be similar to what farmers obtain in nearby production fields. However, asking farmers to plant their trials at a uniform plant spacing will greatly facilitate the accurate determination of yield. In as much as possible, FPR trials should be planted and harvested at the times that farmers in the village normally plant and harvest these same crops.

6. *Local officials and self-help groups should be partners in the project.* When selecting appropriate pilot sites it is important not only to consider the biophysical and socio-economic conditions of farmers, but also to gauge the interest of local leaders and extension officers, and to determine the existence of NGO's or local self-help groups. Working in collaboration with these local officials and groups will greatly facilitate the implementation of the trials and the subsequent adoption of selected practices. Support for the project at the highest levels of government will help to convince local officials that support of, and participation in, the project is not only approved of but also appreciated. Inviting local leaders and extensionists to FPR training courses will contribute much to their understanding of the approach and their active participation in the project. Finally, the presence of NGOs with interest in sustainable agriculture and rural development, as well as the existence of local self-help groups makes it easier to call meetings, initiate the project, conduct the trials and enhance the adoption and implementation of selected practices.

E. Conclusions

Research on sustainable land use conducted in the past has mainly concentrated on finding solutions to the biophysical constraints, and many solutions have been proposed for improving the long-term sustainability of the system. Still, few of these solutions have actually been adopted by farmers, mainly because they ignored the human dimension of sustainability. For new technologies to be truly sustainable they must not only maintain the productivity of the land and water resources, but they must also be economically viable and acceptable to farmers and the community. To achieve those latter objectives farmers must be directly involved in the development, adaptation and dissemination of these technologies. A farmer participatory approach to technology development has shown to be quite effective in developing locally appropriate and economically viable technologies, which in turn enhances their acceptance and adoption by farmers.

The conducting of FPR trials is initially time consuming and costly, but once more and more people are trained and become enthusiastic about the use of this approach - including participating farmers - both the methodology and the selected improved varieties or cultural practices will spread rapidly. The selection and adoption of those farming practices that are most suitable for the local environment and in tune with local traditions will improve the long-term sustainability of the cropping system, to the benefit of both farmers and society as a whole.

Tribute

In memory of Mr. Chalor Naksri, driver and office assistant in the project, as well as seven other persons, who lost their lives in a road accident on June 5, 1996 during one of the trips in support of the project. May they rest in peace.

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THE NIPPON FOUNDATION PROJECT ON IMPROVING THE SUSTAINABILITY OF CASSAVA-BASED CROPPING SYSTEMS IN ASIA - A PROJECT EVALUATION REPORT[1] -

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The Problem and Context

Sustainable management of Asia's upland areas, particularly in the humid and sub-humid areas, has remained an unfulfilled development objective. The concentration of research, extension, and development resources on the more productive lowland areas, the more limited road infrastructure and greater distance to urban markets, and the more constrained crop options have limited agricultural incomes and, in turn, investments in land improvement in the upland areas. Extensive land management on gentle to steep slopes leads to significant rates of soil erosion, with Southeast Asia's rivers carrying some the highest sediment loads of any region in the world. The relatively favorable food balance, rising per capita incomes in favored agricultural areas, and increasing government budgets allow a potential shift in resources to upland areas. Moreover, such a resource shift is congruent with a potential policy objective of alleviating rural poverty, as this tends to be concentrated in upland areas.

Cassava competes with maize and to a lesser extent upland rice as the most important field crop grown in the upland areas of the tropical and sub-tropical areas of Southeast Asia (tree crops are important in humid areas with low population densities). Cassava is particularly important in more marginal areas where either drought or soil constraints limit the production of other crops. These advantages, however, result in cassava often being grown on sloping land and because of the wide plant spacing and 3-4 month period to closed canopy, soil erosion is often a significant problem if appropriate control measures are not taken. A project focusing on controlling soil erosion in cassava-based systems is a logical entry point into the problem of reducing soil loss in Asia's uplands. In fact, addressing soil erosion by linking it to broader-based crop technology allows a more direct link between productivity, soils management, erosion control, and farmer incomes.

The review team noted the extraordinary diversity in cassava production systems and the factors leading to soil erosion across the sites in the four countries. The team views this to be a very positive feature of the project in that methods and ideas are tested in very different contexts with the possibility of transfer of experience between sites. This leads to a far more robust methodology and deeper insights into the factors that condition farmers' adoption of soil erosion control techniques. However, one of the tensions in such a project structure is the balance between comparing relatively common or standardized methods or trials across different sites and within different contexts versus adapting those trials and methods to the more particular needs of each of the individual sites - especially given the range of diversity.

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[1] Adapted from Project Evaluation Report, submitted to the Nippon Foundation, based on an Evaluation of the Project conducted from June 29 to July 19, 1998.

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Each pole of this strategic continuum has its pros and cons and one of the themes of this review will be to explore this evolving balance within the project.

Farmers' adoption of soil erosion control techniques should be viewed as an investment in land - that is a significant upfront investment which pays off over time and where tenure rights in land are important. This investment usually requires a significant application of labor and is most successful if the farmer has knowledge of the various options available - therefore, the importance of farmer participatory research (FPR). Farmers will be more interested in investing in technologies that have larger and more immediate impacts on productivity and incomes. Thus, market access and income potential of cassava are important, as is the impact of the control measures on either moisture or nutrient availability and cassava yield. When combined with technologies such as improved varieties or nutrient management, productivity effects from soil erosion control can be enhanced. Most soil erosion control projects have tended to focus on single technologies, such as live barriers on the contour or bench terraces, which have been independent of the principal crop or income source, and as a result have not been very successful or widely adopted. This project attempts to combine different options of soil erosion control with other yield increasing technology options within a farmer participatory research framework. The review team strongly endorses this approach as the way forward in developing more sustainable land management systems in Asia's uplands.

The review team visited all but one of the FPR sites in the four countries. This was essential to understanding the project, the challenges that the project has set for itself, and the diversity in both institutions and farming systems across the sites. Some of the diversity in the factors conditioning the suitability or type of erosion control technology and the potential for adoption are presented in **Table 1**. Even this table simplifies the complexity found across the sites, but the team would like to use this table as a framework to evaluate progress within the project and possible future directions for the project. What is suggested in this framework is something of a continuum in upland land use intensity across the sites, running from very intensive in Indonesia (on the left) to relatively extensive in Thailand (on the right). There is something of a divide in the table between Pho Yen village and Phong Linh village, both in Vietnam, in intensity of management of upland areas, particularly in the level of prior investment in soil erosion control. While the project has a role in the more intensive villages, the real challenges of developing appropriate soil erosion control measures are found in the villages of extensive upland land use where there has been little terrace development. By Asian standards, most of this land has been brought into cultivation relatively recently, having previously been in forest. In Thailand extensive land use is due to the relatively large size of the farms and the more constrained rural labor situation, while in China and Vietnam, there is access to communal land on steep slopes which is being brought into cassava production within an extensive slash and burn fallow system. This framework will be used to explore the impact of the project and the next steps for the project in each of the countries.

Review of Project Implementation and Impact

Each of the three principal objectives of the Nippon Foundation project is important and challenging, and meeting any one would be an achievement in and of itself. In essence, the project has addressed the following: (1) the development, testing, and extension of crop

Table 1. Upland land use intensity in FPR sites in four countries in Asia.

Village	Sumbersuko	Ringinrejo	Tien Phong/	Kieu Tung	Dong Rang	Kongba	Noon Sombuun
Municipality	Dampit	Wates	Dac Son	Phuong Linh		Shi Feng	
District/county	Malang	Blitar	Pho Yen	Thanh Ba[1)]	Luong Son	Baisha	Soeng Saang
Province	E-Java	E-Java	Thai Nguyen	Phu Tho[2)]	Hoa Binh	Hainan	Nakorn Ratchasima
Country	Indonesia	Indonesia	Vietnam	Vietnam	Vietnam	China	Thailand
Land-labor Relations							
-Upland/lowland ratio	High	High	Low	Medium	Medium	High	Very high
-Farm size (ha)	0.2-0.5	0.3-0.6	0.7-1.1	0.2-1.5	0.5-1.5	2.7-3.3	4-24
-Relative labor availability	High	High	High	Medium	Low	Low	Low
Land Tenure							
-Lease/ownership	Long-term Usufruct	Long-term Usufruct	30 year lease	30 year lease	30 year lease	Long-term lease	Quasi title
-Communal/Unassigned land	No	No	Yes	No	Yes	Yes	No
Existing Investments							
-% Uplands terraced	~70%	~70%	~70%	~50%	~40%	~20%	~10%
On-farm cassava use	High	High	High	High	High	Low	Low

[1)]formerly known as Thanh Hoa district
[2)]formerly known as Vinh Phu province

and soil management practices that both reduce erosion and increase farmers' income; (2) development of FPR methods appropriate to testing and extension of these technologies, and their institutionalization within complex organization structures, and (3) the maintenance and continued development of national cassava research capacity in Asia. The project builds on 15 years of research work within the context of CIAT's Asian Regional Cassava Program, which provided strong and necessary foundations from which the project could move forward as quickly as it did. The last objective was not explicitly stated at the initiation of the project, but it became apparent in the review team's discussions with cassava researchers in the region that the project has become by default the principal vehicle for maintenance and support of often struggling cassava research programs in the region.

Given the complexity and difficulty of the objectives, the necessary lags in project start up, the individual and institutional learning associated with new methods, and inherent constraints to rapid institutional uptake of such methods, five years seems a very short time indeed. The team therefore viewed the task as much more of a midterm review, rather than an end-of-project review. Such an approach was felt necessary not only to give an idea of what has been accomplished but also to evaluate this progress in relationship to a second generation of issues which the project has stimulated in the course of its work—which, in turn, provides opportunities to build upon for either the Nippon Foundation or another donor. Thus, this section reviews the progress and accomplishments of the project over the last five years, while the following three sections evaluate issues and opportunities that the review team felt deserved more discussion. The review team visited all but one of the FPR sites, interacted with virtually all of the national program staff, had access to and reviewed all the pertinent literature and reports, and interacted intensively with the project coordinator. As such, the review team feels that it has all the information necessary to provide an adequate and balanced report.

A. Applied Research Trials

As noted, the project builds on and supports continuing applied research on soils and crop management in cassava-based systems. This research is carried out by national program or university staff, with backstopping from the project coordinator. The trials are organized around three principal areas, namely soil fertility maintenance in cassava systems, soil erosion control in cassava-based systems, and intercropping trials. These are usually carried out on existing experimental stations in the region, although sometimes are executed as researcher-managed trials on farmers' fields. There is a large, but not complete, degree of standardization of objective and design to these trials across sites and countries, which provides a comparative basis for evaluation of results across the region.

These trials serve dual functions within the framework of the project. They serve their traditional role of testing research hypotheses or answering questions. Also, they provide a core set of technologies from which alternatives can be drawn for testing on farm, either by researchers or by farmers. In terms of the latter function, the trials were necessary to the start of the project, giving researchers some confidence in their understanding of the techniques and options, and providing farmers from the FPR sites with an array of options which they could visually evaluate in selecting a reduced set for testing on their own farms. A relatively standardized array of trials was therefore appropriate to the initiation of the FPR project. However, as the project has moved on farm, in many instances reproducing the on-station trial as a researcher-managed, demonstration trial in the FPR site, a certain amount of duplication becomes apparent, with a reduced need for the on-station trials. Accordingly, the number of on-station trials has been declining over the project period, as much of the applied research has shifted to on-farm sites. This trend is natural and to be commended, with the on-station trials reserved for long-term experiments or for questions that require better control over inter-plot variation and/or more intensive monitoring.

In terms of the more traditional objective, the on-station trials have also produced a comparative set of data, both on plant nutrition and fertilizer response and on yield and soil loss under varying treatments involving live barriers, fertility, intercropping and ridging, as well as across different soil types and rainfall regimes. Virtually all of these trials are well designed, executed and maintained. The soil fertility trials are long-term in nature, many having continued for up to nine seasons. These trials were designed to answer research questions dominant at the start of the project. Having now developed a solid set of trials and data on these questions as well as having identified new questions arising in the application of these techniques on-farm, the project has in many respects reached a point where the research questions driving the on-station research should be more critically evaluated. The recent trials on evaluation of competition effects of various live barriers on cassava is a good example of movement in this direction. The project, probably through the Asian Cassava Research Network, could now usefully explore a possible mechanism by which new ideas arise from the research sites for experimental evaluation. This would lead to some greater diversity across research groups in the types of applied research trials. A possible mechanism for this could be a competitive, small grants program run by the network.

B. FPR Methods and Team Development

Most of the activities of the project revolved around training in FPR methods and their application in selected sites to the problems of soil erosion and crop management in cassava-based systems. Training in new methods such as FPR is best reinforced and internalized by their application to particular problems, such as soil erosion. The review team endorses the project view that FPR is a methodology that has particular relevance in its application to the problem of developing and disseminating soil erosion control techniques, with the corollary that the methods should be designed to suit the problem. The project organized its FPR activities as follows: (1) a joint FPR methods course for 30 research and extension personnel drawn from all participating countries; (2) an RRA of the target areas and selection of 1 to 2 project villages in each country; (3) farmer selection from demonstration plots of a set of possible techniques, followed by testing these within a set of farmer-managed FPR trials; (4) farmer evaluation of trial results and joint planning of succeeding season's trials; and (5) a Training-of-trainers course in each of the four countries to expand the pool of personnel with FPR skills- 27 in China, 31 in Indonesia, 28 in Vietnam and 27 in Thailand.

The review team was impressed by the progress achieved in the establishment of FPR research within the national teams and sites. From very much a perspective of hindsight, the team would make the following observations, none of which detract from the progress achieved in the project. First, much of the material in all the FPR courses focused on diagnostic FPR tools, but there was not much evidence that they were applied in the project. Given the technological and cropping systems' focus of the project and the reliance on participatory research trials, there in fact was little need for application of these tools. This is standard FPR course material and the project provided effective training in this material.

However, any future courses should attempt to achieve a better congruence between course material and project activities - this will be discussed in more detail in the succeeding section on FPR methods.

Second, the result of the RRAs are presented in the Fifth Regional Workshop Proceedings. They were effectively carried out, building on previous RRAs and surveys conducted in China and Vietnam, respectively. While they obviously gave the researchers a more in-depth understanding of the farming systems, they were only utilized in either selecting or rejecting the sites, providing little input into trial selection or design. While RRAs are standard FPR procedure, there is a question for future projects of the value of the exercise in relation to both costs and project design and objectives. Finally, the trials involved not only erosion control, but also varieties, fertilization, and intercropping. These were relatively standardized across the sites, and like the applied research trials were a logical and necessary starting point. It was useful for the review team to view these trials in the different sites and the comparative references or adoption of alternatives between the sites. The succeeding FPR methods section will review this very useful experience and make recommendations on future directions for trial design.

C. Institutionalization of FPR

The organizational locus of the project was cassava research programs and capacity within both NARS and universities in the region. As mentioned above, the project initiated its FPR activities by drawing on ongoing cassava research trials on experiment stations in the region. These researchers also provided the core personnel in the initial training course. There was a tendency in the project for universities and NARS programs to implement their own independent FPR sites, particularly in Vietnam and Indonesia. Given that both universities and NARS offered very similar capacity - for example, universities in both Vietnam and Indonesia have cassava breeding program - there in fact was little scope for collaboration and different sites offered the most logical division of labor. As the FPR sites were established, researchers began to see the gains to collaboration with other institutes, particularly extenstion, and in Thailand, the Thai Tapioca Development Institute. Indonesia was the only case where there were not good interactions with extension, and this limited the effectiveness of a local supervisory capacity in the FPR sites.

D. Farm-Level Impact

In order to reach the goal of increased income and agricultural sustainability, the project conducted research and technology development in four general themes – reducing soil erosion, improving or maintaining soil fertility, intercropping, and varietal improvement. These themes are not independent. Improved soil fertility, intercropping, and improved varieties can all contribute to reducing soil erosion. Strategic research conducted before this project had identified many technological options in the four thematic areas. Particularly, previous research had established a strong foundation of knowledge on soil fertility and cropping systems, and cassava breeding programs had developed many improved clones. At every pilot site that the team visited, farmers had adopted at least one method to control erosion in their fourth year of participating in the FOR project (**Table 2**). Although farmers in all pilot sites adopted some technologies for erosion control, technologies adopted differed widely among sites.

Table 2. Technologies that farmers have adopted at the pilot sites visited in 1998. Level of adoption: * = little, <10%; ** = moderate, 10-25%; * = rapidly growing, 25-80%; **** = high, adoption by >80% of farmers; FP = farmer practice before FPR project.**

Pilot site[1)]	Erosion control	Fertilizer	Intercrop	New varieties
China, Hainan, Kongba	Contour hedgerows -Sugarcane*** -Vetiver**	NPK mix *	Peanut *	**
Indonesia, Malang, Dampit	Contour ridges***	N, P, K (FP)*	Maize (FP)	Undecided
Indonesia, Blitar, Ringinrejo	Contour hedgerows -Elephant grass** -Gliricidia*** -Leucena**	N, P, K (FP)*	Maize (FP)	Undecided
Thailand, Soeng Saang	Contour hedgerows -Vetiver** -Sugarcane*	N, P, K ***		****
Vietnam, Luong Son, Dong Rang	Rice straw mulching (FP) Contour hedgerows -Tephrosia***	FYM[2)] (FP) N, P, K ** Green manure*** Split applications**	Taro (FP) Peanut **	*
Vietnam, Thanh Ba, Phuong Linh	Contour hedgerows -Tephrosia*** -Vetiver ** -Pineapple*	FYM[2)] (FP) Green manure*** N, P, K**	Peanut **	*
Vietnam, Pho Yen, Tien Phong/Dac Son	Contour ridges (FP) Contour hedgerows -Tephrosia** -Vetiver**	FYM2) (FP) N, P, K*** Green manure*** Ca for peanut (FP)	Peanut ***	*** 25 farmers doing own variety testing outside of project

[1)]The pilot site in Kalasin, Thailand, is not included because it is only in its first year of FPR trials
[2)]FYM = farm-yard manure

1. Soil erosion: Most demonstration, on-station, and FPR trials on erosion control methods were very well conducted. Farmers at most sites are adopting contour hedgerows, and a few farmers have adopted contour ridging as well. In two locations, Playen, Yogyakarta, Indonesia and Phuong Linh, Thanh Ba, Vietnam, farmers said that during the dry season they physically moved soil from drainage ditches or from lowland fields back to the upland fields. In addition to reducing soil loss and improving crop productivity, erosion control technologies may reduce labor requirements.

Generally, contour hedgerows have led to gradual terracing of fields. Terrace formation is probably more a function of soil movement during land preparation rather than erosion. Nonetheless, contour hedgerows have resulted in terraces of 15-40 cm over three to four years. Terraces both reduce erosion and conserve soil moisture. Terrace formation was not an explicit treatment in FPR trials. Most farmers reject terrace construction because of high labor demands or costs. Contour hedgerows provide a low cost, relatively low labor alternative to terrace construction and lead to terrace formation over a relatively short time.

The only site where contour hedgerows did not lead to terrace formation was Soeng Saang, Thailand, where fields are plowed by tractors. Special concerns arise for farms that contract mechanical tillage for land preparation. Tractor drivers may not be aware of the need for contour plowing or field shape may prohibit contour plowing. Some contract drivers have destroyed contour hedgerows.

Selection criteria for hedgerow species differed among locations. Although vetiver grass is probably the best species for erosion control and competes little with the crop, it cannot be fed to livestock. Where farmers had livestock, farmers preferred species that could be cut and fed to livestock. Some farmers want a hedgerow species that would also provide fuel, cash income, or green manure.

In most locations, availability of planting material or seed of hedgerow species was a problem. Sometimes farmers' selection of hedgerow species depends more on availability of seed than on the erosion controlling features or other uses of the species. Farmers rely heavily on researchers or extensionists to provide the planting material or seed. To become a self sustaining technology, and for continued adoption of these technologies beyond the project locations, either farmers need the ability to maintain or increase planting materials for hedgerows, or extension services should multiply and distribute planting materials, as is done by the Department of Land Development in Thailand and the National Institute for Soils and Fertilizers in Vietnam.

2. Soil fertility: Native soil fertility varies greatly among project sites. Initial soil fertility levels are relatively high in Kongba, China, where farmers rotate cassava with fallow. Greater use of inorganic fertilizers may increase sustainability of cassava yields and reduce the need for expanding cassava cultivation into steeply sloping lands.

Indonesian farmers say that they do not want to purchase fertilizers for cassava because they grow cassava for home consumption, not for sale. On the other hand, they apply fertilizers to intercropped maize in East Java, or soybean at the on-farm research site in Playen.

Cassava benefits from fertilizers applied to intercrop species, so responses to fertilizers applied to cassava are relatively small. Still, farmers in Dampit cited the value of applying potassium fertilizers to cassava, although the current economic crisis has led to rapid increases in costs and reduced availability of imported KCl in Indonesia.

In Thailand it was shown that yields of cassava had declined gradually over 25 years of cultivation if no fertilizers were applied. Through this and other projects farmers have learned the value of fertilizer application in sustaining cassava productivity. Because most Thai farmers cultivate cassava to sell to livestock feed or starch factories rather than for home consumption, they are willing to purchase fertilizer's and to re-incorporate crop residues to improve yields.

Vietnamese farmers applied pig manure to cassava and other crops before the project began, but only the wealthiest Vietnamese farmers applied fertilizers to cassava before this project. Now many more farmers are aware of the advantages of fertilizer application, and have either improved fertilizer management through split application or increased levels of applied fertilizer, especially K. They have also increased the use of green manure produced from contour hedgerow or intercrop species, mainly *Tephrosia candida* and peanut, respectively.

From our short review we could not determine whether farmers outside the project had adopted fertilizer application technologies. Furhtermore, the application of inorganic fertilizers by farmers in the project may reflect project participation more than true adoption, because in some sites farmers receive a bag of fertilizer as an incentive to participate in the project.

3. Intercropping: Cassava canopy growth is relatively slow. It takes several months for cassava to completely cover the soil. Intercropping reduces erosion because plants more quickly protect the ground from the direct impact of rain. Farmers in Indonesia and Vietnam practiced intercropping before the project. In Vietnam, however, farmers have increased the area of cassava intercropped with peanut as a result of the project. Through FPR, farmers learned that their traditional planting density for cassava was too high. By spacing cassava plants farther apart, stems were thicker, roots bigger, and yields increased. Wider spacing also provided the opportunity to increase peanut intercropping, so that now, about 50% of the cassava has a peanut intercrop.

Farmers' choice of intercrop reflected either a need for quick cash or need for livestock feed. In Pho Yen district, Vietnam, where farmers grow rice for home consumption and cassava for swine feeding, a peanut intercrop has become the principal source of cash income. They also incorporate leaves and stems in contour ridges as a green manure for cassava. In Dong Rang, Vietnam, farmers grow a taro intercrop on more sloping lands farther from the household and a peanut intercrop on more level land near the household. These farmers traditionally apply rice straw mulch to intercropped taro, but now also apply to cassava grown in monoculture to reduce erosion, conserve soil moisture and facilitate land preparation by hand.

4. Improved varieties: Most farmers quickly accept improved varieties. In many cases, farmers' interest in participating in the project was initially through their interest in new varieties. In Soeng Saang, Thailand, farmers completely changed to new varieties. In Vietnam, though farmers are still undecided as to the best variety, many farmers outside of the project have planted one or more new varieties in their fields on their own initiative. Adoption of new high-yielding varieties by farmers is slow only in Indonesia, where traditional varieties are well adapted to ecological niches and are often preferred for home consumption.

Cassava variety selection programs appear to be well established in all locations. Only the pilot sites managed by the National Institute for Soils and Fertilizers of Vietnam does not have a breeder on the team, but this team received cassava varieties from Thai Nguyen University and from the nearby Vietnam Agric. Science Institute.

E. Conclusions and Next Steps

It is the assessment of the review team that the project has met the objectives as set out in the initial project proposal and that the results obtained represent a very worthwhile investment by the Nippon Foundation. The review team was impressed by the progress made in institutionalizing new FPR methods into existing research programs in the region, the obvious value of the methods in very diverse village situations, the technological possibilities for reducing soil erosion in Asia's upland cropping areas, and the benefits of linking yield increasing technological options with soil conservation options. The problem on which the project worked is important to the sustainability of agriculture in the region, often for some of the poorest households and regions in Southeast Asia.

The review team would like to stress the potential that the project has as a real innovator in a challenging field and we will devote the rest of the report to reviewing how the project might think about organizing itself to realize that potential. After virtually a decade of development and evolution, FPR methods are at something of an impasse. They are widely applied but primarily in diagnosis and small plot experimentation. This project has the potential to go beyond that in the exploration and development of new methods, based on problems that now present themselves in the project. Secondly, the real potential of FPR rests on how it is replicated from a few sites to thousands of sites, and therefore in how institutional structures are formed around FPR methods. The project as well offers the potential to explore this critical issue. Finally, the real test of the project is the impact it will have on soil erosion control and farmer welfare. Farmers are exploring these options in the FPR villages and there are initial signs of adoption. Such sites now provide the potential to test the validity of new approaches and techniques and form a possible nucleus for more widespread diffusion of these technologies.

STRATEGIC AND APPLIED RESEARCH NEEDS

As cassava FPR projects disseminate technologies identified for adoption in the first phase of this project, there will be an increasing demand for new technologies (**Table 3**). At the same time, there appears to be a reduced or more diffuse effort in cassava research outside of the project. In other words, demand for research results within the project is increasing while generation of those results outside of the project is decreasing. This situation is exacerbated by the economic decline in the countries of the project partners, which has already resulted in reduction of national program support to cassava activities. Given the importance of a good research base to support FPR, and the fact that one of the benefits of FPR is from its feedback from farmers to researchers in identification of research needs, allocation of project resources to strategic and applied research is a necessary and appropriate component of the project. During its first phase the project allocated about 30% of its resources to conducting strategic and applied research on-station and in farmers fields. In the next project phase, the allocation of resources between strategic-applied research and FPR activities should remain about the same. On the other hand, researchers should be encouraged to reduce redundancy between on-station research and demonstration plots in farmers fields, and shift the resources for on-station research to new areas of strategic research, as discussed below.

Some of the strategic and applied research conducted during the first phase of this project should be continued. Long-term fertility trials give valuable information on the long-term sustainability of cassava production. While the number of long-term fertility trials may be reduced to allow resources to be used for other activities, several of the trials should be continued. Breeding and selection of improved cassava varieties is fundamental to any cassava program. Whether farmer participation earlier in the selection process would benefit cassava improvement is a question that may be addressed in the next phase of the project.

Strategic and applied research needs identified through FPR during the first phase of this project include:

1. Competition between cassava and hedgerow species. Effectiveness in controlling erosion is only one of the critera farmers use when selecting species for contour hedgerows. They also consider ease of establishment, availability of planting material, alternate uses as green manure, fuel, fodder, or cash sales, and competition between the hedgerow and crop. Of these concerns, hedgerow selection and management to minimize competition between the hedgerow and crop for light, nutrients, and water may require strategic research with levels of control and measurement precision that can best be achieved through on-station research.

2. Nutrient cycling and transfers. Sustainable agricultural systems require soils that continue to provide nutrients needed by the crop through time. Much of the research on nutrient cycling and transfers in cassava based systems have been conducted under conditions of ongoing soil erosion, use of traditional varieties, minimal fertilizer inputs, and monoculture. As farmers adopt improved technologies, research is needed to understand the impacts of those technologies on nutrient cycling and transfers.

Table 3. Research and training need for the second phase of the project as identified through feedback from FPR trials. Research needs include strategic and adaptive research.

Pilot site	Research need	Training needs/Community action
China, Hainan, Kongba	Drought tolerant intercrop	Vetiver use for other crops
	Pineapple in contour hedgerows	Farmer-to-farmer extension
	Fertilizer management in crop-fallow rotation	Vetiver multiplication
	Cassava variety selection	
	Improving sugarcane hedgerows for erosion control	
	Tree legumes as hedgerows	
Indonesia, Malang, Dampit	K fertilizer options to replace imported KCl	Farmer-to-farmer extension
	Hedgerows suitable for cut-and-carry feed	Contouring across farm boundaries
Indonesia, Blitar, Ringinrejo	Hedgerow-cassava competition	Farmer-to-farmer extension
	Effect of rotating cassava varieties	Contouring across farm boundaries
	Short duration, drought tolerant cassava	
Thailand, Soeng Saang	Drought tolerant intercrops	Tractor driving for contour plowing
	Hedgerow-cassava competition	Vetiver multiplication
	Chemical or mechanical weed control	Farmer-to-farmer extension
	Minimum tillage	
Vietnam, Luong Son, Dong Rang	Peanut varieties for intercropping with cassava	*Tephrosia* seed production
	Cassava variety selection	Vetiver multiplication
	Combined vetiver and *Tephrosia* hedgerows	Farmer-to-farmer extension
Vietnam, Thanh Ba, Phuong Linh	Hedgerow-cassava competition	*Tephrosia* seed production
	Soil liming	Vetiver multiplication
	Soil fertility in relation to position on hill	Farmer-to-farmer extension
	Mutual benefits of cassava-peanut intercrop	
Vietnam, Pho Yen, Tien Phong/Dac Son	Why have farmers adopted variety testing here on their own, when none of the other villages have done so?	*Tephrosia* seed production
		Vetiver multiplication
	Peanut-cassava intercropping patterns	Farmer-to-farmer extension
	Peanut-cassava competition	
	Livestock feeding of cassava roots and leaves	
	Mg fertility	

3. Socio-economic issues. Farmers in Thailand identified cassava marketing and processing as a major concern. Such issues are important where cassava is grown for sale, whether most or part of the crop is sold. Marketing issues, price fluctuations, and weather can have a major impact on production stability. Farmers are generally more willing to purchase inputs when they have access to markets for cassava sales. They increase or decrease area planted and input use based on market price. Farmers may consume more of their cassava crop if bad weather affects other crops in their agricultural system. How these factors interact in their influence on farmer adoption of new technologies and sustainability of cassava-based systems is an important research area.

4. Soil-water balance. Low or poorly distributed rainfall affects adoption of intercrop technologies in most cassava growing areas. Technologies that reduce erosion should increase both soil water holding capacity and the fraction of rainfall that is retained in cassava fields. Research on soil-water balance should be conducted to verify and quantify these benefits and to ascertain whether farmers adopting technologies that reduce erosion will sufficiently improve soil moisture status to allow intercropping, crop rotation, or cultivation of a more desirable hedgerow species.

NEW DIRECTIONS AND DIVERSITY IN FPR METHODS

The project had used a relatively standardized methodology of FPR introduction across the various sites, consisting of demonstration trials from which farmers chose a more limited set of options to be established as trials on their own farm. These FPR trials consist of four principal technological options, namely varieties, fertilization, intercropping and soil erosion control. These trials are continued for two to three years, with farmers evaluating the results at the end of each harvest.. This was a reasonable approach for the first phase and provided a very successful strategy for introduction of FPR methods into both institutions and village sites, as well as providing a useful comparative set of data for evaluation across sites. However, the team noted differences across sites in adaptation by farmers of these trials and results, and most importantly very different needs for a second generation of methods to take the technologies and approach to scale in the various countries. This section will first review these different needs by country and then explore a few project-wide issues in the evolution of FPR methods.

Country-Specific FPR Strategies

Thailand : Cassava is a priority crop in Thailand. There is a well developed structure for developing and disseminating new varieties to farmers. Much of the land planted to cassava has been opened only within the last 20 to 30 years, and only within the last 5 to 10 years have soil nutrient levels declined to the point where farmers have started applying fertilizer to cassava. There is some scope for improving fertilizer use efficiency, requiring a cassava-specific, compound fertilizer rather than the 15-15-15 currently utilized. Intercropping potential is limited by the large field size and the lack of good drought tolerant legumes. Thus, the FPR results of most interest to farmers have been the erosion control measures, and farmers generally have tended to prefer the vetiver barrier as showing the most potential. The central issue in Thailand is how to scale up this technology from its evaluation in small plots.

There are three strategic issues in the next steps of this scaling up process. The first is how to scale up the technology from a small plot to its application at a whole farm level. There is a range of issues here. The most important issue for vetiver technology is the production of sufficient planting material for farm level application. To be effective the vetiver hills have to be planted closely. Once a live barrier is established, farmers are not willing to disturb it for planting material. Efficient transfer of vetiver to the field and establishment on the contour are issues, compounded by the tendency for fields to be narrow and run up the slope or hill (a general tendency in land allocation during the land reform). There is very little, if any, work on participatory methods for scaling up technologies - compost and agroforestry technologies have similar difficulties. This may involve community-based nurseries, joint contour development across farms based on community-developed land-use maps, farmer research committees for community based planning, and testing of different methods of large scale establishment. Scaling up problems were apparent in the field sites and new methods will have to be developed to tackle what is the central problem to effective adoption of vetiver technology.

Second, land is prepared by hired tractor services. Tractor drivers prefer to plow the length of the field, which tends to be up and down the slope. They view both contour plowing and live barriers to be nuisances. Tractor drivers must become participants in the testing and application of the technology, as they are central to its application. How to do this remains a question, but one which will have to be addressed in the project.

Only with successful resolution of these issues - and this reviewer is of the opinion that other live barrier options based on seed establishment should be kept open - is there a basis for applying the methodology in other locations, either districts or provinces. As will be discussed in the next section, Thailand has an institutional structure for efficient dissemination of proven technologies, and given the relative homogeneity in cassava-based production systems, the project has the potential of moving to a nationwide dissemination mode, building on the structures put in place to quickly extend new varieties.

China: A 1990 RRA of cassava production and utilization in China found that much of the crop is grown on sloping land, often very steep, which is also apparent in the FPR site. Of the four countries the problem of soil erosion in cassava production systems in China is probably the most extensive and faces the greatest challenges to overcoming the problem. The Chinese program is still identifying a technology for erosion control that is both effective and acceptable by farmers. Research on live barriers has tended to concentrate on forages - the research institute at CATAS has a mandate for both field crops and forages - which have either not established well or excessively compete with cassava. Vetiver is a possibility, but with the same problems as for Thailand. More tree species need to be evaluated as possible live barriers and some consideration might be given to tree-based, improved fallows, which ICRAF has found successful in Kenya and Zambia.

The technology problem is compounded by a land use issue. Individual usu rights in land were allocated about 20 years ago on a long-term lease basis. Some of these upland areas had been terraced during the collective period and tend to be closer to the village. These tend to be more intensively managed, and in Kongba village, many are going from cassava to rubber. However, farmers also cultivate unallocated lands that, because of their steepness, are ostensibly illegal to cultivate. Nonetheless farmers are shifting their cassava cultivation to these areas. Erosion control measures under this system must be very low cost. Future FPR trials might best be designed around different land use categories, for example in Kongba, terraced land in permanent cultivation, terraced land in a fallowing system, unterraced with usu rights, and unterraced without usu rights. The hypothesis here is that farmers will choose different technologies for these different land form types. A village mapping of these land forms would be done during the characterization and trial planning process.

Given the limited capacity in the research teams, it may be useful to explore these technology questions in other sites in other provinces, such as Guangxi Province. Nevertheless, the point here is that a useful technology is the essential first step in moving forward, and working with a number of research teams in different sites increases the chances of progress in this important dimension.

Vietnam: According to the 1991/92 nationwide survey of cassava production and utilization in Vietnam, 89% of cassava produced in the northern region is grown on sloping land, compared to only 29% in the southern region. The focus of the project on the northern region is, therefore, appropriate. However, the three sites reflect markedly different situations, with very different implications for next steps. Vietnam has been most successful at introducing a broader spectrum of technologies of interest to the farmer. This is partly due to the much shorter research history for cassava in Vietnam, as compared with Thailand or Indonesia, and partly to the intensity of management of these upland systems where cassava is the dominent crop. An erosion control technology based on *Tephrosia candida* live barriers has emerged from the FPR trials as an acceptable technology, at least in Dong Rang and Phong Linh villages. Vietnam is in many ways a composite of expansion paths in the other three countries, and like China ash gone through a relatively recent process (1990) of allocating lowlands through long-term leases, and is still in the process of allocating uplands.

In Dong Rang and Phong Linh villages, which are managed by the Soils and Fertilizer Research Institute, there are questions of how to scale up the *Tephrosia candida* technology within the village - although not nearly so challenging a technology as vetiver in Thailand. In Dong Rang village there is evidence of illegal expansion onto steep slopes that by law should be left fallow or in forest. Some discrimination of technology by land forms might be useful in planning for scaling up. There has already been significant adoption of *Tephrosia candida* barriers based on seed supplied by NISF. Integrating this process into community structures might be useful, as well as some monitoring and evaluation of this scaling up. When this process is well underway-varietal adoption and *Tephrosia candida* multiplication is also advanced - the site could serve as a demonstration site for extension of technologies and methods to other villages in the district or province. This is already planned by NISF and the institute might usefully consider alternative dissemination modes, such as the village as a demonstration site for both these methods and technologies, farmer-to-farmer extension methods, Farmer Field Schools or alternative farmer training models, and video techniques. Within the overall Nippon Foundation project, the NISF sites offer the greatest potential for exploring efficient dissemination models where access to a well developed extension system is not possible. The Phong Linh site offers similar potential without access to unallocated steep land; like Thailand, land has been mostly allocated in narrow fields up and down the slope.

This provides another avenue for exploring community-based scaling up methods, which the farmers indicated they were interested in trying.

The Pho Yen sites are managed by Thai Nguyen University, and represent areas similar to Indonesia where upland areas are already largely terraced and are quite intensively managed, with intercropping predominating. New varieties have been the primary source of farmer adoption in this area and the site is interesting in terms of the movement by farmers to farmer designed varietal evaluation (and multiplication) trials established independently of the researchers. This is a useful process to monitor and evaluate within the overall scope of the Nippon Foundation project. There may be some scope for expanding FPR to other components in the system such as peanut intercropping, although the potential gains here remained unclear. Given the committed team at the university, another site more typical of the conditions in the NISF sites, would be recommended.

The Vietnam program offers the potential for methodological innovation in a number of directions, with potential for spillover into each of the other three countries. However, this will require increasing the exposure of the relatively small teams to relevant FPR experience in other projects and to a broader base of literature - also a problem given the constraints on language capability, especially for the younger researchers. Donors such as Ford Foundation, that has an office in Vietnam, support work in just this area and might augment project resources. There are possible linkages to the CIP program in Vietnam, which is staffed by an agricultural economist.

Indonesia: Cassava has been an integral part of the upland cropping systems in Indonesia for far longer than any other part of Asia. A wider range of varieties and cropping systems are found there, along with a higher degree of heterogeneity in how cassava is integrated into production systems. This diversity exists within some of the most intensive cropping systems in the region. Most of the upland areas are already terraced, agroforestry is integrated into more marginal upland niches and cassava's relative role in the cropping system depends partly on food preferences and partly on market opportunities and profitability relative to other crops. In such a context, any technology that provides a productivity or profitability advantage is rapidly adopted.

The FPR methodology that worked so well in the other countries was least effective for upland conditions on Java. The erosion trials obviously depend on a minimum slope and in many instances these trials were either unrepresentative of principal land forms in the site or were created by actually taking out existing bunds. Farmers rapidly perceived the advantage of potassium fertilization of cassava, unfortunately made unprofitable or unavailable by the rapid price change of imported commodities with the precipitate devaluation of the rupiah. Live barriers, in fact, compete with other commodities on terrace borders, including cassava. Thus, *Gliricidia,* elephant grass, and *Leucaena* offered some advantages as a dry season forage, although cassava leaves provide a similar fodder resource. Finally, new varieties in Indonesia must compete with indigenous clones that have a long history of selection for particular ecological niches. While farmers are keenly interested in new varieties, it is far more difficult to compete with these well-adapted indigenous clones.

These particular features of Javanese upland systems define three critical features of an FPR program. First, unlike the other countries the approach should be based on production systems rather than just a singular focus on cassava. However, this requires efficient and accurate methods of site characterization, access to and knowledge about a broad range of possible technological interventions, and methods for testing production systems - all three issues are at or beyond the cutting edge of FPR methods. Second, given the rapid uptake of useful technologies, the FPR strategy should be to rapidly test any particularly suitable technologies in any particular village or site and then move to another site. Recommendation domains are probably quite narrow in the Javanese uplands and the trick is to develop rapid FPR methods that allow efficient coverage of mandate areas - again a cutting edge issue in FPR. Finally, the institution should have a mandate and capacity for adaptive research. Such an institute, the Assessment Institute for Agricultural Technology (BPTP), was recently created within AARD and depending on its capacity (not assessed by the review team), provides the logical vehicle for FPR research.

Fostering Diversity in FPR Methods

As implied by the country summaries above, the review team recommends developing a second generation of FPR tools, moving from a standardized methodology across countries to one that develops methods most needed within the countries and sites. The overall project should be a vehicle for developing and testing an interacting body of FPR methods that meets the needs of taking the project to scale. As such this project offers the opportunity to move FPR methods out of the diagnostic strait jacket in which most FPR work is currently concentrated. We see this as the logical evolution of the very solid foundations that have been developed during the first phase of the project, and as providing innovation in FPR methods in response to very clear and different needs in the project sites. Such a division of labor is sketched in **Table 4**.

If the project adopts this course - and by no means is this the only option - there are certain implications in how the project organizes itself. First, there will be a shift in focus of project and field level activities from the current concentration on research trials to research on methods, although within the context of application to problems arising in the FPR sites. This is an organizational and conceptual shift. The national FPR teams would have to understand and agree to such a shift, particularly as it moves them from an area where they feel comfortable to one which requires a large degree of learning by doing. Second, the project would have to access and assess a wider range of FPR experience than is available in the region. Much of this experience is not published and requires interaction with FPR practitioners - one vehicle for this would be the list server for the CG system-wide initiative on FPR. Third, the backstopping required from the coordination office would certainly increase, especially in conceptualizing and planning project activities. More flexibility would also be required, as the set of activities organized around crop calendars is much easier to plan. In this regard, a strong socio-economics input into project backstopping would be important. There are options in how this might be done, from a project staff position to collaborative activities with the two CIP socio-economists in the region to consulting contracts with those FPR experts working in the different areas - each of these obviously having different cost implications.

Table 4. FPR methods development.

FPR Method	China	Indonesia	Thailand	Vietnam
Characterization				
-Regional RRA and site selection	+++	+++		++
-Site characterization	++	++		+
Diagnosis in complex production systems		+++		
Farmer experiments	++			+++
Within-farm technology scaling up[1)]			+++	++
Farmer Research Coordinating Committees[2)]			+++	++
Technology dissemination and farmer training			+++	+++
Monitoring and evaluation				
-Technology/Trials	+++	++	++	++
-FPR methods		++	+++	+++

[1)] mainly for hedgerow technologies
[2)] community nurseries, research planning and execution, across-farms contouring

The project should not underestimate what is required in terms of this conceptual shift in the FPR teams. The research teams' experience with FPR methods is limited and primarily defined in terms of the different categories of trials in the current FPR approach. Researchers see the advantages of providing farmers with more choice, rather than the traditional approach of prescribing a new variety, an improved fertilizer recommendation, or even a soil conservation technique, for example vetiver. The introduction of farmer choice plays out in terms of key distinctions between types of trials. Thus, there are on-farm trials managed by researchers - for example, the RILET trials in Malang - demonstration trials managed by researchers from which farmers make selections, and FPR trials incorporating these selections and under farmer management, but with a significant involvement of researchers in their design and data collection. This has been an effective way of changing traditional researcher practice, but researchers' understanding of FPR largely ends there. Researchers noted the expansion of farmer designed and managed varietal trials in Pho Yen, Vietnam, but did not know how to incorporate such trials into their FPR activities, or how to build upon this process of farmer experimentation. The project iss now at a stage where researchers should be encouraged to move to a wider conceptualization of what constitutes FPR practice.

The real test of soil conservation technologies comes in their application at a whole-farm scale. There is little FPR experience and therefore virtually no methodology to guide this work, yet the FPR projects in both Thailand and Vietnam now must address this issue. Application at higher scales tests such issues as labor constraints, provision of planting or seed materials, establishment problems where management is much less intensive, and capital constraints. Whether alternatives can be experimented with at this scale is an issue, possibly comparing different methods between farms. Joint action is often a feature of some of the problems and constraints, e.g. village level nurseries or contour formation across farm borders. Understanding farmers' choice and decision-making becomes more relevant at this scale, and because experimentation potential is reduced, other avenues of learning and evaluation must be pursued. How FPR research teams think through and plan this next set of activities will test the validity of combining FPR trials with methods development.

Cross Cutting Issues for FPR

Models to extend technologies developed through FPR

All pilot sites began their FPR with the same process. First a training for research and extension personnel. Next diagnosis and site selection. Then demonstration trials in farmers fields. And finally, design of FPR trials by cassava team members and farmers. In all cases, FPR led to the identification of superior technologies and combinations of technologies, and at least initial stages of farmer adoption of selected technologies. At this stage, the most critical issue is how to increase the numbers of farmers that are able to benefit from the technological packages developed through FPR, which is one of the targets for the next phase of the project.

Integrated agricultural systems

As farmers become more familiar with the activities and scope of FPR, a natural extension of this project is to shift from a strict cassava-based approach to broader components of agricultural systems. Farmers in Vietnam expressed a desire to conduct FPR on pigs and chickens, to which they feed much of the cassava they produce. Farmers in Thailand mentioned that one of their biggest problems is marketing and pre-sale processing.

The challenge with any integrated systems approach is that financial and other resources limit the extent to which it is possible to study different components of the integrated. Some teams may find it important to conduct FPR on variety selection for intercrops to be grown with cassava, cassava utilization, or other components of the system. Teams may need to seek inputs from other experts. To the extent possible, the project should encourage FPR teams to address important components of their agricultural systems in addition to cassava.

Institutionalization of FPR

In addition to developing technologies that improve agricultural sustainability, the project can have a major impact if it contributes to the institutional adoption of FPR as a standard tool for technology development and dissemination. Many researchers remain skeptical of FPR's value. Through continued technological impacts, the project may teach researchers, extensionists, and administrators of the appropriate use of FPR, which problems FPR can solve, and how to extend technologies developed through FPR. Project leaders should explicitly encourage participating researchers and extensionists to promote FPR at their own institutions through presentation of seminars and publishing scientific papers outside of the traditional FPR literature.

Research balance

FPR does not stand alone. The approximate allocation of resources in this project is 70% for FPR and 30% for on-station or on-farm strategic and applied research, which we agree is the proper allocation for this project. As institutions assimilate FPP into their overall portfolio of activities, they need to consider the best balance between different research modes. The balance should not be static, but clearly they should allocate resources to FPR to solve problems for which researchers claim to have developed adequate knowledge and technology without commensurate farmer adoption of technologies.

Gender equity

Farmer participants in this project included nearly equal numbers of men and women. Except in Indonesia where only men participated in discussion, we observed no gender bias for either the project activities or suitability of adopted technologies.

From FPR to FPIDT

Active participation of extension personnel is essential and will become more essential as the next phase of the project shifts its emphasis from developing FPR methods to extending FPR methods and results. To attract greater participation of extension personnel, it may be worthwhile considering a more inclusive name. Some extension personnel may shy from FPR merely because of the word *Research*, which belongs in another department. Some options are Farmer Participatory Technology Development and Transfer (FPTDT), or FP Technology Development and Dissemination (FPTDD).

Models for extending FPR

The project proposal for the next phase lists as an objective that it will test various models to extend technologies developed through FPR, but the proposal does not describe those models. The following list of models is not exclusive. The project may consider testing these or other models, either singly or in combination.

1. Farmer-to-farmer extension. Pilot sites host field days at harvest and during crop season for farmers and village leaders from neighboring villages within a 25 to 50 km radius. Suitably trained farmers from the pilot site would visit other villages with research and extension personnel on request of villages that would like to adopt FPR identified technologies. Preferably farmers in the new village would develop their own FPR trials using their own resources and receiving only guidance from formal project participants. Alternately, farmers in the new village could move directly to technology adoption.

2. Establish new pilot sites. Once farmers of a particular village have adopted technologies identified through FPR, reduce FPR activities in that village and initiate new pilot sites. This model must balance the needs for long-term research on agricultural sustainability, with needs to extend technologies to as many farmers as possible.

3. Training trainers. Leverage project resources through training members of research and extension teams for other commodities, NGOs, and other institutions interested in improving agricultural sustainability or natural resource management. These trainers would use their own resources to conduct FPR.

4. Communications media. All participating countries have made video tapes of their training courses. Through appropriate editing, they may produce training videos appropriate to show to farmer groups, extension groups, or aired on television. Though beyond the scope of this project, some institutions may be able to produce such videos with their own resources and the project may encourage and guide them in this effort.

Institutional Issues Within FPR

CIAT's FPR project for cassava-based systems in Asia represents a dominant trend in the CGIAR to organize and undertake research through and as partner with national institutions. CIAT facilitates and backstops the research, but local researchers within national institutions actually carry out the trials and activities. Such projects build local capacity along with the research, provide a conduct for new ideas into often isolated research institutes, and when organized within a network framework, allow for cross-country learning and innovation. The downside is that such projects require experienced researchers with a broad range of skills; there are significant time lags in project start up and institutional learning curves requiring longer project periods to meet multiple and intersecting objectives; and the project must have the capacity to develop and source new ideas, methods, and research results that makes the project attractive to Asian researchers and institutions.

A principal project objective is to strengthen national institutional capacity for generating and transferring appropriate crop/soil management practices. This is done within a context of significant institutional diversity across countries, significant organizational barriers to inter-institutional collaboration within countries – as discussed below, a necessity for successful FPR research – and an almost universal lack of capacity in socio-economic research to support the field research sites within the NARS institutions with principal responsibility for executing the project. The idea of an institutional model for both FPR and soil conservation must recognize this diversity and work within existing institutional structures – although there is a question, addressed below, of where to locate most effectively such a project. We leave open the question of whether a generalized model is in fact possible, with an alternative conception being to gauge how certain critical fractions are integrated into different institutional structures.

The challenge of institutionalizing FPR within Asian research and extension systems should not be underestimated. These systems tend to have a strong hierarchial structure. Decision-making is centralized, where information, methods, and techniques tend to flow downward, resulting in widespread replication rather than adaptation to local conditions. New technologies tend to focus on varieties that pass through restrictive testing and release systems. District or provincial capacity is structured to implement nationally designed programs and campaigns, with little capacity for lingkages or collaboration between field personnel of different institutions.

FPR as a method is designed to give farmers choice, to allow adaptation of technology to local conditions, to provide an avenue for upward flow of information from farmers and within institutions, and to decentralize decision-making to the field. As such, FPR represents a significant change in how research and extension systems undertake their work and clearly FPR programs will not be incorporated wholly or quickly within such systems. Rather, there will be a process of introduction, experimentation, and institutional change around these methods and the challenge is to guide and understand that process within any particular institutional context.

The CIAT project has adopted an appropriate and effective strategy to institutionalize FPR methods. That is, the process starts at selected district or provincial offices with training, pilot field sites, and experimenting with new methods of interaction with farmers. A focus on soil conservation moves the technology issues out of strict variety or commodity boundaries to consideration of more components and complexity within the production system. To date, the project has built on the long-term institutional and personal relationships CIAT scientists have had with cassava researchers in the region, and has started with a standardized model for all four countries. Again, this is logical and an appropriate starting point. However, the next phase should start to adapt to the institutional diversity found in each of the project countries. This section discusses some issues the project might consider in a next phase.

A. project Interaction with CIAT Headquarters

During the course of the project, program and funding structures within CIAT and within the CGIAR have changed radically. IARCs have moved from organizing and funding research around programs to projects. Projects are grouped around themes but nevertheless they function as relatively autonomous entities within relatively fixed time frames. The linkages between this project and CIAT headquarters have necessarily changed in the process. The CIAT cassava program no longer exists. The Nippon Foundation project now resides within a larger CIAT project on Small-holder Farming Systems. The positions for cassava economist and cassava physiologist/soil scientist at CIAT headquarters have been eliminated. Also, the CIAT cassava breeder based in Asia has recently resigned, with some uncertainty as to whether that position will continue with another breeder. The project acitivities have relied primarily on the senior agronomist funded within the project itself.

These changes raise a number of issues for a possible next phase. CIAT is effective in the region because of the goodwill and personal capital developed with cassava researchers and their institutes over 20 years. However, there is little sustained capacity at CIAT on which this project can draw, yet there is the need to access advances in research and methodology in FPR, soil conservation, and cassava research. The new structure of the IARCs forces projects such as this one to establish linkages with such capacities wherever they exist, most often outside of CIAT headquarters, and especially if they exist in the region. The projects' interactions with CIP's regional program is logical and has been productive. IBSRAM is a possibility, but as yet their capacity in FPR remains limited and their focus is on very steep slopes. The project could usefully review the IPM Farmer Field School experience in the region, as utilized by CIP and others.

There is an emerging body of experience applying FPR methods to soil management and soil and water conservation problems. In Latin America, especially in Honduras and Mexico, this has focused primarily on green manure cover crops. KIT has developed participatory methods to understand organic resource flows within livestock-cropping systems in Mali. CIMMYT is starting to utilize participatory methods in its soil fertility network in Southern Africa. Finally, much of CIAT's participatory research network in eastern Africa deals with soil management issues. The Nippon Foundation project could usefully exchange experience with many of these projects, particularly as a source of new ideas for what is an emergent capacity in Southeast Asia.

B. Institutionalizing FPR in Research and Extension Systems

The CIAT FPR project has been successful by applying a relatively standardized model of demonstration plots, FPR trials, and farmer evaluation in two or three pilot sites within institutions with which CIAT has had a long-term working relationship. However, as Farrington (1998) has noted, the real test of FPR methods is in how efficiently they can be scaled up and "where wide-scale replicability should be a key design criterion." Intensive interaction with farmers over extended periods of time, complemented by research trials, is expensive. It places heavy demands on researchers' time and on travel, and vehicle and operational costs. More importantly, higher costs come with direct interaction with only a limited number of farmers. The test of FPR is how to reach more farmers at significantly lower costs. How to do that is the challenge for a possible next phase. Complementing the suggestions for FPR methods, the design of institutional strategies has to take into account the large differences between countries in research and extension systems.

The project to date has been based in cassava research programs. Where cassava is a priority crop, such as in Thailand, there is a rationale for basing an FPR project focused on soil conservation within a commodity research framework. Where systems are more complex, as in Indonesia where cassava is one among three or four major crops in the system, an adaptive research unit would be more appropriate. This is possible in Indonesia where such an institutional capacity has recently been developed in BPTP. It is more difficult in China and Vietnam where there is no adaptive research capacity and extension is weak. There the work has to continue to be an extension of an on-farm research capacity within the cassava or soils research programs.

FPR is a methodological approach applicable to all-farm research. As the experience with farming systems research indicates, separate farming systems or FPR units are not the solution to institutionalization, as they tend to be staffed by junior personnel and are isolated from the on-going research of the institute. FPR methods have been particularly effective within adaptive research teams, natural resource management research, and research on particularly complex system components such as soil conservation or IPM. There is not a unique solution to where to locate FPR within research and extension systems. FPR must be adapted to the existing organizational structure and problem context – although we can expect some organic institutional change in response to incorporating these methods.

Locating FPR within national cassava research programs offers limited capacity for scaling up the number of FPR sites or the dissemination of proven technologies. Cassava research programs in Asia tend to be small and have limited transportation and operational resources. They tend to be restricted to sites relatively close to the research institute and can independently manage only a limited number of field sites, in addition to other ongoing research responsibilities. As such, any impact with FPR has to have inherent within it a strategy for replication, usually requiring linkages to other institutes. Some of the issues that influence such a strategy are found in **Table 5**, with suggestions for institutional dimensions through which to implement such a scaling up.

Central to a scaling-up mode is the decision to expand the number of FPR sites or to move to dissemination of technologies developed within FPR sites. Factors influencing this decision are the degree of cassava dominance in the system, homogeneity in land forms, and complexity and heterogeneity in the production/farming system. Significant heterogeneity between "recommendation domains" result in a strategy focused on efficient expansion in the number of FPR sites, usually combined with withdrawal from older sites. Such should be the strategy in Indonesia and eventually in China and Vietnam. When there is more homogeneity, and usually simplicity in the system, dissemination of technologies developed in FPR sites through effective linkage to extension systems is the preferred route to scaling up. This should be the strategy in Thailand, if whole-farm scale methods can be developed for hedgerow technologies.

Table 5. Factors influencing FPR institutionalization strategy.

	Thailand	Indonesia	China	Vietnam
Adaptive research units	RRDO[1)]	BPTP[2)]	No	No
Research-extension linkages	Good with potential to be better	Ineffective outside rice	Minimal	Variable
Government priority for cassava	High	Low	Low	Low
Centralization of decision-making	National	National/ Provincial	Institute/ Provincial	Institute/ Provincial
Institutional scaling-up	RRDO or through Provincial Extension Office	BPTP	Provincial cassava research teams	Provincial cassava research teams

[1)] RRDO = Regional Research and Development Office
[2)] BPTP = Assessment Institute for Agric. Technology

C. Possible Country Strategies

Thailand: Thailand is probably the only country that offers the scope for rapid institutional scaling up of FPR, based on dissemination of FPR results rather than expanding the number of FPR sites. As was argued in the last section, issues in the application of live barrier, particularly vetiver, technology in their application at a whole-farm scale, need to be resolved. Given that, the project can advantageously use the hierarchical structure of both research and extension, together with the fact that cassava is a priority crop in Thailand, as a vehicle for rapid scaling up. Within the Rice and Field Crops Promotion Division of the Department of Agricultural Extension (DOAE) there is a cassava group and people directly responsible for and with a budget for the expansion of the cassava FPR program. Given the good working relations between the DOAE and the Department of Agricultural (DOA), and the number and distribution of research centers with capacity in cassava, joint research and extension FPR teams at a district or provincial level are possible. Targeting particular districts and developing a strategy and plan for farmer training – probably in association with the Thai Tapioca Development Institute – and technology dissemination through farmer-to-farmer extension would form the core of programs organized at the provincial level. The recently established Regional Research and Development Office (RRDO under DOA), may become another vehicle for participatory technology testing and dissemination.

Indonesia: The design elements for an institutional strategy in Indonesia include efficient regional and site characterization methods, FPR trials in selected villages for one to two years, and then repeating the process in other villages. Such a strategy is most logically executed by the adaptive research unit of AARD, BPTP. However, given its relatively recent formation, questions remain about its capacity. Moreover, there is a key question of how BPTP sources technology and research expertise for a range of crops and soil management problems. Building an initial linkage between BPTP and the cassava group in RILET would be the logical first step in exploring this issue.

China and Vietnam: Both countries present similar institutional constraints. Research is decentralized in universities and provincial or regional research institutes, extension is relatively weak and dependent on local government structures, and resources available to both research and extension are very limited. FPR programs are built around research capacity wherever it exists, with site selection partially dependent on the capability of local extension personnel. The balance between expanding the number of FPR sites and moving to a dissemination mode within a district (rarely a province) will be based on relative heterogeneity in production systems in the district. How many separate institutes the project can accommodate and backstop in these two countries will obviously be an issue.

CONCLUSION AND RECOMMENDATIONS

Conclusions

The project has made significant and sustained progress toward its broad goals. It has established and trained FPR teams in four countries, in itself a challenging undertaking. The FPR teams established pilot sites and implemented initial FPR methodologies within a common framework. Pilot sites and FPR teams cover a broad range of soils, slopes, history of cassava cultivation, intensity of land use, and institutional capacities. Although the FPR teams differed in effectiveness depending on levels of governmental support, inter-institutional cooperation, and availability of new cassava technologies to farmers, all FPR teams were successful in establishing demonstration plots in farmers fields. These demonstration plots included either contour ridges or contour hedgerows for soil erosion control, fertilizer and organic matter amendments, improved cassava varieties, and several intercrop species. From these demonstration plots, farmers selected treatments for FPR trials and have conducted three to four seasons of FPR. It is too early in the FPR process to assess how farmer adoption of new technologies will affect incomes or sustainability of agricultural systems, but in all pilot sites farmers had identified technologies that they adopted in at least part of their fields. In some sites, neighboring farmers were also beginning to adopt or test improved technologies.

Support from CIAT outside project funding has included support to cassava breeding through a senior scientist posted to Bangkok until March'98, and a continuing flow of seed-based crosses from CIAT/Colombia. A CIAT project on forages for small holders (FSP) has provided guidance and planting materials in the use of hedgerow species. CIAT has provided resource scientists to conduct training courses and workshops on FPR methodologies. CIAT also provides some logistical support to the project, such as performing soil and tissue analyses. CIAT's ability to support the project has been constrained by changes in its organizational structure, by declining funding levels, and by the distance of CIAT headquarters from Southeast Asia. Despite these constraints, CIAT has supported the project to the extent of its abilities.

The project has made good use of other sources of support and information. The Asian Cassava Research Network has assembled many sources of information from the region and beyond. The network facilitates communication among project participants for germplasm and information exchange. Proceedings from network workshops are a valuable resource for FPR and other cassava researchers. In Thailand, the Thai Tapioca Development Institute (TTDI) has worked closely with the project leader to establish demonstration plots for erosion control and soil management. Through TTDI, project results have gone out to about 7000 farmers each year. The project has also interacted with complementary projects in some of the sites, notably CIP in Vietnam. In the future, information may become available from new activities of IBSRAM and IRRI.

Although only one of the countries participating in the project includes cassava among their priority crops for research and extension, they all produce significant amounts of cassava, and cassava plays an important role in the disadvantaged agricultural areas. Thus, the project is highly relevant, but may not have the visibility that it merits. Cassava production in Indonesia, with its long history of cassava cultivation and research, with one of the highest levels of cassava production in the region, probably benefited least during the first phase of this project. This was because farmers already cultivated relatively high yielding varieties in an intensively managed system in which cassava was not the most important component.

Distance and communication barriers have somewhat hindered development of close collaboration among the project countries. From its regional nature, the project benefited from shared training courses, transfer of ideas and innovations among sites, and germplasm exchange. Farmers in Vietnam have begun to adopt cassava varieties developed in Thailand. Such benefits would not have accrued at nearly the same level with a bilateral project.

Cassava farmers at all pilot sites expressed great appreciation for the project. They liked the close interaction with researchers and the fact that they could see the performance of new technologies in their own fields. The level of farmer interest in the project has varied with time. In Soeng Saang, Thailand, farmers quickly selected the new technologies they wanted and converted from FPR to technology adoption. More than 125 farmers met with the review team during our visits to the pilot sites to discuss their findings and to show their FPR trials. Farmers' willingness to spend their time with us during a period of intense agricultural activity at several sites attests to a high level of farmer interest and project relevance to farmers.

Not only are farmers enthusiastic about the technologies they have selected from FPR trials, farmers in several sites reported increases in income and productivity, reduction in erosion, and increased efficiency of input use. Still, a second phase of the project is needed to build on the excellent foundation that has been established during the first phase. As future FPR continues to adapt new technologies to farmer conditions, we expect economic and environmental benefits to grow. These economic and environmental benefits should represent a highly positive return on investment in the second phase of the project.

Recommendations

1. We endorse the outstanding accomplishments of this project and strongly recommend that the Nippon Foundation support a second phase. Including start-up and development of FPR methods, five years is too short a time for a project to have significant technology adoption or environmental and economic benefits.
2. A second phase is needed to develop methods for extending or scaling up of technologies that have been adopted at pilot sites. We recommend an approach that develops methods for extending FPR research that are tailored to each of the sites, depending on the intensity of cultivation, the importance of cassava, and relative capacities of the different research teams.
3. In the second phase, the project should promote efforts to institutionalize FPR methods within the national programs. These efforts may require solicitation of support for project activities at higher administrative levels of the participating institutions.
4. Many of the FPR methods and technologies developed in the project should be suited to adoption in crops other than cassava. We recommend that FPR teams distribute their findings as widely as possible within their own and other institutions and promote the use of FPR to solve other agricultural problems for which traditional research has developed technologies that farmers do not adopt.

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THE USE OF CASSAVA LEAF SILAGE FOR FEEDING GROWING PIGS AND SOWS IN CENTRAL VIETNAM

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ABSTRACT

This study aimed at using cassava leaves, ensiled with rice bran, sugar molasses and cassava root meal (at 5 and 10% levels), as a protein source for growing pigs and pregnant Mong Cai sows. The added ingredients contributed to producing good quality silage (pH 3.8 or less; HCN 90-120 mg/kg fresh silage) which could be stored for up to five months.

Digestibility and nitrogen balance trials were conducted to evaluate the substitution of fish meal by ensiled cassava leaves (ECL) at the levels of 0, 50, 75 and 100 g/day of protein in diets based on ensiled cassava roots (ECR). There was an indication (P = 0.08) that apparent digestibility of the dry matter (DM) decreased with increasing levels of ECL. The decrease in crude protein (CP) digestibility, from 86.6 to 79.6 for 100 g/day substitution, was highly significant (P = 0.001). Nitrogen retention also decreased from 14.5 to 9.0 g/day when ECL was used at the level of 100 g/day of protein.

The inclusion of 10% ensiled cassava leaves as replacement for sweetpotato vines and partial replacement for fishmeal in growing Mong Cai gilt had no effect on reproductive performance. However, at the 20% level, the live weight gain of gilts was decreased, age at first mating was increased from 170 to 196 days, and live weight increased from 40.2 to 43.8 kg.

Twenty-four crossbred pigs (Mong Cai x Large White) were allocated (4 pigs/household) among two groups of families to compare the effect of supplementing the traditional diet with ensiled cassava leaves. The overall difference was not significant and no effect on the growth of pigs was observed.

In another 16 households, feeding of 15% ensiled cassava leaves to Mong Cai sows during pregnancy, as replacement for sweetpotato vines and partial replacement of fishmeal, had no effect on reproductive traits.

INTRODUCTION

In Central Vietnam, the ingredients used by farmers in pig feeds are generally low in protein, as they consist mainly of cassava root meal and rice by-products. Conventional protein sources such as fishmeal, soybean, fermented fish and groundnut meal, are expensive and rarely available. So, it is very important to identify local sources of protein, particularly those that can be produced by small-scale farmers.

Cassava is considered the third most important food crop after rice and sweet-potato. About 702,000 tonnes of fresh roots are produced annually in Central Vietnam, which are used both as human food and animal feed. At harvest, the fresh leaves are a potentially valuable by-product (about 10% of the weight of the fresh roots) but are rarely used for animal feed. Cassava leaves are high in protein and thus have good potential as an animal feed. Limitations to its use for monogastric animals are due to its high fibre content and low protein digestibility (Abdelsanie and Tanggend, 1981). Buitrago (1990) mentioned that the greatest limitation to the use of cassava as animal feed is its high content of potentially toxic cyanogenic glycosides. Sun-drying, artificial dehydration and ensiling have been used as means of conserving the leaves and reducing the cyanide content. Sun

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drying is difficult in Central Vietnam because harvesting coincides with the rainy season. Ensiling is thus the preferred technology.

The objective of these experiments was to identify appropriate preservation methods of cassava leaves by ensiling with different additions of sugar molasses, rice bran and cassava root meal, and to evaluate the use of ensiled cassava leaves for feeding pigs under farm conditions in Central Vietnam.

EXPERIMENTAL RESULTS

Experiment 1. The effect of additives on the quality of ensiled cassava leaves

Fresh leaves of cassava were collected at time of root harvest and these were ensiled together with either sugar molasses, rice bran or cassava root meal at inclusion levels of 0, 5 or 10% (fresh basis). The leaves were separated from the stems and petioles, chopped into small pieces (2-3 cm), mixed with salt (0.5%) and one of the additives (no additive in the control treatment), and then put in plastic bags, taking care to eliminate the air by packing the contents tightly. There were 7 bags for each additive level so that sampling could take place at 0, 7, 14, 21, 28 and 56 days as well as at 6 months after ensiling. After sampling the rest of the contents was discarded.

The silage was analyzed for pH, dry matter (DM), crude protein (CP) and HCN (AOAC, 1988) at 0, 7, 14, 21, 28 and 56 days after ensiling. The analyses were done in the University laboratories.

The inclusion of the additives (at levels of 5 and 10%) resulted in good quality silage, which had an acceptable aroma for pigs, with no mould growth and good keeping quality for at least five months. Without the additives the silage deteriorated after two months.

The effect of additives on pH at various times after ensiling is shown in **Figure 1**. The pH of both types of silage decreased quickly to 3.7-4.1 at 28 days of ensiling, but was maintained at close to that level until 56 days. With additives in the silage the pH decreased more rapidly and remained at a low level of 3.7 at 28 and 56 days; without additives the pH of silage decreased to 4.1 at 28 days and then increased to 4.3 at 56 days of ensiling.

The effect of various additives on dry matter, crude protein and HCN content of ensiled cassava leaves is shown in **Tables 1** and **2** and in **Figure 2**, respectively. **Table 1** shows that for both additive supported silage and the control silage without additive the DM content decreased slightly from 0 to 56 days of ensiling.

The crude protein content (**Table 2**) for additive supported silage decreased slightly from 0 to 56 days of ensiling; without additives, the crude protein content decreased slightly from 0 to 28 days and then decreased quickly from 28 to 56 days of ensiling.

Figure 2 shows that the HCN content of ensiled cassava leaves decreased very quickly from 0 to 28 days and then further decreased until 56 days of ensiling. The HCN was about 8, 30 and 25% lower in additive supported silage than in the control silage without additives at 0, 28 and 56 days of ensiling, respectively.

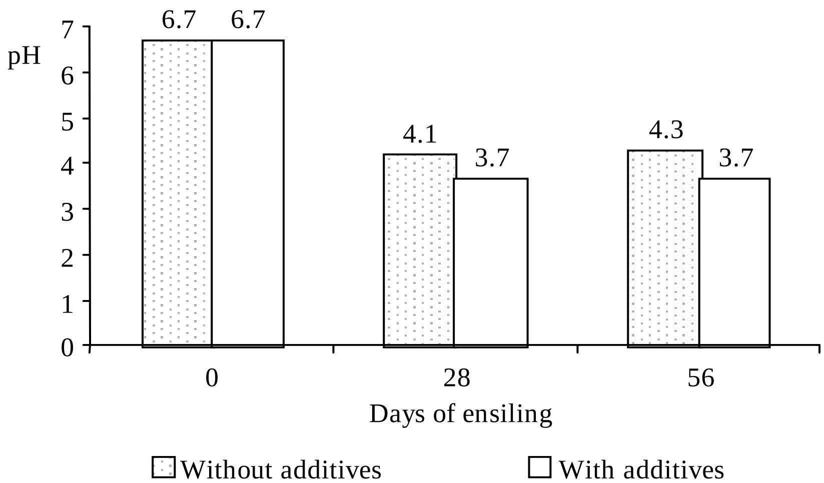

Figure 1. Average effect of three additives and two levels of inclusion on the pH of ensiled cassava leaves at various times after ensiling.

Table 1. Effect of additives and time on the dry matter content of ensiled cassava leaves.

Treatments[1)]	0	7	14	21	28	56
	(Days of ensiling)					
	Dry matter (%)					
Control	28.73	28.86	28.60	28.70	28.80	27.24
M5	31.96	31.85	31.18	30.45	30.57	30.70
M10	33.93	33.8	32.40	29.88	29.16	29.35
CR5	31.69	33.19	32.12	32.10	32.30	31.14
CR10	34.70	35.27	33.40	33.60	33.80	33.99
RB5	33.75	33.70	30.90	30.46	30.76	30.50
RB10	34.81	34.20	33.60	32.70	32.90	32.67

[1)] M= "A" molasses; CR= cassava root meal; RB= rice bran; 5 and 10 refer to % inclusion.

Table 2. Effect of additives and time on the content of crude protein of ensiled cassava leaves.

Treatments[1)]	0	7	14	21	28	56
	(Days of ensiling)					
	Crude protein content (%)					
Control	29.65	29.49	29.23	29.46	27.40	23.34
M5	28.77	28.68	26.75	26.05	26.33	25.78
M10	25.91	23.92	23.52	23.86	23.32	24.09
CR5	29.23	29.90	29.54	27.55	28.29	26.54
CR10	26.82	24.92	24.89	24.47	24.91	24.21
RB5	29.79	29.41	28.19	27.85	27.17	27.23
RB10	27.88	26.72	25.98	25.53	25.84	25.09

[1)]M= “A” molasses; CR= cassava root meal; RB= rice bran; 5 and 10 refer to % inclusion.

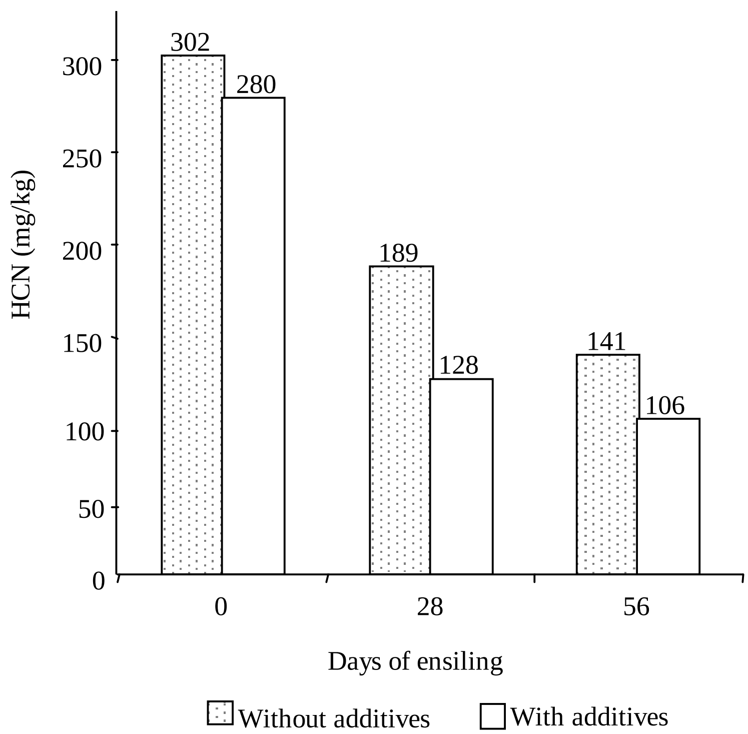

Figure 2. Average effect of three additives and two levels of inclusion on the HCN concentration (fresh weight basis) of ensiled cassava leaves at various times after ensiling.

Experiment 2. Digestibility and nitrogen retention in fattening pigs fed different levels of ensiled cassava leaves (ECL)

Animals

The various diets were randomly allocated to eight F1 (Mong Cai x Large White) castrated male pigs with initial weight of 48-50 kg at four months of age. The pigs were housed individually in metabolism cages that allowed the separate collection of urine and feces. The experimental periods were 10 days: 5 days for adaptation and 5 days for collection of feces and urine.

Treatments and experimental design

The four treatments were:

1. ECL_0: Fish meal (150 g CP/day) + ensiled cassava roots (ECR) provided *ad-libitum*.
2. ECL_{50}: The same as ECL_0 but 50 g of protein from fish meal replaced by ECL
3. ECL_{75}: The same as ECL_0 but 75 g of protein from fish meal replaced by ECL
4. ECL_{100}: The same as ECL_0 but 100 g of protein from fish meal replaced by ECL.

The experimental design was a double 4 x 4 Latin square arrangement.

The digestibility and N retention for different levels of ECL inclusion in the diets of fattening pigs is shown in **Table 3**. The data indicate that there were no statistically significant differences of DM digestibility (p=0.13), but that the N digestibility and nitrogen retention decreased markedly as levels of ECL increased.

Daily nitrogen retention decrease significantly (p=0.001) from 14.2 g/day for the ECL_0 diet to 9.9 g/day for ECL_{100}, a similar fall to that reported by Bui Huy Nhu Phuc *et al* (1996). The values were high and there were significant differences (p=0.03) in the nitrogen retained as percentage of nitrogen consumed.

Table 3. Digestibility and N retention for different levels of ensiled cassava leaves (ECL) used for fattening pigs.

Parameters	ECL_0	ECL_{50}	ECL_{75}	ECL_{100}	Standard error	Prob.
	Treatments					
DM intake (g/day)	1260	1226	1251	1191	42	0.62
DM in feces (g)	126	129	158	124	11.53	0.15
DM digestibility (%)	90	89.5	87.4	89.6	0.82	0.13
N intake (g/day)	24.9	23.7	24.2	20.3	1.02	0.02
N in feces (g/day)	3.3	3.6	4.8	4.1	0.36	0.04
N digestion (g/day)	21.6	20.1	19.4	16.2	0.89	0.002
N digestibility (%)	87	85	80	80	1.3	0.001
N in urine (g/day)	7.5	6.2	7.4	6.3	0.64	0.37
N retention (g/day)	14.2	13.8	12.0	9.9	0.72	0.001
% N retention/N digested	66	69	63	61	2.81	0.23
% N retention/N intake	57	58	50	48	2.59	0.03

Experiment 3. Effect of ensiled cassava leaves in the diet of Mong Cai female pigs on reproductive performance

Animals and experimental designs

Twelve Mong Cai female pigs (gilts) of 14 kg live weight were randomly allocated to three treatments (four gilts/ treatment) with four replicates (one pen for each pig) per treatment. **Table 4** shows the nutritional characteristics of the diets at three stages of development.

Table 4. Diet of Mong Cai gilts at three stages of development for three treatments.

Diet characteristics	10-20	20-30	30-40
	Live weight (kg)		
Dry matter (kg/day)	0.86	1.04	1.32
Crude protein (g/day)	119	133	159
Metabolizable energy (MJ/kg DM)	8.2	10.5	13.7

Diets for Mong Cai gilts

Control diet: Rice bran, cassava root meal, fish meal and sweetpotato vines.
Treatment 1: 90% DM of control diet + 10% DM of ensiled cassava leaves.
Diet contains 25 to 50 ppm total HCN
Treatment 2: 80% DM of control diet + 20% DM of ensiled cassava leaves.
Diet contains 50 to 100 ppm total HCN

The effect of inclusion of ensiled cassava leaves at three levels in the diet of female Mong Cai pigs on reproductive traits is shown in **Figures 3**, **4a** and **4b** and in **Table 5**.

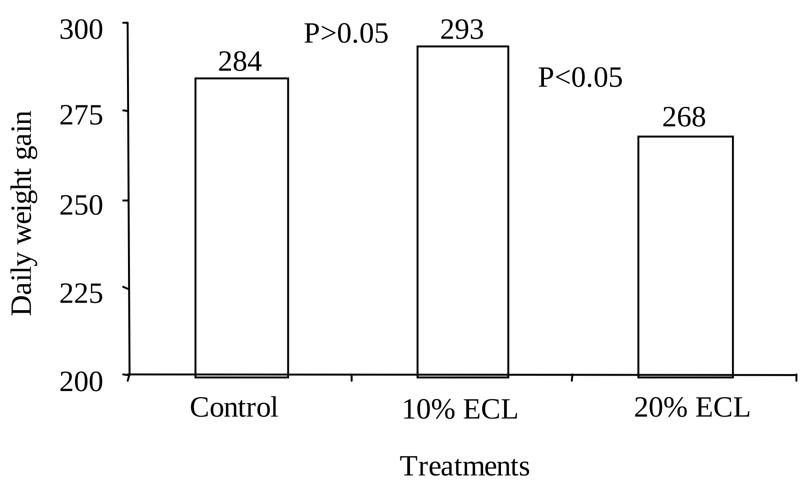

Figure 3. Effect of three levels of inclusion of ensiled cassava leaves (ECL) in the diet on daily weight gain of Mong Cai gilts.

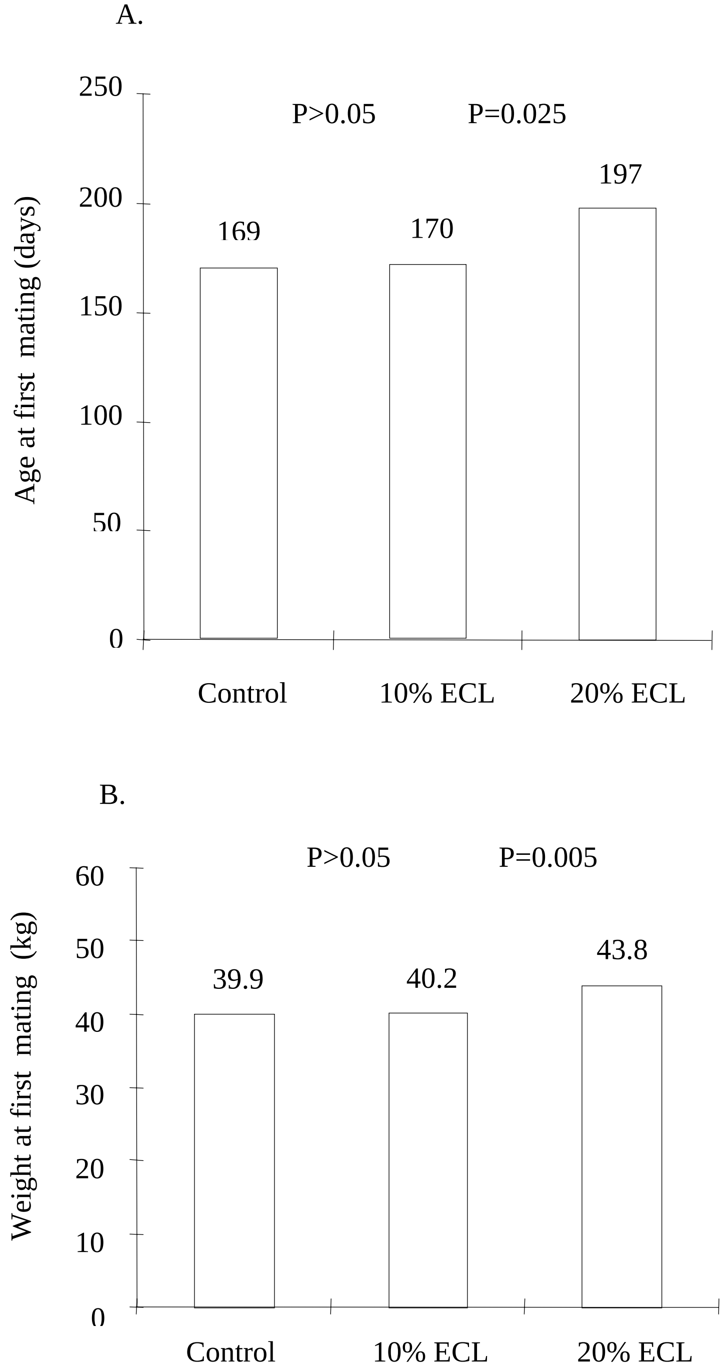

Figure 4. Effect of three levels of inclusion of ensiled cassava leaves (ECL) on age (A) and weight (B) at first mating of Mong Cai gilts.

Table 5. Effect of three levels of inclusion of ensiled cassava leaves (ECL) in the gilt diet on the reproductive performance of sows.

	ECL_0	ECL_{10}	ECL_{20}	Standard error	Prob.
	Treatments				
Initial live weight (kg)	14.2	14.1	14.9	0.39	0.321
Live weight gain of gilt (g/day)	284a	293a	268b	7.90	0.117
No. of live piglets born	7.00	7.75	6.67	0.73	0.542
Mean weight of piglets (kg)	0.72	0.72	0.67	0.155	0.05
No. of pigs weaned	6.67	7.50	6.67	0.629	0.528
Mean pig weight at weaning (kg)	7.3	7.1	7.1	0.20	0.792

Note: Values followed by the same letter in the row are not statistically significant at p = 0.05

Figure 3 shows that the daily gain of gilts at the level of 20% inclusion of ECL was significantly lower ($p < 0.05$) than those of the control and ECL_{10} treatments. Similar findings were reported by Tewe *et al*. (1984), who also reported a significant reduction in serum thyroxin levels in growing pigs fed cassava diets containing 96 ppm total cyanide.

Figures 4A and **4B** indicate that the age and live weight at first mating of the ECL_{20} treatment was significantly higher than those of the control and ECL_{10} treatments (p=0,025 and p=0.005, respectively). There were no significant differences between treatments for these parameters at furrowing and weaning ($p > 0.05$).

Experiment 4. The use of ensiled cassava leaves in growing pigs rations

The experiment was carried out in six households of Thuy Xuan village, Hue provinces from June to Oct 1997. Six families raised a total of 24 pigs, all cross breeds between Mong Cai and Large White with live weights of around 23-25 kg (4 pigs/household). One group of pigs (three households) was fed the control diet: ECR + brewery by-product + rice bran + CRM + sweetpotato vines, provided *ad-libitum*. The second group of pigs was fed the experimental diet: 90% control diet + 10% ECL. The experiment lasted for 120 days.

The effect of using ensiled cassava leaves in growing pig rations is shown in **Table 6**. There were no significant differences in daily weight gain and feed conversion ratio between the pigs fed the control diet and the ECL diet. Feed cost was lower with ensiled cassava leaves supplementation. Using a 10% of DM inclusion of ensiled cassava leaves in the pigs' ration did not effect the growth rate but significantly reduced feed cost/kg gain (p = 0.001).

Experiment 5. Effect of ensiled cassava leaves in the diet of pregnant sows on reproductive performance

The experiment was carried out in 16 households of Huong Van village, Hue province, from Oct to Aug 1998. Sixteen Mong Cai sows at the third litter stage were randomly allocated to two treatments in 16 households. The ingredients and quantity fed to the Mong Cai sows are given in **Table 7**.

Table 6. Effect of inclusion of ensiled cassava leaves (ECL) on the performance of growing pigs.

	ECL	Control	Standard error	Prob.
	Treatments			
Live weight (kg)				
- initial	25.8	23.3	0.89	0.06
- final	78.1	74.5	1.02	0.02
Daily gain (g/day)	435	426	0.01	0.34
DM feed conversion	4.99	4.81	0.16	0.43
Feed cost/kg gain (dong)	9,357	11,143	280	0.001

Table 7. Ingredients in the diets of pregnant sows of Mong Cai pigs (60-70 kg) and diet characteristics in Huong Van village.

	Control[1)]		ECL[2)]	
	DM (kg/day)	% of DM	DM (kg/day)	% of DM
Rice bran	0.79	57.9	0.79	56.8
Cassava root meal	0.23	16.5	0.23	16.2
Fermented fish	0.15	11.0	0.06	5.0
Sweetpotato vines	0.20	14.6	0.1	7.2
Ensiled cassava leaves	0	0	0.21	14.8
Dry matter (kg/day)	1.37	100.0	1.39	100.0
Metabolizable energy (MJ/kg DM)	14.0		14.1	
Crude protein (g/day)	186		186	

[1)]Control treatment: rice bran, cassava root meal, fermented fish, sweetpotato vines.
[2)]ECL_{15} = 15% ensiled cassava leaves in the diet.

Control treatment: rice bran, cassava root meal, fermented fish and sweetpotato vines.
Experimental treatment: 85% DM of the traditional diet +15% DM of ECL. This diet contains on average 45 ppm total HCN. The composition of the diets for sows during lactation (% of DM): rice bran 28%, cassava root meal 27%, broken rice 17%, fermented fish 11%, sweetpotato vines 13%, bone meal 4%. Total DM: 2.17 kg, ME (MJ/kg): 13.5 and CP: 287 g.

The effect of using ensiled cassava leaves in the diet of pregnant sows is shown in **Table 8**. There were no significant differences between the two treatments for all the measured reproductive parameters of sows, except for the effect on mean pig weight at weaning. It is possible that this improved performance with inclusion of ensiled cassava leaves in the diet is related to the slightly lower number of piglets at weaning. These results agree with those of Tewe and Maner (1981).

Table 8. Effect of using ensiled cassava leaves in the diet for pregnant sows on reproductive traits.

	Control	ECL_{15}[1)]	Standard error	Prob.
No. of live piglets born	11.3	10.3	1.06	0.535
Mean weight of piglets (kg)	0.68	0.70	0.015	0.209
No. of pigs weaned	9.75	9.14	0.925	0.632
Mean pig weight at weaning (kg)	6.9	7.5	0.11	0.010
Total litter weight (kg)	67.04	68.97	4.57	0.777

[1)]ECL_{15} = 15% ensiled cassava leaves in the diet.

CONCLUSIONS

1. Ensiling cassava leaves supplimented with cassava root meal, rice bran or molasses at 5 or 10% (fresh basis) produced good quality silage that could be stored for up to five months.
2. Including 10% ensiled cassava leaves (on a DM basis) as replacement for sweetpotato vines and partial replacement for fish meal in diets of growing Mong Cai gilts and fattening pigs had no effect on reproductive performance and on growth. However, at the 20% level, the live weight gain of gilts was lower, while age and live weight at first mating increased.
3. In households of 16 families, feeding of 15% ensiled cassava leaves to Mong Cai sows during pregnancy, as partial replacement of sweetpotato vines and fermented fish had no significant effect on reproductive traits at farrowing and weaning.
4. Ensiled cassava leaves can be used as a protein source for feeding pigs under village conditions.

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THE USE OF DRY CASSAVA ROOTS AND SILAGE FROM LEAVES FOR PIG FEEDING IN YUNNAN PROVINCE OF CHINA

Liu Jian Ping[1] and Zhuang Zhong Tang[1]

ABSTRACT

Since 1990 we have undertaken a large number of experiments and conducted research on the development and use of cassava roots and leaves as animal feed resources, in order to explore the possibility of substituting cassava-based feeds for those of grain, thus saving grain for human consumption that was previously used for feeding animals. We have conducted chemical analyses to determine the nutrient composition of cassava roots and leaves, conducted animal feeding trials using cassava, and experimented with the substitution of cassava-powder for maize in raising animals and fish, as well as the feeding of pigs with silage of cassava leaves. The results are very satisfactory.

At present we have introduced 32 improved varieties of cassava and we have set up a 200 ha production base for selection and multiplication of these varieties.

Use of cassava in animal feeds now accounts for 32.2% of total output of cassava in Yunnan province. The cassava cultivated area increased from 2,453 ha in 1988 (five counties) to 14,000 ha in 1998, resulting in a production increase of 6.5 times compared with the output in 1988. This has removed some of the competition between people and animals for grain, and promoted the development of animal husbandry in Honghe district.

INTRODUCTION

With the rapid development of the animal husbandry industry in Honghe district, there is more and more demand for animal feed, especially high energy feed from grains. But grain crop production can not meet the ever increasing demand for animal feed. Since 1990 we have conducted many experiments and have researched the possible use of cassava-based feed stuff in order to explore the possibility of substituting cassava for grain-based feeds. This would eliminate the existing competition between people and animals for grain crops. We have conducted chemical analyses to determine the nutrient composition of cassava roots and leaves, experimented with the use of cassava dry root powder to feed livestock, poultry and fish, and the use of cassava leaf silage to feed pigs. The results indicate that it is possible to substitute cassava roots and leaves for grain-based feeds.

For that reason we have introduced a series of improved varieties of cassava, such as Hainan 124 (SC124), Hainan 205 (SC205) and Nanzhi-188. In Yunnan the area planted with cassava was only 2,450 ha in 1988, but increased to 14,000 ha in 1998, a 5.7 times increase over the past ten years; production of dry cassava chips increased from 5,520 tonnes in 1988 to 36,200 tonnes in 1998.

The development and application of cassava feed resources have become an important measure to promote the development of animal husbandry in Honghe district. More then 140 million pigs were slaughtered in 1998. The slaughter rate reached 72%, an increase in number of 163% over the last ten years. The consumption of meat increased to an average of 37.8 kg per person, an increase of 425% over the last ten years. The total value of animal products reached 7.4 billion Yuan (RMB), an increase of 7 billion Yuan over the last ten years. The development and application of cassava-based feed resources

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helped alleviate the poverty of people living in mountainous areas. Farmers have greatly benefitted from cassava planting. The development of animal husbandry now meets the market needs for livestock and poultry products.

We have substituted dry cassava powder for maize in different proportions as an energy source in feed used for fattening pigs and the results are very satisfactory. Governments at all levels have paid attention to these experiments. The local government has put cassava planting as a feed resource into the grain crop development plan. Meanwhile, improved varieties of cassava were introduced and a 200 ha cassava varietal improvement area was set up. This would meet the needs of farmers for improved cassava. In 1998 about 65% of the total cassava cultivated area was planted with improved varieties. The Fudian Feed Processing Factory, under the Animal Husbandry and Veterinary Station of Honghe district, has researched and produced animal feeds based on cassava, and these enriched feed rations were well received by farmers when they were sold in the market. The project on the development and use of cassava-based feed resources has become a part of the Ninth 5-year National Economic Plan. In order to speed up the application and development of cassava feed resources in Honghe district, the governments and various departments involved at different levels have invested more than 7 million Yuan to support this project since 1994. A plan for the development of cassava has been drawn up and local governments, enterprises, collectives and farmers have been encouraged to develop cassava production.

It has been reported that the metabolizable energy (ME) of one kg of fresh cassava roots is about 3.6 MJ (0.860 Mcal), or 12.5 (2.99 Mcal) per kg dry powder (Kayouli and Lee, 1999), which is equivalent to about 12,900 Mcal per ha. For other crops this is: taro 3.3 MJ/kg fresh matter, sweetpotato 4.1 MJ and cassava leaves 1.1 MJ/kg fresh matter. Crude protein production is 16 g/kg dry cassava root powder and 235 g/kg dry leaf powder. Cassava starch consists mainly of carbohydrate ($C_6H_{12}O_6$), of which 80% is starch and 20% sugars. Two of the main constituents of starch are starch sugar and colloidal starch. Starch sugar is a linear polymer while colloidal starch is a branched polymer, which is more easily digested and absorbed by animals. It has been shown that feed grains in compound animal feeds can be replaced by cassava.

The nutrient composition of dry cassava roots is as follows:
Dry matter (DM): 87.0%; Gross energy (GE): 4.00 Mcal/kg; Digestable energy (DE): 3.50 Mcal/kg; Metabolizable energy (ME): 3.33 Mcal/kg; Crude protein (CP): 3.8%; Ether extractable (EE): 0.2%; Crude fibre (CF): 2.8%; Nitrogen-free extractable metabolic energy (NFE): 78.4%. The digestibility rate is: CP 68%, EE 23%, CF 76% and NFE 99%. **Tables 1** and **2** show the ash content of dry cassava root powder and the amino acid composition of protein in cassava roots, respectively.

EXPERIMENTS ON THE USE OF CASSAVA ROOTS AND LEAVES

1. Replacing Maize with Cassava Powder to Feed Fattening Pigs

The daily nutrient levels of the feed rations for fattening pigs are shown in **Table 3**.

Table 1. The ash content (mg/kg) of dry cassava roots.

	Parenchyma	Cortex
K_2O	41.58	14.70
P_2O_5	15.09	2.45
CaO	10.64	6.62
MgO	7.35	3.32
Na_2O	1.28	0.95
Fe_2O_3	0.66	2.45
SO_3	3.73	1.71
CO_2	0.91	2.51
SiO_2	0.94	10.94[1)]
SiO_2	7.15	52.58[2)]
Cl+	2.75	1.41

[1)]dissolved in Na_2O solution
[2)]not dissolved in Na_2O solution

Table 2. The amino acid composition of protein in cassava roots

Amino acid	mg/g of N	mg/100 g of roots
ILE	175	46
LEU	247	64
LYS	259	67
MET	83	22
CYS	90	23
PHE	156	21
TYR	100	26
THR	165	43
TRY	72	19
VAL	209	54
ARG	683	178
HIS	129	34
ALA	235	61
ASP	406	11
GLY	106	42
GLU	1009	262
SER	172	45
PRO	284	53

Table 3. The effect of replacing cassava powder for maize in feed rations for fattening pigs on the daily nutrient levels of feed.

Body weight of 20-35 kg	Experimental rations				
	1	2	3	4	Check
DE (Mcal/kg)	3.10	3.10	3.06	3.04	3.11
CP (%)	16.00	16.00	14.79	14.39	16.00
CF (%)	4.72	4.60	5.14	5.14	4.14
CA (%)	0.56	0.56	0.61	0.64	0.58
P (%)	0.46	0.46	0.43	0.41	0.46
LYS (%)	0.69	0.71	0.62	0.60	0.67
MET+CYS (%)	0.38	0.36	0.38	0.37	0.46
THR (%)	0.57	0.57	0.53	0.51	0.60
ILE (%)	0.64	0.63	0.55	0.53	0.62

Body weight of 35-60 kg	1	2	3	4	Check
DE (Mcal/kg)	3.10	3.10	3.04	3.02	3.10
CP (%)	14.02	14.01	12.89	12.47	14.15
CF (%)	4.35	4.18	4.75	4.75	4.75
CA (%)	0.65	0.66	0.72	0.73	0.67
0.54	0.54	0.52	0.55	0.54	0.59
LYS (%)	0.61	0.62	0.54	0.54	0.59
MET+CYS (%)	0.39	0.37	0.34	0.31	0.41
THR (%)	0.50	0.49	0.46	0.44	0.53
ILE (%)	0.54	0.55	0.48	0.46	0.55

Body weight of 60-90 kg	1	2	3	4	Check
DE (Mcal/kg)	3.10	3.10	3.04	3.02	3.10
CP (%)	13.01	13.02	11.80	11.35	13.03
CF (%)	4.30	4.19	4.74	4.74	4.74
CA (%)	0.65	0.67	0.65	0.66	0.61
P (%)	0.51	0.49	0.53	0.56	0.57
LYS (%)	0.54	0.55	0.47	0.45	0.52
MET+CYS (%)	0.36	0.36	0.32	0.30	0.40
THR (%)	0.47	0.47	0.43	0.41	0.50
ILE (%)	0.50	0.50	0.43	0.41	0.50

An experiment was conducted using 50 fattening pigs fed with two different rations: one is to replace 28.5 and 39.8% of maize with dry cassava powder in the daily ration; the other is to replace 60 and 80% of maize in the daily ration with dry cassava powder. We set up four groups and one check: each group consisted of 10 piglets. The check groups used basic feeds. The nutritional levels of feeds for groups 3 and 4 are slightly lower than those of groups 1 and 2. The experimental period was 87 days. The results are shown in **Table 4**.

Table 4. Results obtained in fattening of pigs using four experimental feed rations and a check treatment (see Table 3).

	Experimental rations				
	1	2	3	4	Check
Daily gain (gm)	723	740	681	701	681
Feed intake (kg)	2.66	2.69	2.68	2.78	2.69
Feed conversion rate[1])	3.17	3.66	3.97	3.92	3.95
Maize consumption (kg/kg gain)	0.68	0.34	0.77	0.38	1.93
Cost (Yuan/kg gain)	2.80	2.69	2.85	2.68	3.25
Benefit (Yuan/kg gain)	1.20	1.30	1.15	1.32	0.75

[1)]Feed conversion rate=kg of feed needed to produce 1 kg of body weight

Another experiment was conducted using 72 cross-bred piglets and replacing maize by cassava in ten farmer's families at Jinhe Town of Jinpin County. **Table 5** shows the daily nutrient levels in the feed rations of fattening pigs at three levels of body weight, and **Table 6** the daily feed composition and nutrient levels of four types of feed. The results are shown in **Table 7**.

Table 5. Nutrient concentration of daily feed rations of fattening pigs at three levels of body weight in experiments conducted with ten farmers in Jinhe town, Jinpin county, Yunnan, China.

	Weight 15-35 kg		Weight 35-60 kg		Weight over 60 kg	
	Experim. ration	Check	Experim. ration	Check	Experim. ration	Check
DE (Mcal/kg)	3.17	3.05	3.13	3.11	3.10	3.10
CP (%)	13.34	16.00	11.84	14.39	9.71	10.34
Ca (%)	1.11	1.09	0.91	0.90	0.72	0.71
P (%)	0.62	0.70	0.57	0.66	0.51	0.53
LYS (%)	0.63	0.73	0.55	0.64	0.43	0.46
MET+CYS (%)	0.39	0.52	0.35	0.48	0.28	0.32
THR (%)	0.48	0.61	0.42	0.54	0.32	0.35
CF (%)	5.92	5.50	7.18	0.76	8.54	8.44

Table 6. Composition (%) of daily feed rations using four types of feed tested by ten farmers for fattening pigs in Jinhe town, Jinpin county, Yunnan, China.

Feed	Weight 15-35 kg		Weight 35-60 kg		Weight over 60 kg	
	Experim. ration	Check	Experim. ration	Check	Experim. ration	Check
Concentrate[1)]	25	25	20	20	15	15
Maize	13	65	13	65	13	65
Cassava powder	52	-	52	-	52	-
Chaff	10	10	15	15	20	20

[1)]Concentrate produced by the Animal Husbandry and Veterinary Station of Honghe district.

Table 7. Results obtained in fattening pigs using two feed rations by ten farmers in Jinhe town, Jinpin county, Yunnan, China.

Items	Total number of piglets	Age at start of experim. (months)	Starting weight (kg)	Days of experim.	Final weight (kg)	Daily gain (kg)	Net income Yuan/pig	Feed conversion rate[1)]
Exp. groups	36	3	23.3	174	107.2	0.46	99.62	3.8
Check	36	3	22.7	179	101.9	0.44	63.68	3.9

[1)]Feed conversion rate = kg of feed needed to produce 1 kg of body weight.

2. Fattening Beef Cattle with Cassava Powder

The Animal Husbandry Bureau of Honghe district has conducted an experiment on fattening beef cattle of 10-24 months age using a certain amount of ammoniated molasses and ammoniated rice straw and adding 500 g cassava powder each day for each head of cattle. The experimental period was 87 days. The cattle gained 104 g per day more than using conventional feeds. The digestibility of cassava was CP 69%, EE 51%, CF 53%, and NFE 90%.

3. The Use of Cassava Powder to Raise Chickens

Reports from the Mengzhi Experimental Chicken Farm shows that if 173% of cassava powder was added to the feed, the body weight of chickens can be up to 2 kg after 49 days of feeding chickens; the CP was 3%, EE 10%, CF 4% and ME 76.3% higher than the check group.

4. The Use of Cassava Leaves as a Protein Source

Table 8 shows that dry cassava leaves have about 27% (some up to 38.6%) protein. Each hectare of cassava can produce annually about 2 tonnes of protein in the leaves, in which ß -carotene is 53 mg/100 g, and xanthophyl 92 mg/100 g. The leaves are high in amino acids except for methionine, which is below the critical value (**Table 9**). The amino acids in cassava leaf protein are richer than in soybean cake, oilcake and fish meal (**Tables**

10 and **11**). Sixty percent of protein can be extracted of which 90% is digestible. The crude fiber and ash contents in cassava leaves is very low (**Table 8**). Leaves can be easily mixed and combined with dry cassava powder without decreasing the digestion rate. Thus, cassava leaf protein can be a good ingredient in animal feeds.

Table 8. Nutrient compositions (%) of dry cassava and sweetpotato leaves and rice bran.

Items	Water	Crude protein	Crude fibre	Crude fat	NFE	Ash
Dry cassava leaves	9.02	27.50	12.28	11.81	31.79	5.38
Dry sweetpotato vine	11.50	9.60	24.00	3.90	43.60	8.50
Rice bran and broken rice	11.29	7.01	30.81	6.11	30.77	14.61
Rice bran	10.50	10.80	11.50	11.70	45.00	9.20

Table 9. Amino acid contents of dry cassava leaves (mg/100 g).

ASP	2002.91	CYS	107.85	PHE	992.33
THR	803.99	VAL	1108.40	LYS	824.24
SER	915.38	MET	196.44	NH3	435.55
GLU	3126.21	ILE	855.26	HIS	860.05
GLY	939.41	LEU	1623.15	ARG	532.33
ALA	1099.18	TYR	520.07	PRO	1096.28

[1)]Total amount: 18,059 mg/100 g.

Table 10. Protein (%) and amino acid (mg/100 g) content of dry cassava leaves in comparison with fodder grass, maize and soybean.

	Cassava leaves	Cassava leaves with petioles	Fodder grass	Maize	Soybean
CP	27.50	20.30	12.60	11.90	45.70
ARG	5.21	3.89	6.10	-	7.41
CYS	1.18	0.98	0.51	5.64	1.52
HIS	2.47	2.32	2.54	2.82	2.39
ILE	4.12	4.40	4.32	3.45	5.45
LEU	10.00	8.75	8.64	7.55	6.97
LYS	7.11	5.89	1.02	4.82	6.32
MET	1.45	1.83	1.86	1.36	1.52
PHE	3.87	4.37	5.42	5.82	4.79
THR	4.70	5.70	4.41	4.73	4.14
TRY	1.07	1.24	-	-	1.30
VAL	6.18	8.43	6.27	5.18	5.23

Table 11. The amino acid content (g/100 g) of protein in dry cassava leaves, soybean cake, oil cake and fish meal.

	Cassava leaf-protein	Soybean cake	Oil cake	Fish meal
ISO	3.17	2.43	1.01	3.23
LEU	5.89	3.49	1.88	5.42
LYS	4.26	3.06	1.34	5.81
MET	1.48	0.72	0.46	2.05
CYS	0.90	0.84	0.48	0.92
PHE	3.92	2.52	1.65	2.89
TYR	2.83	1.91	0.95	2.32
THR	3.27	2.15	1.06	3.18
VAL	4.10	2.64	1.40	3.82
ARG	4.36	3.57	3.40	4.60
HIS	1.51	1.28	0.79	1.93
GLS	3.64	2.24	1.33	5.35

5. Processing and Use of Cassava Leaves

We have used two types of technologies for feed processing; i.e. using the leaves only or the leaves with petioles for producing either dry powder or silage. Farmers did not use cassava leaves for feeding animals before because of the toxic levels of hydrocyanic acid that can poison pigs. Ensiling can solve this problem and maintain the nutrient composition (**Table 12**) increase microbial protein and improve the taste.

Table 12. Nutrient composition (%) of cassava leaf silage (on DM basis).

Water	Crude protein	Crude fat	Crude fibre	Ash	NEF	Ca	P
74.0	12.04	7.79	21.94	9.32	36.61	2.08	0.17

The ensiling process

There are two steps in making leaf silage:

Step 1: Reduction in the respiration rate of leaves

Leaf cells do not die immediately after picking but continue to respire; this will consume sugar:

$$C_6H_{12}O_6+6O_2\rightarrow 6CO_2+6H_2O+ATP+calories$$

Sugar in the cells is oxidized during leaf respiration, releasing ATP and heat. To produce 676 cal will consume 180 g of sugar. Oxygen is an important factor in leaf respiration; so, putting the fresh leaves into containers and sealing up the containers to reduce respiration is essential. If the heat can not be released, the temperature inside will go up to 76^{o}C which will produce a lot of aerobic bacteria and fungi, which makes the silage musty, can poison the animals and cause female animals to abort. Reducing respiration and lowering the temperature are very important. The way to do this is:

a. cut the leaves into pieces of about 2-5 cm
b. pack tighty in plastic bags or containers
c. seal these tightly

Step 2. Fermentation

Silage that is tightly sealed up produces three kinds of acids by anaerobic bacteria: lactic acid ($CH_3CH(OH)COOH$), acetic acid (CH_3COOH) and butanoic acid ($CH_3CH_2CH_2COOH$); of these lactic acid is the best one. Good ensiling produces ethanol and lactic acid by lactic acid bacteria which exists in leaves. It has been shown that one leaf contains between 100 and 1000 lactic acid bacteria. One kilogram of dry-matter contains 80 grams of acid in good quality silage. The more lactic acid, the lower the pH, and the less other bacteria. The multiplication of lactic acid bacteria is controlled by the amount of acid formed, which tends to reach a stable state after which the silage can be kept for a long time.

The control of water content is very important in silage making. According to common practice the most suitable water content is between 70% and 75% (not less than 55%). More water will cause the sugar and colloidal-matter in plant liquid to be diluted, which will damage the lactic acid bacteria and cause silage to be putrid. On the other hand, the air remaining inside the container will allow harmful microorganisms to multiply, resulting in bad silage. To avoid this, add dry feed such as rice bran. This is an effective method to avoid losing nutrients, control the moisture content and improve the quality of silage.

The formula for adding dry feed is as follows:

$$M = \frac{A-B}{C-D} \times 100, \text{ where}$$

M = amount of material to be added (per 100 kg), A = moisture content of material, B = desired moisture content of silage, C = fresh feed moisture requirement, D = dry feed moisture content.

The visual quality evaluation of silage is shown in **Table 13**, while the digestibility is shown in **Table 14**, and the amount of cassava leaf silage that can be fed to various animals is shown in **Table 15**.

CONCLUSIONS

The results of these and other experiments have shown that compound feed made from dry cassava roots and leaf silage has an advantage over maize with respect to taste, daily gain, feed conversion rate, and economic returns. Maize can be partially or completely replaced by cassava to feed various livestock and poultry. Cassava leaf silage has enormous value and can compensate for the lack of protein in cassava root powder, in order to meet the needs of animals for feed during winter and spring.

Cassava roots and leaves contain hydrocyanic acid, but this will be reduced to non-toxic levels by either drying or ensiling. We have not examined the amount of hydrocyanic acid because of lack of facilities, but no poisoning has occurred in veterinary clinical practice. No carcass of livestock and poultry examined by the Veterinary Health Department has shown any signs of toxins. Test results are included in the documentary records.

Table 13. The visual quality evaluation of silage.

	Very good	Good	Poor
Color	Green, yellow-green, Same as primary color	Yell-brown or dark brown	Black, brown or dark green
Smell	With strong smell	With irritating smell, light fragrant	Smelly or musty
Structure	Moist, tight; leaves keep their original shape; easy to be separated; not sticking to hands	Parts of leaves keep original shape; soft and loose; sticks slightly to hands	Putrid, pasty state; sticky or dry blocky structure; vein dim

Table 14. The digestibility of cassava leaf silage in various animals.

Animals	Digestibility (%)	
	Silage	Dry fodder
Cattle and sheep	75-85	55-60
Horses	50-60	30-40
Pigs	40-50	18-20

Table 15. The amount of cassava leaf silage[1] that can be fed to different animals.

	Daily ration
Cattle	(kg/100 kg of body weight)
- milkcows	5-7
- fattening cattle	4-5
- draft cattle	4-5
- breeding bulls	1.5-2
Sheep (or goat)	(kg/animal)
- ewe	3-6
- strong sheep	2-4
- fattening sheep	3-6
Pigs	(kg/animal)
- barren sows	2-4
- pregnant sows	1-2
- suckling sows	3-6
- fattening pigs	3-5

[1]mixed with rice bran and cassava root meal

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BIODEGRADABLE PLASTICS FROM CASSAVA STARCH IN THAILAND

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and Christopher G. Oates[3]

ABSTRACT

The paper reviews the role of starch and biodegradable plastics production in Thailand, emphasizing the potential contribution of cassava starch in these products. Types of biodegradable plastics and their manufacturing processes are described. The major types of biodegradable plastics discussed are directly-expanded starch products and various starch-polymer blends (PCL, PLA, PVA and PHA). Research focusing on cassava starch incorporation into biodegradable plastics is summarized.

INTRODUCTION

The world production of plastic is estimated to be more than 100 million tonnes per year. The need for such large quantities of conventional plastics and their dominance over other materials is due to their excellent "long-life" properties. These properties include resistance to chemical reactions, specially enzymatic reactions. For example, it can take up to one hundred years to degrade only a few grams of plastic (such as polyethylene) under normal environmental conditions. Degradation at high temperature, such as in pyrolysis (burning) tends to cause emission of toxic fumes. Plastic accumulation in the environment thus creates tremendous problems for the world, presently and in the future. Environmental problems caused by plastics include changes to the carbon dioxide cycle, problems in composting, and increased toxic emissions. Stimulated by environmental concerns, scientists are now concentrating on ways to develop plastic use more efficiently. Two simple strategies are to "recycle" (reuse), or to produce plastics that will degrade when no longer required.

Degradable plastics are grouped by the American Society for Testing and Materials (ASTM D20.96) as:

a) Photodegradable plastics – A degradable plastic in which the degradation results from the action of natural daylight;
b) Oxidatively degradable plastics – A degradable plastic in which the degradation results from oxidation;
c) Hydrolytically degradable plastics – A degradable plastic in which the degradation results from hydrolysis; and
d) Biodegradable plastics – A degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae.

As the plastics defined in categories a), b) and c) require additional inputs, such as light (UV) or oxygen for degradation, the biodegradable plastics (d) offer the only products which are "naturally" degradable.

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Biodegradable plastics are polymers or polymer blends, which in addition to possessing properties similar to conventional plastics are susceptible to “natural” enzyme hydrolysis or other chemical attack. The plastic is therefore either broken down to oligosaccharides or monomers, through “depolymerization”, or are degraded to gaseous components through mineralization. Starch, a natural polymer, is biodegradable and as such can play an important role in the biodegradable plastic manufacturing process. It is also inexpensive and renewable. In tropical countries cassava starch offers opportunities due to its purity, clearness of its paste and low cost of production. This starch also posseses properties that enable it to be blended with other expensive polymers required for producing biodegradable plastic. Projections for the requirement of biodegradable plastic, by the year 2000, is 1.68 million tonnes (**Table 1**).

Table 1. Projections of world consumption of biodegradable plastics in the year 2000.

Application	Quantity (million tonnes)
Trash bags	1.00
Agricultural	0.09
Food containers/utensils	0.18
One–way packaging	0.27
Food packaging	0.14
Total	1.68

Source: *Chemical Week, October 27, 1993.*

The “Cradle–To–Grave” concept (**Figure 1**) has been designed by the Michigan Biotechnology Institute (1994). As the end use of products from biodegradable plastic is composting, it can serve as a reserve for carbon dioxide and as a means to return nutrients back to the soil (as compost).

MANUFACTURING PROCESS TECHNOLOGY

1. Starch Puff

This kind of product is known also as “Gelatinized starch puff” or “Plate expanded by extrusion” or “Baking with water”. The products are formed by the swelling and expansion of starch through the action of high temperature and water vapor. The products formed in the extruder are starch foam, snack, etc (**Figures 2** and **3**). Plate expansion or baking give products such as waffles, which can be formed in tray shapes or other packaging material.

Clean Green Company in Minneapolis, MN, USA, has produced “starch foam” called “peanut” (American name of loose fill packing material) by extrusion of wheat starch (90 portion) and polyvinyl alcohol (10 portion). “Eco–Foam”, a product of National Starch, uses waxy corn as raw material. In European countries, the baking technology is also at a commercial scale. Packaging products, such as fast food utensils, are available in the market using both cereal and potato starches. The marketing of biodegradable packaging products are supported in the EU.

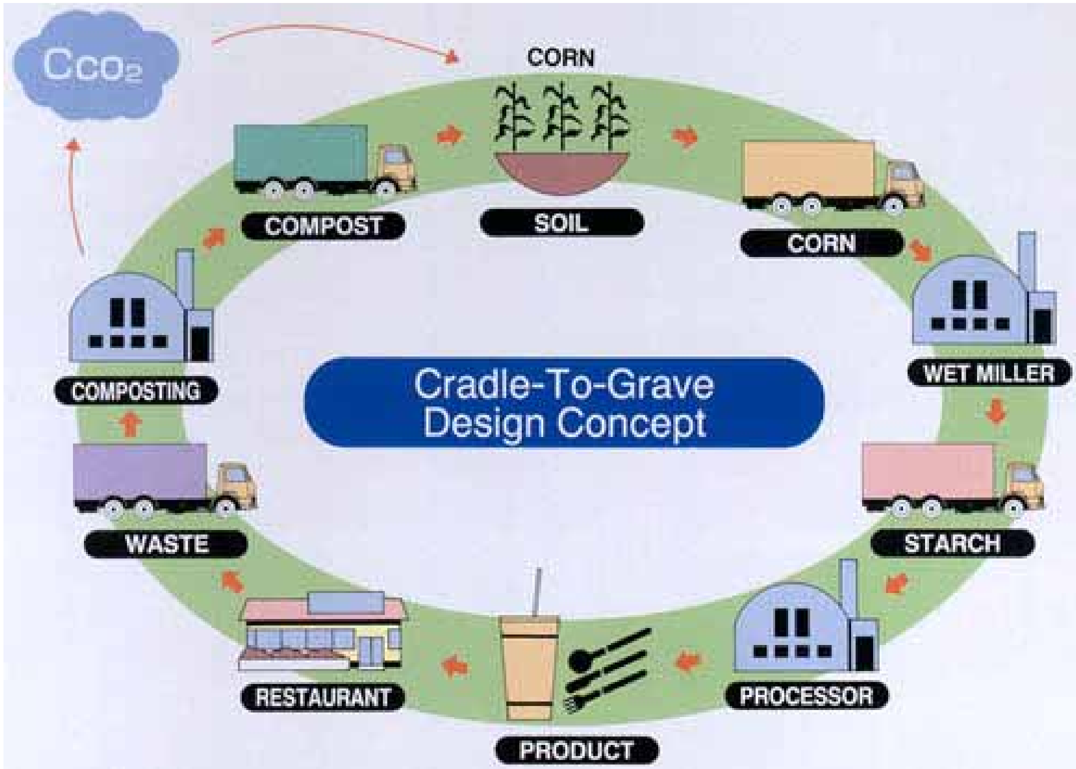


Figure 1. Design concept of biodegradable plastic "from cradle to grave".
***Source**: Michigan Biotechnology Institute, 1994.*

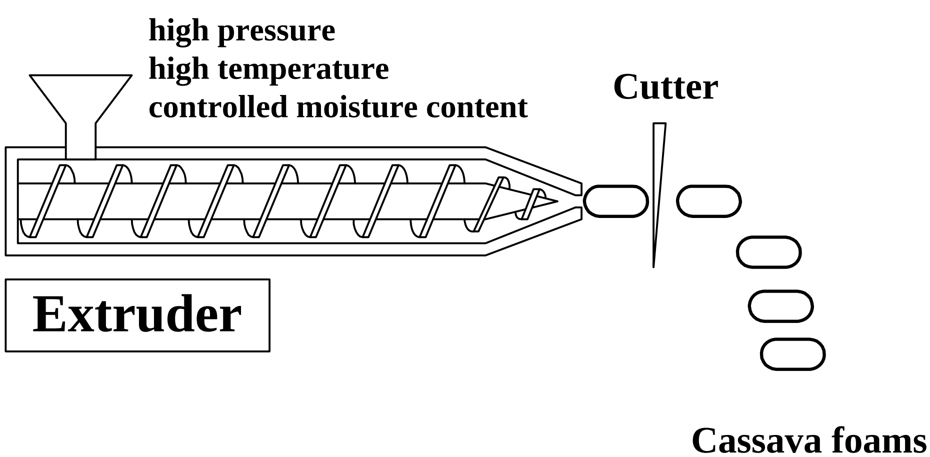


Figure 2. Extrusion of starch foam.

(a) (b)

Figure 3. Starch foam: (a) Pesika Naturpack GmbH; (b) Suedstraerke GmbH.

Cassava starch has been successfully expanded under extrusion conditions. Due to its low bulk density, a little modification is needed so that its moisture content is increased. Twin screw extrusion is recommended for direct expansion of cassava starches. Cassava starch can also be used as the raw material for plate expanded or baking products. Cassava starch can be expanded in moulds, at 200-240°C for 1-3 minutes, to form into package utensils, such as bowls. About 10% additives, including calcium carbonate, agar, or emulsifier are needed to improve the properties. The bulk density is reported in the range of 0.15 to 0.176 g/cm^3 (Poovarodom and Praditduang, 1999)

Even though this group of products has been introduced to the market for some time, and can be produced at reasonable cost, constraints to its wider adoption still exist. First, special machinery is required, such as high shear extruder (not plastic extruder), continuous molding machine with high temperature (continuous waffle moulds using high pressure and temperature). Thus, the investment cost for the machinery is high. Distribution of the products is limited, due to its rigidity and short shelf life. Further, these products can not be applied to high moisture conditions. Lamination with other polymers, to improve shelf life and tolerance to high moisture conditions, will increase production cost, and such polymers have to be approved before using as a food packaging material.

2. Polymer/Starch Blends

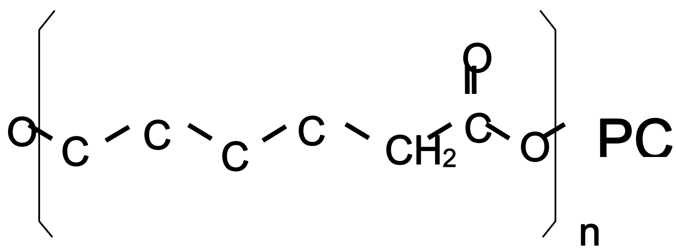
The biodegradable polymers (polylactic acid, polyhydroxyl butyrate) are in this group produced by fermentation (using starch hydrolysis products: glucose, maltose, etc.). The blending of polymers with starch under controlled conditions leads to co-polymerization that in turn results in high molecular polymers with thermoplastic properties. Though the mixing or blending needs special machinery, such as an extruder, the products (polymer blend) can be handled as easily as conventional plastic resin.

Polymer blends can be distributed or transported to normal plastic converters, which can process the blends to products using normal injection or blow moulds.

2.1 Polymers

Though starch, such as that of cassava, is used as a polymer, other polymers are frequently used in the blend:

a. Polycaprolactone



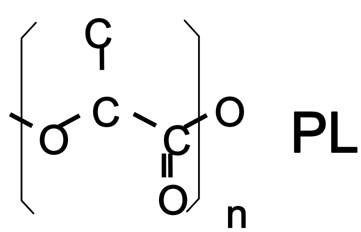
Mn = $4x10^4$ Tm = 62^oC

This polyester is manufactured by catalytic ring-opening polymerization of ε-caprolactone. Union Carbide is the biggest manufacturer (**Table 2**). Polycaprolactone blend is the most used polymer/starch blend because of its low melting temperature (Tm) and high susceptibility to amylase and lipase hydrolyses (Tokiwa *et al.*, 1990a; 1990b). A number of patents of polycaprolactone/starch blend are held:

- Michigan Biotechnology International (MBI), USA (US 5,578,691 etc.)
- Chuo Kajuku Co., Ltd, Japan (US 5,256,711 etc)
- Bioplastics Inc., Suite, Ml.
- Daicel Chemical Industries Co., Ltd, Japan
- Japan Corn Starch, Japan

Most patents describe a generic starch, this includes cassava.

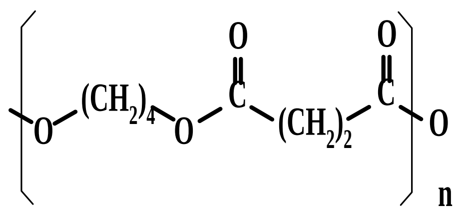
b. Polylactic acid



Mn = 1.88×10^5 Tm = 175^oC

This polyester is manufactured by catalytic ring-opening polymerization of lactide (dilactone of lactic acid). Cargill, Minneapolis, MN, USA is the biggest manufacturer (**Table 2**). Polylactic acid is used because lactic acid can be produced by microorganisms through a fermentation process. Many research laboratories in Japan claim that polylactic acid can be produced from a condensation-polymerization reaction of free lactic acid (from fermentation of starch). Polylactic acid from direct condensation polymerization is on the market under the names of “Lacty” (Shimadzu Corp. Japan) and “Lacea” (Mitsui Chemicals, Japan). These products offers the opportunity for a polymer blend totally derived from starch-based materials.

- Polybutylene succinate (PBS), and
- Polybutylene succinate/adipate (PBSA)

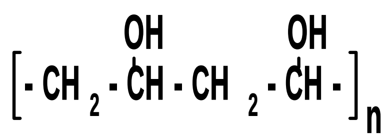


PBS

Mn = $3x10^4$ Tm = 96^oC

These products are derived from polycondensation of linear dicarboxylic acid with glycols. In the market they are sold under the name of “Bionolle” (Showa Highpolymer Inc., Japan); a wide range of molecular weights and properties are available.

c. Polyvinyl alcohol (PVA)



Mn = $7x10^4$ Tm = 180^oC

This is one of the most common synthetic polymers which can be easily biodegraded (Sakai *et al*., 1987). However due to its solubility, applications are limited.

d. Polyhydroxyalkanoates (PHA)

This group of products are obtained from microorganisms through a fermentation process. Properties can be thermoplastic to elastomeric depending on the monomers used. The most popular product of this group is poly (3–hydroxybutyrate) (PHV).

The manufacturers and prices of polymers are shown in **Table 2**.

Table 2. Manufacturers, capacity and cost of biodegradable polymers.

Company	Base Polymer	Feedstock	Cost ($/lb)	Capacity (10^6 million lb/yr)
Cargill, Minneapolis, MN	Polylactide (PLA)	Renewable resources, Maize	1.00-3.00	10('94 scale up) ;250(mid-1996)
Ecochem, Wilmington, DE	Polylactide Copolymers	Renewable resources, Cheese whey, Maize	<2.00 proj'd	0.15 ('94 scale up)
Zeneca (business unit of ICI)	Poly(hydroxybutyrate-co-hydroxyvalerate), PHBV	Renewable resources, Carbohydrates (glucose), organic acids	8.00-10.00; 4.00 proj'd	0.66, additional capacity slated for '96 is 11-22
Novamont, Montedison, Italy	Starch-synthetic polymer blend containing approx. 60% starch	Renewable resources Petrochemical	1.60-2.50	50, in Turni, Italy
Novon Products (Warner-Lambert), Morris Plains, NJ	Thermoplastic starch polymer compounded with 5-25% additives	Renewable resources, Starch	2.00-3.00	100
Union Carbide, Danbury, CT	Polycarpolactone (Tone polymer)	Petrochemical	2.70	<10
Air Products & Chemicals, Allentown, PA	Polyvinyl alcohol (PVOH) & Thermoplastic PVOH alloys (VINEX)	Petrochemical	1.0-1.25 (PVOH); 2.50-3.00(VINEX)	150-200 (water sol, PVOH); 5(VINEX)
National Starch & Chemicals, Bridgewater, NJ	Low DS starch ester	Renewable resources, Starch	2.00-3.00	Not available
MI Biotech Inst./GRT-Japan Corn Starch Joint Venture, MI	Water repellant, thermoplastic modified starches	Renewable resources, Starch	1.0-1.50	0.1 (pilot scale); 150 slated for early '96
Showa Highpolymer Co.,Ltd.	Condensation polymer of glycols with aliphatic dicarboxylic acids (BIONELLE)	Petrochemical	approx. 3.00	0.2 (pilot);7 (semi-commercial , end '94)
Shimadzu Corp. Technology Research Lab.	Poly (lactic acid) (Lacty)			Not available
Mitsui Chemicals, Inc.	Poly (lactic acid) (Lacea)			Not available

***Source**: Narayan, 1994.*

2.2 Blending techniques

There are four ways to blend starch with polymer:

a. Starch in the granular form

Mixing or blending starch with limited moisture content causes less loss of structure of the starch granule. Cassava starch can be completely gelatinized at 65-70°C with 45% moisture content, but the granule is maintained at a moisture content under 5%. The melting point (Tm) of dry cassava starch (almost anhydrous) is about 170°C. After blending polymers with granular starch, the structure consists of a continuous polymer phase with starch granules embedded and reinforcing the network. This increases the strength, water absorption and vapor permeability, and decreases the production cost (**Figure 4**).

b. Gelatinized starch

By controlling the moisture content, starch granule structure can be totally gelatinized at the same melting temperature as the polymer; thus, the two are blended together. This affords improved properties of elongation and tensile strength to the polymer (**Figure 4**).

c. Thermoplastic starch

Under severe extrusion conditions, low moisture content, high temperature and pressure, starch can be melted. This thermoplastic starch is then a single component continuous phase. Thermoplastic starch was patented by Werner-Pfleiderer Co., Ltd, Germany.

d. Modified starch

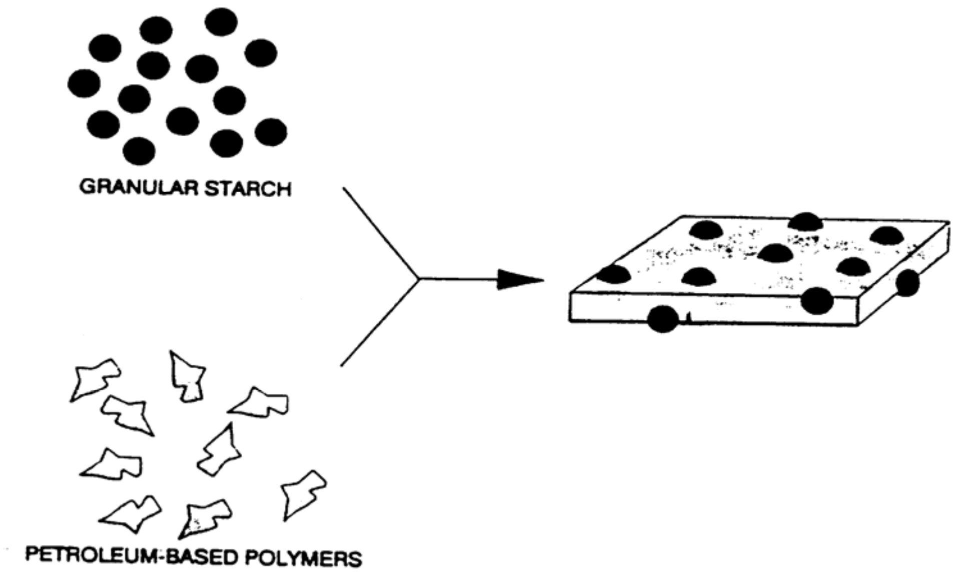
Modification of starch, such as addition of ester groups, to manipulate its properties supports the blending mechanism.

The manufacturing process is shown in **Figures 5** and **6**

Cassava starch blended with polycaprolactone (PCL) was developed in 1996 (Pranamuda *et al.*, 1996). Blended in the proportion of 50/50, the product exhibited a tensile strength of 3.9±0.4 MPa and % elongation of 240.9±56.7. The effect of varying the proportion of cassava starch to PCL has also been investigated (Chollakup *et al.*, 1998). The tensile strength and % elongation of these products are shown in **Table 3**. Other attempts to improve final product quality, such as irradiation treatment (Chollakup *et al.*, 1999a, **Table 4**), inclusion of silk protein to the blend (Chollakup *et al.*, 1999b, **Figure 7**) and addition of sucrose ester (SE) as plasticizer (Sriroth *et al.*, 1999; **Table 5**) have been reported.

The Cassava and Starch Technology Research Unit, a research unit supported by the National Center for Genetic Engineering and Biotechnology (BIOTEC), the Thai Tapioca Development Institute (TTDI), and Kasetsart University (KU), conducts research on modification of cassava starch for blending with polymers.

(a) Granular starch



(b) Gelatinized starch

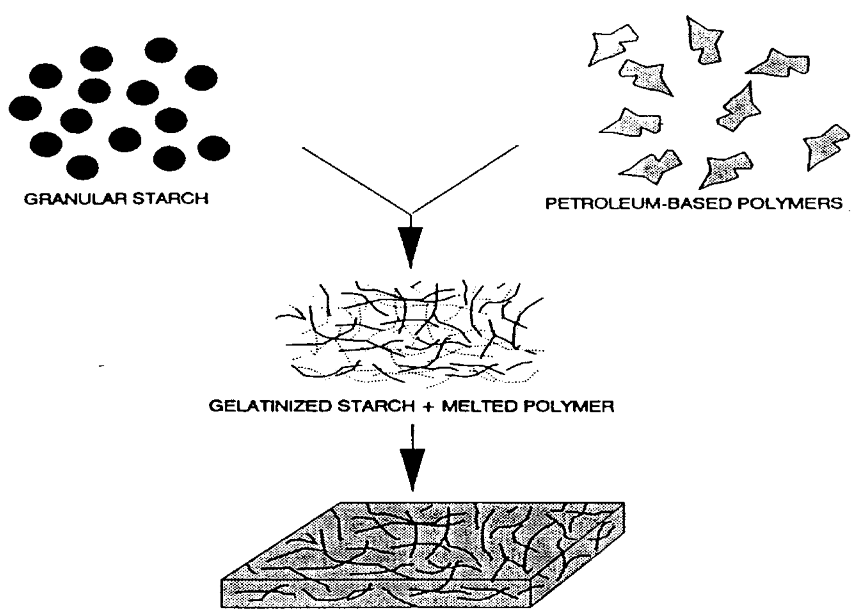


Figure 4. Characteristic of granular and gelatinized starch as blending material for polymer blend.
***Source**: Gould et al.,1990.*

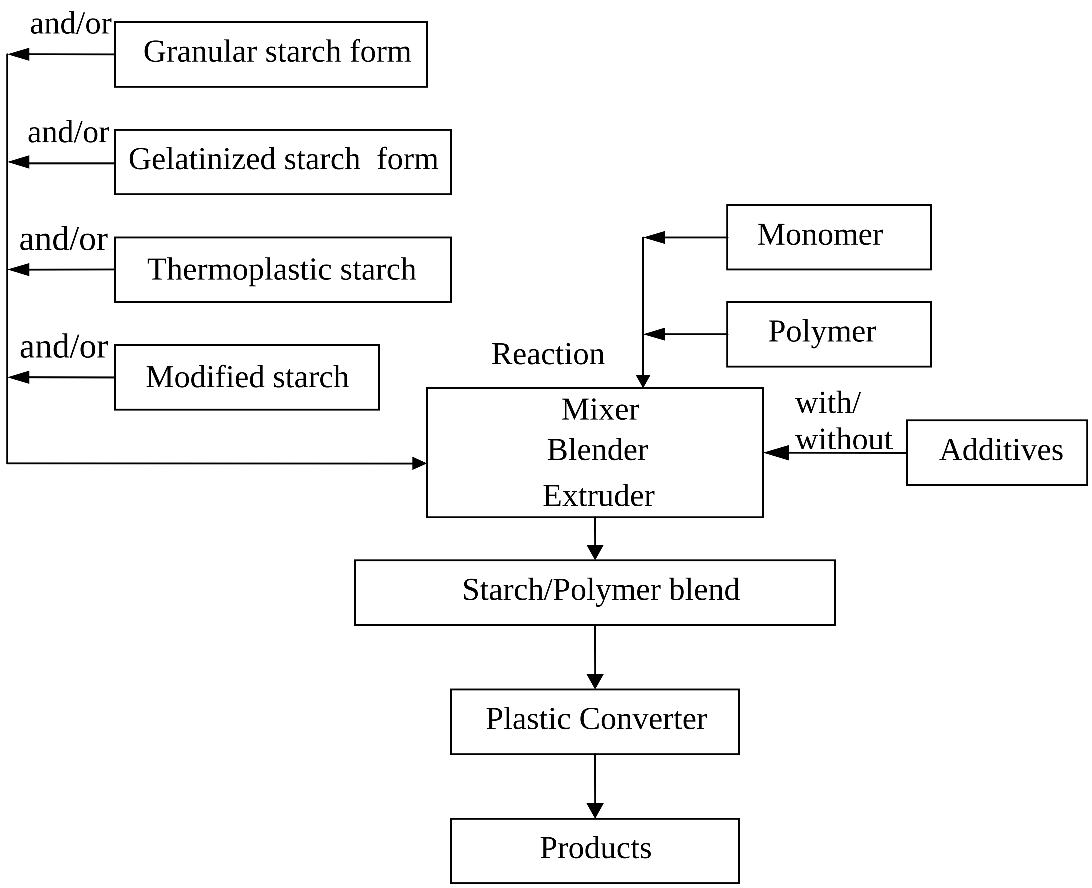


Figure 5. Biodegradable starch plastic manufacturing process.

Starch/Water/Polymer
or Plasticizer

Blend in
single screw extruder

Molding by
heat press machine

Testing mechanical properties and biodegradability

Figure 6. Extrusion process of biodegradable plastic.

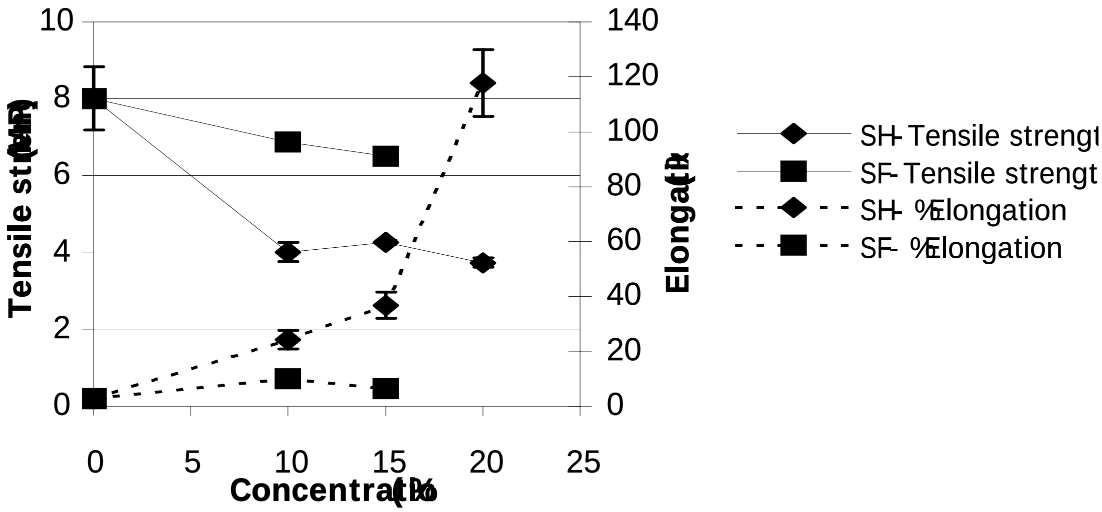
Table 3. Physical properties of cassava starch/PCL blends using granular (TS) and gelatinized (GS) starch in various proportions.

	Tensile strength (MPa)	Elongation (%)
Granular starch (TS)		
TS/PCL (0/100)	30.40 ± 4.6	613.40 ± 108.5
TS/PCL (10/90)	19.40 ± 3.4	435.50 ± 24.2
TS/PCL (20/80)	17.70 ± 0.6	401.60 ± 45.1
TS/PCL (30/70)	15.10 ± 1.3	406.60 ± 43.5
TS/PCL (40/60)	9.00 ± 0.6	297.80 ± 37.3
TS/PCL (50/50)	8.30 ± 0.7	276.80 ± 61.5
Gelatinized starch (GS)		
GS/PCL (0/100)	30.40 ± 4.60	613.40 ± 108.50
GS/PCL (10/90)	19.44 ± 3.00	388.97 ± 98.95
GS/PCL (20/80)	16.64 ± 0.95	394.19 ± 44.35
GS/PCL (30/70)	16.74 ± 0.95	396.65 ± 36.36
GS/PCL (40/60)	8.33 ± 0.47	132.48 ± 11.83
GS/PCL (50/50)	2.91 ± 0.39	2.20 ± 0.36

Values are the average of eight determinations ± SD.
***Source**: Chollakup et al., 1998*

Table 4. Physical properties of starch/PCL blends in the ratio of 30:70 using either granular (TS) or gelatinized starch (GS).

	Tensile strength (MPa)	Elongation (%)
Irradiated starch* and irradiated PCL* blend		
1. Before radiation		
- PCL	53.6	972.8
- TS/PCL	16.5	403.8
- GS/PCL	8.9	166.1
2. After radiation		
- PCL*	31.9	678.0
- (TS/PCL)*	8.2	27.1
- (GS/PCL)*	9.2	13.5
Irradiated starch* and PCL blend		
1. Before radiation		
- TS/PCL	16.5	403.8
- GS/PCL	8.9	166.1
2. After radiation		
- TS*/PCL	12.0	383.6
- GS*/PCL	10.0	135.0



Source: *Chollakup et al., 1999a.*

Figure 7. Physical properties, determined as tensile strength and % elongation, of cassava starch and PCL blends with the inclusion of silk protein (silk hydrolysis-SH or silk fibroin-SF) at various concentrations (0 to 20%).
Source: *Chollakup et al., 1999b.*

Table 5. Physical properties of PCL/partially hydrated starch (PS) and PCL/ Hydrated starch (HS) at the ratio of 70/30 with various contents of sucrose ester (SE).

	Tensile strength (MPa)	Elongation (%)
PCL/PS		
+ 0% SE	10.18 ± 0.95	217.28 ± 38.52
+10% SE	7.82 ± 0.98	176.94 ± 63.13
+15% SE	7.53 ± 0.58	200.59 ± 22.08
+20% SE	7.73 ± 0.79	197.39 ± 32.25
PCL/HS		
+ 0% SE	8.39 ± 0.68	125.22 ± 38.86
+10% SE	7.36 ± 0.82	157.29 ± 47.66
+15% SE	6.58 ± 0.50	124.59 ± 25.19
+20% SE	6.53 ± 0.28	134.74 ± 15.10

Source: *Sriroth et al., 1999.*

CONCLUSIONS

Cassava starch is the cheapest carbon source in the region and can be applied for the production of biodegradable plastics in the future in two different ways:

a) As polymers: cassava starch can serve as a carbon source in the fermentation process leading to the formation of high molecular weight polymers, PHB etc., or organic acids such as succinic acid and lactic acid, which can subsequently undergo direct condensation to high molecular weight polymers. The future polymers will be from fermentation processes that give more consumer confidence.
b) As the blending material cassava starch can be modified in different ways, so that the properties of the starch in the polymer blend are the best possible. This will lead to the most reasonable production cost.
c) Through genetic engineering some plants are reported to have the ability for polymer production, such as a transgenic tobacco plant expressing a bioelastic protein-based polymer (Daniell and Guda, 1997). If biodegradable polymers could be synthesized in plants, like starch or lipid, the polymer's cost should be competitive with those from more conventional sources.

Despite the superior properties of conventional plastics, biodegradable plastics will be required in increasing amounts in certain markets. Major polymer producers are therefore increasing their research and development investments in this area.

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PRODUCTION AND USE OF MODIFIED STARCH AND STARCH DERIVATIVES IN CHINA

Jin Shuren[1]

ABSTRACT

Due to rapid economic development and increasing market demand after the 1980s, research on the production of modified starch and starch derivatives developed very quickly in China. This paper describes the present situation and the development potential of modified starch, starch sweeteners, saccharide alcohol, degradable starch plastics, oligo-saccharides, and lactic acid made from cassava starch in China, including the production and the use of the most popular products. Progress made and future planning for the development of these products will also be discussed.

I. Industrial Development of Starch in China

In recent years the production and application of starch, modified starch and starch derivatives developed very fast, in line with the overall development of the Chinese economy (**Table 1**).

The development of starch derivatives depends mainly on the rapid development of the starch industry. From 1989 to 1998, total production of Chinese starch increased about 2.7 times, from 1.12 to nearly 3 million tonnes. The scale of the starch factories has also increased considerably, while their numbers have decreased (**Table 2**).

Production of cassava starch showed a similar trend. Guangxi is the largest cassava producing province in China, with cassava production there accounting for more than 50% of total national production. The cassava planted area, total fresh cassava root production and starch output are shown in **Table 3.**

As indicated in **Table 3**, from 1989 to 1998 the cassava planted area increased 24%, the yield 72%, fresh root production 113%, and cassava starch production 170%.

II. Modified Starch and its Applications in China

1. The present situation of Chinese modified starch

Recently, the modified starch industry in China has developed very rapidly (see **Table 1**); modified starch production in 1998 was 7.5 times greater than in 1989. This has been the result of the following factors:

1. Production of starch in China has increased very rapidly, so the starch factories had to search for new markets.
2. The demand for modified starch from various industries increased very quickly.
3. With the opening up and reform of the Chinese scientific system, a more creative technological development framework was established, resulting in new progress being made in research, development and utilization of modified starch.
4. As new foreign technologies were introduced, demand for modified starch

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increased.

5. New enterprises have high quality requirements, so demand for modified starch with high added value increased.

Table 1. Production (in ‘000 t) of starch, modified starch, crystal glucose and liquid glucose in China from 1989 to 1998.

	Starch	Modified starch	Crystal glucose	Liquid glucose
1989	1,117	21.6	109.4	144.5
1992	1,200	34.8	134.0	70.8
1993	1,600	54.0	149.0	85.0
1994	2,470	59.8	198.8	138.3
1995	2,600	80.9	220.9	108.1
1996	2,645	73.4	196.4	168.6
1997	2,589	91.3	145.8	170.1
1998	2,978	162.0	157.4	256.0
% increase since 1989	167	650	44	77

Table 2. The scale of the starch industry in China.

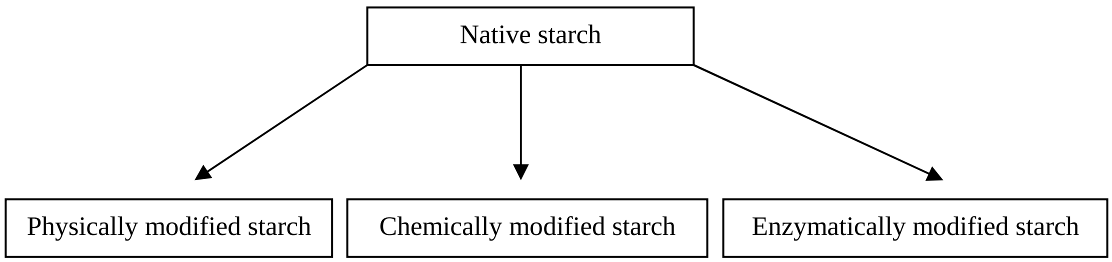
	1989	1993	998
Numbers of starch factories	388	243	157
Total annual capacity (million tonnes)	1,167	1,520	2,978
Average capacity (t/year)	2900	6255	
Number of factories of >100,000 t/year capacity	14	37	67
Number of factories of >200,000 t/year capacity	0	0	2

Table 3. Cassava planted area, total fresh root production and starch production from 1989 to 1998 in Guangxi province of China.

Year	Planted area (‘000 ha)	Yield (t/ha)	Fresh root production (‘000 t)	Starch production (‘000 t)
1989	210.6	8.24	1,734.9	
1990	219.3	8.82	1,934.5	122.5
1991	221.5	9.00	1,993.8	168.2
1992	213.3	9.95	2,121.4	191.0
1993	219.7	11.43	2,511.7	230.0
1994	229.6	12.15	2,789.3	258.2
1995	272.9	13.68	3,733.5	273.0
1996	288.9	13.41	3,873.7	321.2
1997	273.3	14.22	3,886.1	385.0
1998	260.5	14.21	3,701.6	330.3

2. *Types of Chinese modified starch*

Modified starch can be divided into three main groups according to the modification process utilized. These three groups are further subdivided according to processes and products as shown in **Figure 1** and **Table 4**.



1. Pyrodextrin
   - -white dextrin
   - -yellow dextrin
   - -soluble dextrin
2. Pregelatinized starch
   - -α-starch
3. Fractionated starch
   - -amylose
   - -amylo-pectin

1. Oxidized starch
2. Esterified starch
3. Etherified starch
4. Graft co-polymerized starch

1. Enzyme degradation starch
   - -maltodextrin
   - -cyclodextrin

Figure 1. Modified starch processing technologies and products.

3. *Current and future applications of modified starch*

Chinese modified starch has a very good development prospect (**Table 5**). The paper and cardboard industry of China in 1996 consumed 300 thousand tonnes. Moreover, for the paper making industry in China, unlike in most other countries, wood pulp is a minor raw material while the main raw materials are straw pulp and bagasse. The fiber of straw pulp is shorter and is of lower strength so it needs more modified starch. The proportion of modified starch used in the American paper making industry is 2%. It is estimated that the consumption of modified starch in China's paper making industry will be above 700,000 tonnes. Other industries, such as textile, food, medicine and materials used for construction and for environmental protection, consume also a lot of modified starch.

4. *Advantages and development prospects of modified cassava starch*

Cassava starch is characterized by low pasting temperature, high viscosity and easy enzymatic hydrolysis. Pregelatinized starch and cationic starch made from cassava starch has special quality advantages.

Table 4. Principal modified starch products in China, their production process and application.

Product	Production process	Application
Yellow dextrin	Heat for roasting	Casting, construction materials
White dextrin	Heat for roasting	Binding agent in medicines
Pregelatinized starch	Dried and milled by drum	Feed, casting, construction materials
Oxidized starch	Oxidized by oxidizing agent	Binding agent for cardboard, textile, food
Acid- hydrolyzed starch	Hydrolyzed by acid	Food, sizing for textile, paper making
Starch acetate	Esterification by acetic acid	Paper making, textile, casting, food, snack food
Cationic starch	Etherification by trimethyl amine	Paper pulp additive coating
Complex modified starch		Paper pulp additive coating
Carboxymethyl starch	Etherification by chloroacetic acid	Lubricant for oil drilling medicine, construction materials
Hydroxy-propyl starch		Food, candy
Cross-linked starch		Food, medicine, textile, chemical industry
Graft co-polymerized starch	Graft co-polymerized by acrylo-nitrile	High water-absorbent materials, such as disposable diapers, female napkins, textile sizing material

Table 5. The current situation and future markets for Chinese modified starch ('000 tonnes).

Application of modified starch products	Current production	Current domestic market volume	Expected future domestic market volume
1. Textile	50	100	120
2. Paper	40	350	700
3. Food	3	200	400
4. Medicine	10	20	40
5. Agriculture	-	100	200
6. Casting	-	37	75
7. Animal feed	-	100	200
8. Construction materials	-	50	80
9. For oil drilling	-	30	50
10. For fine chemicals	-	10	30
Total	**103**	**997**	**1895**

1. *Pre-gelatinized starch*

About 10,000 tonnes of pregelatinized starch are being produced annually in Guangxi. The quality of pregelatinized starch from cassava starch is better than from maize starch, resulting in good market demand and a 10% higher price compared with that made from maize starch.

2. *Cationic starch*

Approximately 10,000 tonnes of tri-methyl amine cationic starch are being produced annually in Guangxi. The cationic starch made from cassava starch has a low viscosity, and a high degree of substitution, making it especially suitable for the sizing and coating of high-speed paper making machines. Recently, the Guangxi Nanning Cassava Technical Development Center in co-operation with the Mingyang Starch Factory, succeeded in the development of a solid process for cationic starch production. The degree of substitution of the product is higher than that of the original wet process, there is no pollution, and the production cost is 20% lower, giving it a strong competitive advantage.

Besides, Guangxi also produces oxidized starch, starch acetate, amphoteric starch, yellow dextrin, starch phosphate etc.

III. Starch-based Sweeteners

China has a 3000 year history in the production of sweeteners made from starch. Ancient China was the first to invent the production of sugar from raw materials of plants, especially the production of maltose from rice starch. Starch-based sweetener production started with the manufacture of malt syrup. At present, China produces several kinds of starch-based sweeteners as indicated below:

1. Glucose syrup

After starch is hydrolyzed either by enzymes or acid, malt syrup is obtained, which is divided into high-DE, medium-DE and low-DE syrups according to their different DE-values as shown in **Table 6**.

2. Maltose

Table 7 shows several types of maltose syrups produced in China.

Fresh wheat bran contains a considerable amount of β-glucosidase, an enzyme which can decompose starch molecules to produce maltose; this technology is used for producing maltose syrup in China.

3. Glucose

Table 8 lists the principle types, characteristics and uses of glucose produced in China. So far, China has mainly four production technologies of glucose, as indicated in **Table 9**.

4. Conversion and isomerization sweeteners

In the Chinese market, we have four types of fructose-glucose products, as shown in **Table 10**.

Table 6. Glucose syrups of different DE values.

Product	DE value[1)]	Degree of hydrolys	Main ingredients	Product form	Useage
Malt dextrin	10-15	low	low molecule dextrin malt polymaltose iso-maltose glucose	powder liquid	milk powder, substitute solid drink, oral soluble dosage food
Malt syrup	25-35	medium	maltose glucose maltotriose	liquid 70-80^o Bx	confectionery
Glucose syrup	42-55	medium	glucose maltose	liquid 70-84^o Bx	confectionery
Liquid glucose	75-94	high	glucose maltose malt poly-saccharide salt	liquid 70^o Bx	syrup, food, anti-freeze, sorbitol
Mother liquid of glucose	75-80	high		liquid 60^o Bx	caramel-coloring, anti-freeze, sorbitol

[1)]measure of the ratio of reduceable saccharide over total saccharide.

Table 7. Types and characteristics of maltose produced in China

Product	Maltose content (%)	Characteristics	Usage
Maltose	<50	liquid, sweet, sensitive to moisture	daily food
High-maltose syrup	50-75	liquid, sweet, sensitive to moisture	special food
Super-high-maltose syrup	75-95	liquid, sweet	special food
Crystal maltose	>90	strong water absorption	special food
Crystal anhydrous maltose	>90	highly soluble	dehydrating agent
High purity maltose	>99	high purity	injection solution

Table 8. Main types of glucose in the Chinese market.

Product	Specification	Price (Yuan/t)	Usage	1996 Production('000 t)
Medical anhydrous glucose	China Pharma-copoeia 1995	5200	injectable solution	20
Medical glucose	China Pharma-copoeia 1995	4500	injectable solution	120
Oral glucose	China Pharma-copoeia 1995	4200	food; sorbitol for production of Vitamin C	50
Industrial glucose	Industrial grade	3900	general industrial use sorbitol production	40
Industrial total powder sugar	DE 90	3000	industrial use	20

Table 9. China's glucose production technology.

Production process	Main procedure						
	Mixing	Acid liquification	Enzymatic liquification	Acid sacchari-fication	Enzymatic sacchari-fication	Decoloration and filtering	Concen-tration
Acid process	✓	✓		✓		✓	✓
Enzymatic process	✓		✓		✓	✓	✓
Acid-enzymatic process	✓	✓			✓	✓	✓
Enzymatic acid process	✓		✓	✓		✓	✓

Table 10. Various fructose-glucose products produced in China.

Product name	Viscosity	Fructose content (%)	Sweetness compared to sucrose	Usage
Fructose-glucose syrup	70 Bx	42	0.9	food
High-fructose syrup	75 Bx	55	1.1	soft drinks
High purity fructose syrup	80 Bx	90	1.6	special drinks
Crystaline fructose	solid	>98	1.8	special food/drinks

5. Oligo-saccharides

1. Oligo-iso-maltose

The enzyme transglucosidase (TG) interacts with maltose and glucose, resulting in an inversion reaction, which produces iso-maltose, panose, iso-malto-triose, etc.

Oligo-iso-maltose can not be digested and fermented by yeast, but it can be used by *Bifdobacterium bifidium* to enhance its reproduction; this is good for the intestinal bacterial colonies and elevates the proportion of favorable colonies resulting in a more healthy functioning of the digestive system.

This kind of oligo-iso-maltose has been produced in the starch industry; the procedure is as follows: 1) liquify starch milk with the use of α-amylase; 2) saccharify with the combination of β-amylase and glucose group invertase; β-amylase yields maltose, invertase yields iso-maltose and panose through the linking of α-1,6 link yields glucose and maltose. 3) refine and concentrate to 75%. A colorless, transparent solution is obtained which contains the following substances (dry weight basis): 16.9% iso-maltose, 12.5% panose, 3.4% iso-malto-triose, 6.7% maltose and 40.5% glucose. The content of iso-maltose can be elevated to as high as 85% with resin chromatography while glucose is removed.

2. *Oligo-fructose*

Oligo-fructose is one of the edible enhancement and function foods. Because the bio-reactions of oligo-fructose are almost the same as short-link soluble cellulose, it can be used as a source of edible cellulose. In China, oligo-fructose is now produced on an industrial scale and marketed. The first production line of 3000 t/year was set up in Yunnan province. Researchers of Guangxi University used the immobile enzyme to successfully produce oligo-fructose; a 1000 t/year production line has been built.

Besides oligo-iso-maltose and oligo-fructose, new types of oligo-saccharides such as oligo-saccharide, oligo-mannose, etc. have also been researched.

IV. Hydrogenated Sweeteners

1. Sorbitol

Sorbitol is the main raw material for production of vitamin C. It is also a favored sweetener for diabetic patients and can function as an effective moisture absorbent; it absorbs water strongly, so it has been used widely in the production of toothpaste and cosmetics.

The present diversity and characteristics of various sorbitol-based products in China are shown in **Table 11**.

2. Mannitol

Mannitol is the only polylol which is solid under normal conditions. It is a favored medicine for diuretic and dehydration problems. Mannitol is one of the essential medicines in all hospitals. In industry, mannitol is the main raw material for producing polyester and polyether, which in turn are essential raw materials for production of foamed plastic.

At present, mannitol in China's market is mainly derived from seaweed with an annual production capacity of 8,000 tonnes. The cost is high and the production process is out of date. In recent years we have developed a new technology, which uses either sucrose or glucose to manufacture mannitol, and we have begun industrial production. Hydrolysis of sucrose can yield the inversion sugars fructose and glucose, which in turn produce 25% mannitol and 75% sorbitol, respectively, when hydrogenated.

After special isomerization, part of the glucose can be inverted to mannose and fructose, which can yield 42% mannitol and 58% sorbitol when hydrogenated.

Recently, research on the adoption of a simulated fluid bed to separate mannitol and sorbitol has been successful.

3. Maltol

Maltol is a new type of dietary supplement, produced by hydrogenating maltose. Maltol is a transparent, colorless or lightly yellow solution.

Maltol is non-fermentable, so it may be used to prevent dental decay; it is low in calories, so may be used to prevent obesity; it has good flavor with a sweetness of 90% of that of sucrose; it has high viscosity and may be used as a thickener; moreover, it has high heat and acid resistance, good moisture retention, so may be used for moisture adjustment;

it hardly decomposes by insulin, so it can be used as food for diabetics. About 10,000 tonnes are produced annually in China, mainly using cassava starch.

Table 11. Sorbitol-based products and applications in China's market.

Characteristic	For vitamin C production	For detergent and cosmetics production	For toothpaste production	Injectable Sorbito l	Hard crystal sorbitol	Solid sorbitol	Icy sorbitol
Appearance	colorless and transparent solution	colorless and transparent solution	colorless and transparent solution	white powder	white hard granules	white soft granules	icy
Degree of substitution	45-51	67-73	69-71	99.5	99.5	99.0	98.0
Specific weight (gm/ml)	1.228	1.280-1.316	> 1.285				
Refractive index	1.42	> 1.460	1.459-1.461				
Reducing sugar (%)	> 0.2	0.63	>0.5	0.2	0.3	0.2	0.2
Main usage	raw material for vitamin C	food, cosmetics and detergents	toothpaste	medical injection solution	food gum	chemicals and food	chemicals and food
Relative price[1)]	1.1	1.0	1.0	3.5	2.8	1.6	1.3

[1)]Calculated according to the current market price on a dry weight basis.

V. Degradable Plastics

China proclaimed a law which prohibits the pollution of the environment with disposable plastic packing materials. The annual production of plastic in China is nearly 4 million tonnes. The consumption of plastic is more than 1.4 million tonnes in the packing industry. The potential market for degradable plastic is very big.

So far, domestically produced degradable plastics includes the following two types:

1. Bio-degradable starch resin

By adding starch or modified starch to polyvinyl hydrocarbons, particles of bio-degradable starch are produced. These can be further manufactured into degradable plastic bags, disposable plates, forks and spoons, degradable products for medical care, etc.

2. Bio-and photo-degradable starch plastics

These are mainly used for plastic mulching in agriculture, packing film for food and groceries, packing film for industrial products. These plastics are not only decomposed by bio-degradation, but also by photo-degradation.

Presently, China has more than 50 manufacturers, with an annual production capacity of 100,000 tonnes. Among them, about ten factories introduced production technologies from abroad. But, these degradable plastics are mainly starch plastics which require 7-40% of starch as filling. The base materials are polyvinyl and polystyrene plastics, which are not fully degradable plastics. The plastic mulch produced by this process is difficult for the farmers to use, because this starch-based plastic has low water resistance, it is rather thick and of high cost. Further research is needed to improve this product.

Recently, some local companies have developed a technology for producing fast-food boxes using starch and plant fiber as raw materials. The technology uses maize cobs, rice bran and sweetpotato as raw materials to manufacture bowls, discs, boxes, spoons etc.. Their hardness and brightness are nearly the same as ceramic. Once used they can be recycled as feed and fertilizer, and will thus not pollute the environment and be a source of waste.

VI. Organic Acids

Besides citric acid and acetic acid, two kinds of organic acids using starch as the raw material have been developed successfully.

1. Lactic acid

Lactic acid is an important organic acid; it can be used in the production of beer for adjustment of the pH of the malt, in the pharmaceutical industries and in the production of cosmetics, fine chemicals, tobacco, food and silk. Stearoyl lactate sodium and calcium salts are the most important lactate salts, being a general food additive used throughout the world. Monoglyceride lactate ester is an emulsifier, suitable for producing biscuits, meats, milk products and fruit jams, as well as pectin. In recent years, researchers have developed L-lactic acid, i.e. poly-lactic acid, which is an ideal fully-degradable plastic material, and easier to be produced industrially. Therefore, research on lactic acid in China has developed very fast. Presently, a 10,000 t/year L-lactic acid production line is under construction.

2. Itaconic acid

Itaconic acid and its esters are very good additives and raw materials for the manufacturing of synthetic resins, plastic, rubber, ion-exchange resins, surfactants, anti-rust agents, etc. The enzyme for producing itaconic acid has been produced in Yunnan and Hubei provinces. These factories succeeded in producing itaconic acid from native cassava starch. So far, China has produced more than 5,000 tonnes of itaconic acid.

VII. The Effect of Value-adding of Starch

Cassava is a low-value product. When we produce only native starch, farmers and manufacturers can only get a low income. The increase of product value and the average increase of added value for cassava-based products are shown in **Table 12**. It is based on recent market prices: 600 Yuan/t of dry cassava chips, 1800 Yuan/t of native starch.

As seen in **Table 12**, further processing of native starch into modified starch and its derived products plays a very important role in increasing the value of cassava-based products.

Table 12 The effect of further processing on the added value of cassava-based products.

Product	Consumption of cassava dry chips (t/t)	Cost of processing (Yuan/t)	Sales price (Yuan/t)	Product value/ cassava value	Income increase per tonne of cassava (Yuan/t)
Native starch	1.5	400	1,800	2.00	333
Low-grade modified starch	1.5	800	3,50	3.89	1,200
High-grade modified starch	1.5	1,600	6000	6.67	2,333
Special modified starch	1.5	3,000	12,000	13.33	5,400
Liquid glucose	1.5	1,000	2,700	3.00	533
Crystal glucose	1.5	1,800	5,000	5.5	1,533
High purity maltose	1.5	1,100	4,500	5.00	1,677
Sorbitol 70%	1.3	1,400	4.200	5.38	1,554
Crystal sorbitol	2.0	3,000	14,000	11.67	4,900
Mannitol	2.0	3,000	12,000	10.07	3,900
Maltol 70%	1.5	1,600	6,500	7.22	2,667

VIII. Opportunities and Challenges

Cassava-based modified starch and its derivatives face a great challenge from the competition of maize starch. In 1998, maize starch production was 2.75 million tonnes, accounting for 92% of total starch production in China. Cassava starch production was only 286,000 tonnes, or 9.6% of total starch. The average yield of maize in Jilin province of China has reached above 9 t/ha, while that of dried cassava chips is only 6 t/ha in Guangxi. The scale of maize starch factories in China is larger than that of cassava starch factories. Factories with an annual capacity of one million tonnes of maize starch have been set up in northeastern areas, such as Shandong province of China, while the biggest cassava starch factory can produce only 30,000 tonnes per year. Even though the Guangxi Mingyang Starch Factory is still the biggest modified starch manufacturer in China, it must confront strong competition from maize starch manufacturers.

IX. Proposal

1. Production of modified starch and starch derivatives hold great significance for increasing the value of cassava products, and for improving the economic benefits in cassava production areas. Therefore, strong emphasis should be placed on research and development of modified starch and starch derivatives, in order to develop the cassava economy.
2. For the sake of enhancing the competition of cassava starch and starch derivatives, it is very important to continuously increase cassava yields, so it can compete with maize. Consequently, it is equally important to breed and select good varieties of cassava and to improve the cassava cultivation methods.

3. It is very important to strengthen the collaboration between agriculture and industry, to emphasize the linkage between agricultural and industrial development and research, which are all important factors for developing the cassava economy.

NEW CASSAVA PRODUCTS OF FUTURE POTENTIAL IN INDIA

T. Premkumar, G. Padmaja, S.N. Moorthy, S.K. Nanda, Mathew George and C. Balagopalan[1]

ABSTRACT

The Green Revolution and increasing living standards of the people of India, especially in Kerala, have resulted in a gradual shift in the cassava utilization pattern. Despite the fact that India has the world's highest cassava yield, the crop's importance for food security is giving way to its role as an industrial raw material. A well-organized grain distribution system and shifts to more remunerative plantation and horticultural crops also reduced the importance of cassava as a subsistence food crop in traditional farming systems in Kerala. In order to overcome this and retain cassava in the cropping system, concentrated efforts are being made to promote value-addition and find alternative uses.

In the 1940s, cassava became an important raw material for the starch and sago industries established in Salem and Dharmapuri districts of Tamil Nadu. The cassava-based starch industry recorded a high rate of growth over the past five decades and has currently a turnover of 3000 million Indian rupees worth of starch and sago. The produce is marketed through a well-organized cooperative society, which is presently the largest agro-processing cooperative venture in South and East Asia. The sustainability of industrial growth of cassava depends to a large extent on diversification and value-addition, for increasing internal demand as well as export markets.

Three and a half decades of research on cassava utilization at CTCRI has led to the development of several technologies for value addition and *in situ* utilization. The potential markets for products, such as pregelatinized instant and convenience foods, extruded and fermented food products, feed products using by-product utilization for poultry, and value-addition through microbial enrichment, modified starch products like adhesives, sweeteners, cold water-soluble starch, commodity chemicals like citric acid, ethanol, biodegradable polymers incorporating cassava starch, biogas from starch factory wastes, etc. are discussed in this paper.

The future priorities and utilization strategies for cassava, comprising diversified products, setting up of rural agro-enterprises through the involvement of NGOs, by-product utilization as fish or poultry feed, biofertilizers from cassava starch factory waste and large commercial ventures like biodegradable plastics and alcohol are enumerated. The need for an effective technology transfer system to inform industrialists of the benefits of adopting root and tuber crop technologies is also highlighted.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is believed to have been cultivated in India for more than a century. The ability of cassava to supply adequate calories at a lower cost encouraged its maximum use among low-income social groups. While the cultivation of cassava spread widely in Kerala as a food crop, it slowly became an industrial crop in the neighboring state of Tamil Nadu. Cassava cultivation in Kerala and the northeastern states has proved that rural food security can be met by local measures, which will help not only farm output but also promote rural employment. The production of a food surplus in response to guaranteed markets will provide additional income for producers, besides ensuring a continuous food supply in rural areas. This additional produce can also be

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processed into various food products to suit the taste and needs of the people in urban and rural areas. Demand for cassava for human consumption depends on income, relative prices and taste preferences. Some cross-section surveys have indicated a negative relationship between cassava consumption and income. In the low-income groups there is an increase in consumption of cassava with an increase in income, while in the middle and upper classes increases in income reduce the consumption of cassava.

Cassava was originally a food security crop to supplement the rice diet during periods of food scarcity, but gradually it has become a subsidiary food even in normal years. During periods of food scarcity cassava played a vital role in averting famine in Kerala. However, the success of the green revolution and increases in the living standards have changed the food consumption pattern of the people of India. This has led to a lower preference for cassava as a staple food. The low income generated from cassava when compared to high-value horticultural crops is another reason for the recently experienced shift in cropping system, placing cassava at the bottom of the cropping agenda in the cassava-growing state of Kerala. By contrast, cassava has emerged as a cash crop in Tamil Nadu, Andhra Pradesh and Maharashtra where it caters to the needs of the massive starch and sago industries in those states.

Approximately 300,000 tonnes of sago and starch are manufactured from cassava roots by nearly 1,100 factories in Tamil Nadu and 42 factories in Andhra Pradesh. Sago is consumed as a breakfast food, or is used for the preparation of wafers. It is also an ingredient in *payasam* (a sweet semi-solid food preparation served during feasts). West Bengal, Maharashtra, Gujarat, Rajasthan and Madhya Pradesh are the largest consumers of sago in India. In neighboring countries such as Nepal, Bangladesh and Sri Lanka, sago is also consumed in various preparations. A limited quantity of sago is exported to Middle-eastern countries where there are Indians who have migrated there to work. The cassava-based sago industry has experienced a phenomenal increase during the last few decades.

During the past 40 years, India achieved a remarkable increase in cassava yields due to the introduction of high-yielding varieties and improved management practices. Further increases in cassava production, consumption and income-generation are only possible by expanding the utilization avenues for various cassava-based diversified products. The Central Tuber Crops Research Institute (CTCRI) over the years has built up into a strong centre for crop utilization with a multidisciplinary approach to tackle the multifaceted problems in cassava utilization. Hence, research programs are oriented towards developing technologies for utilization at the home, farm and industrial fronts (Balagopalan, 1988; Balagopalan *et al*., 1988; 1990; Padmaja *et al*., 1990; Balagopalan and Ray, 1992). Besides CTCRI, several state agricultural universities and developmental agencies have also developed technologies for cassava utilization in India.

HOME FRONT TECHNOLOGIES

Food Products

1. Pre-gelatinized cassava starch (yuca rava and yuca porridge)

Rava is a wheat-based convenience food used for the preparation of various breakfast recipes like *uppuma* and *kesari*. Conventionally, wheat semolina is used for this purpose. The properties of wheat *rava* is based on its gluten-gliadin content which makes it swell to a small extent without breakdown. Attempts were therefore made to develop a simple economic process for the production of cassava-based *rava* as a substitute for wheat *rava*. The conditions for controlled gelatinization and swelling of starch for the preparation of *rava* were worked out. The process developed suits the cottage and small-scale industry programs. The process of making cassava *rava* has been transferred to village-level workers to promote rural employment and technology development.

The process for producing cassava *rava* consists of the following steps:

1. Partial gelatinization of cassava
2. Drying, and
3. Powdering.

By partial gelatinization, the granules swell to a small extent and give a granular form to the product. Care must be taken to avoid too much steaming or treatment in hot water as this can lead to too much swelling, resulting in a cohesive texture on powdering. It has been found that a steam treatment of less than 5 min at 5 psi of steam, or immersion in boiling water for less than 10 min is ideal for gelatinization The moisture content at this stage increases by 10-15% over the original moisture content in the cassava roots.

After draining the water, the chips are spread out on mats in the sun or placed in a mechanical dryer (drying temperature of 70°C). The moisture content is brought down to around 15%. At this stage, the chips are hard. The dried chips are then powdered in a hammer mill, taking care that the powder is not too fine nor too coarse. The maximum fraction should have a granule size between 0.5 and 3 mm, and should pass through sieves of 20-80 mesh. Sieving is carried out on the powdered product. The fraction passing through 80 mesh is too fine, but possesses a cohesive texture useful in the preparation of sweets, puddings, etc., i.e. products which require fast miscibility of starch in milk/water, etc. The fraction which is retained by a 20 mesh sieve may be re-powdered and sieved. The fraction which does not pass through 80 mesh but passes through 20 mesh has a granule size range of 0.5 to 3 mm, and is most suitable as a wheat semolina substitute. It can be used for the preparation of products such as *uppuma* and *kesari*. The process is shown in **Figure 1** and the properties of two cassava rava products are shown in **Table 1** in comparison with those of wheat semolina.

The fine grade pre-gelatinized cassava starch (*yuca* porridge) can be utilized to make an instant energy drink using hot milk or hot water. Two teaspoonfuls of porridge can be added to hot milk or water after adding sugar to taste, and served to infants and invalids as an energy drink. Addition of cardamom powder to *yuca* porridge will add flavor to the product.

2. Papads

Cassava *papad* is an important snack food item prepared from cassava flour. The preparation involves gelatinization of the flour with a minimum quantity of water, spreading out the paste on a mat or some similar surface to dry in the sun. After drying it is stored in polythene bags. The *papad* is consumed by deep-frying in oil, especially coconut oil. The final product undergoes 2-3 times expansion on frying. It is crisp and can be consumed as a side dish. The preparation of papad is shown in **Figure 2**.

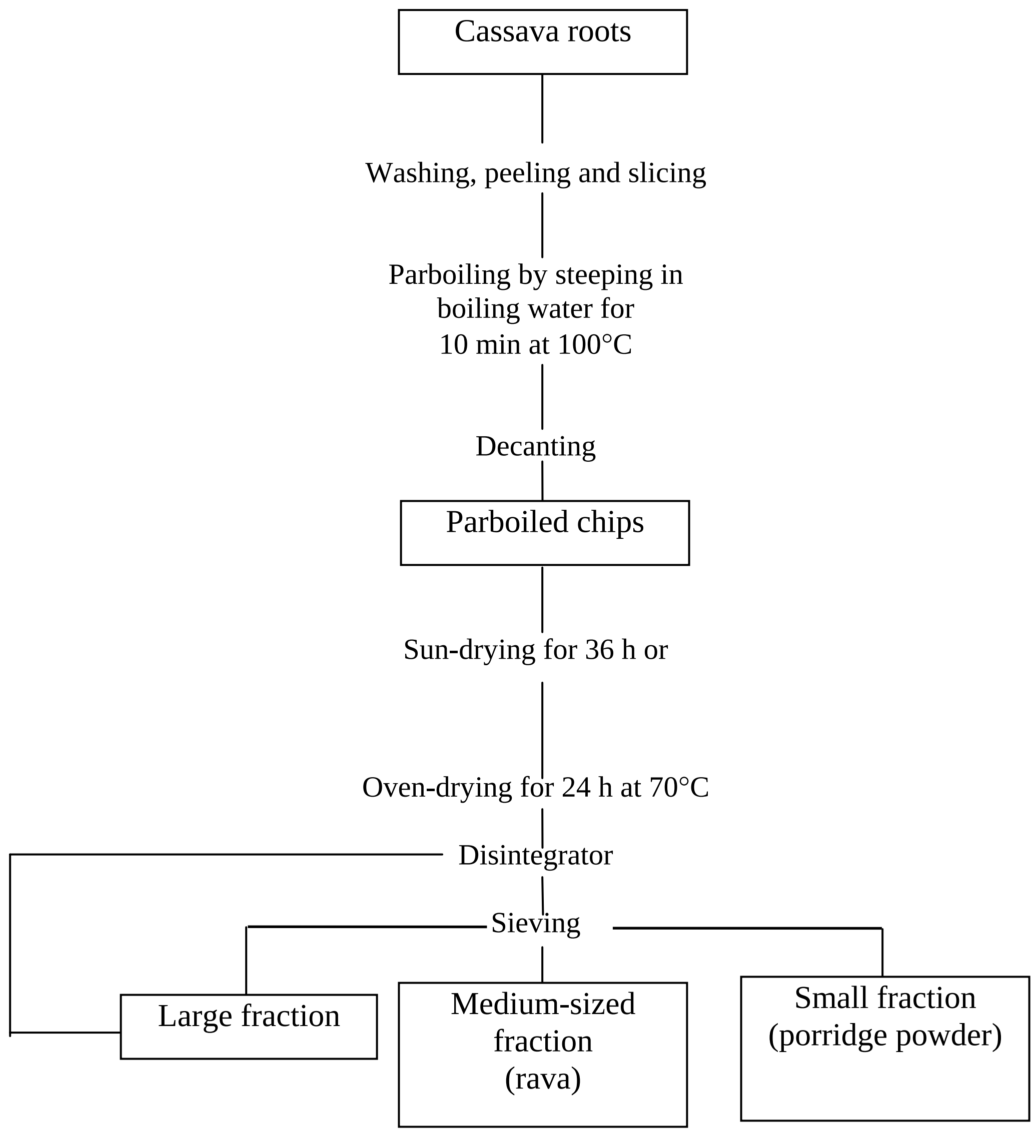

Figure 1. Flow chart for the preparation of yuca rava and porridge.

Table 1. Properties of cassava rava in comparison with wheat semolina.

	Wheat semolina	Medium-sized cassava rava	Small size cassava rava
1. Granule size	0.1- 0.5 mm	0.5 to 3 mm	0.5 to 1.5 mm
2. Reducing value (ferricyanide)	2.8-3.5	Nil	1.5-2.5
3. Congo red staining	Fast	Slow	Fast
4. Swelling in water	2 times original volume	Negligible increase	1½ times original volume
5. Stickiness	High	Low	Low
6. Taste and flavor	Acceptable	Acceptable	Acceptable
7. HCN content	na	55 ppm	55 ppm

na: not available

Source: *Balagopalan and Anantharaman, 1995.*

Flour

Heat in water (3-5 min)
to obtain a gelatinized flour
Add salt and pepper to taste
Cool partially

Spread out as round discs on mats/polythene sheets/cotton cloth

Drying in sun for 6-8 h

Peeling out

Cassava papad

(Fry as required)

Figure 2. Flow chart for making papads.

The *papads* lose their crispness if stored in the presence of moisture; hence, the fried product has to be stored in air-tight containers.

3. Sago wafers

Sago wafer is an important product made at a cottage level in many parts of Tamil Nadu. The wafers are deep-fried in oil and consumed as a side-dish. Preparation involves spreading sago pearls in round aluminium trays. The trays are then introduced into steam boilers and steamed for 20 min. Gelatinization takes place, making the pearls adhere together and giving them a round shape. The trays are then sun-dried and resulting wafers are peeled off. Natural food colors and salt are added.

4. Wafers

Wafers made from cassava starch are similar to sago wafers. In this case a starch cake containing approximately 40% moisture is used instead of sago. Wafers can be made into different shapes and sizes, such as round, square, floral patterns, etc. The product on frying expands three to fourfold.

5. Fried chips

Fried chips are made by deep frying thin french fries made from cassava. The roots are washed thoroughly and the peel and rind removed. The roots are then sliced as thinly as possible. The quality of the chips depends very much on the thickness of the slices and the age of the crop. Chips made from the roots of varieties having high sugar content turn brown on frying. Similarly, roots from varieties harvested early or late do not give chips of good quality. Chips from varieties having high dry matter content also become very hard. Hence, for the production of good quality chips, roots of correct maturity with relatively lower dry matter should be used. In addition, the roots may be subjected to some blanching. The slices may be dipped in sodium chloride or sodium bisulfite solution for 5-10 min, and then removed. They are then washed with water and surface-dried on filter paper or cloth. The chips are fried in oil (preferably coconut oil which has been heated to nearly boiling temperature and to which a salt solution has been added). Usually, the frying takes 5-10 min. The fried chips are removed from the oil and drained before packing them in polythene bags. The bags are sealed tightly to prevent the entry of moisture and air.

Compared to potato chips, cassava chips have a harder texture, but a major advantage is that the chips do not become leathery like potato chips within a few minutes of exposure but maintain their crispness. There is vast potential for cassava chips, in view of the increased preference by consumers for convenience foods and ready-to-eat items. The shelf life of chips may be further increased by vacuum-sealing or using an inert gas during packing.

FARM FRONT TECHNOLOGIES

Poultry and Animal Feeds from Cassava

1. Microbial technology for enriching protein in cassava

The possibility of utilizing cassava starch factory waste (a by-product from the starch industries) as a broiler feed was investigated. Cassava fibrous waste contains approximately 56% unextracted starch, which therefore is an ideal substrate for microbial growth. Dumping wastes in the factory premises leads to foul smell, resulting in air pollution, and this has led to a lot of complaints in recent years. In order to help the starch factories from the threat of being closed down, effective by-product utilization seems to be a promising option. Studies conducted at CTCRI have shown that cassava waste can be converted to a broiler feed. The process consists of mixing the waste with cassava flour and steaming after partial moistening to increase the digestibility of the hemicelluloses and lignin. This flour-waste mix is dried and then mixed with other ingredients like peanut meal, fish meal and a mineral-vitamin premix to form a composite broiler feed. Feeding studies conducted with this feed showed that broiler performance was satisfactory, and that the birds reached a weight of 1.9 to 2.0 kg within eight weeks. The proportion of peanut meal in the feed mix can be reduced by enriching the waste-flour mix with microbial proteins through the use of a safe fungi such as *Trichoderma pseudokoningii.*

2. Ensiling technology

The poor postharvest storage life of cassava roots necessitates rapid processing into some stable product. Sun-dried cassava chips are susceptible to attack by a number of insect pests, making an economical and eco-friendly storage practically impossible. In order to ensure the supply of animal feed all year round, the possibility of ensiling cassava was investigated (Padmaja, 2000).

It was found that whole cassava chips mixed with rice straw can be ensiled to obtain stable quality silage with good feed value for cattle (**Table 2**). Cassava silage substituted at levels of 28% in a concentrate feed was found to increase the daily milk yield by 700 ml to 1000 ml . This low-cost technology can promote *in situ* cassava utilization as animal feed.

COTTAGE INDUSTRIES

Cassava Starch

Cassava roots are washed by hand and peeled with hand knives. These are then manually rasped to a pulp on a stationary grater, which is simply a tin or mild steel plate perforated by nails so as to leave projecting burrs on one side. The pulp is collected on a piece of fabric fastened by its corners to four poles, and washed vigorously with water by hand. Finally, the fiber is squeezed out while the starch milk collects in a bucket. When starch granules settle out, the supernatant water is decanted, and the moist starch is crumbled and dried on a tray or on a bamboo mat. In some places, the starch milk is squeezed through a closely woven thick fabric to trap the starch granules, or the fabric is hung overnight to remove gravitational water. Finally, the product is sun-dried. This simple process is used by many people in the rural areas of the tropics.

Cassava Starch Based Adhesives

Adhesives can be made from cassava starch using simple low-cost technologies. These include gums made by gelatinizing starch by heat treatment without any additives as well as those made by extraneous addition of different kinds of materials.

**Table 2. Biochemical analysis of a cassava: rice straw silage.
(cassava variety H 1687)**

Components	Initial (0 day)	Final (72 days)
Proximate principles		
Crude protein (N x 6.25), %	4.66	3.62
Ether extractives, %	0.38	0.27
Ash, %	4.07	3.81
Crude fiber, %	7.60	6.83
Carbohydrate, %	83.45	85.37
Amino acids (g/16 g N)		
Aspartic acid	3.45	3.51
Threonine	1.74	1.77
Serine	1.77	1.55
Glutamic acid	9.63	10.21
Glycine	2.40	2.65
Alanine	3.04	3.48
Valine	2.47	2.72
Isoleucine	1.64	1.58
Leucine	2.79	2.57
Tyrosine	1.59	1.76
Phenyl alanine	1.83	1.50
Histidine	4.72	4.80
Arginine	3.48	1.95
Proline	< 1.6	< 1.6
Total lysine	1.55	1.76
Cystine	1.23	1.41
Methionine	0.73	0.70

Source: *Padmaja, 2000.*

1. Gums without additives

The simplest liquid starch pastes are made by cooking starch with water, with preservatives being added later. These are useful in bill pasting, bag making and in tobacco products. These gums have extensive demand, and the quality and color of the starch are not very crucial. However, they lose their fluidity after a day or two. In spite of these defects, they are in high demand because of their low cost.

The starch is cooked in stainless steel or wooden vats with excess water until all the starch has gelatinized. The consistency of the paste is gauged by the appearance and flowability of the gum. It should flow freely and pour out in a long, continuous stream. On cooling, the product becomes more viscous. Copper sulfate is added to resist microbial infestation. Cassava starch is preferred in view of its excellent cohesiveness, clarity and bland flavor. However, it cannot be stored for more than two days as the pastiness is lost, and it becomes too thick to handle.

2. Gums prepared using different chemicals

Various chemicals may be added during the preparation of the gums. These include inorganic salts like calcium and magnesium chlorides, borax, urea, glycerol, carboxy methyl cellulose and carboxy methyl starch. The chemicals assist in increasing viscosity and flowability, and in humidity control. They are added by stirring while the starch is being gelatinized to prevent lump formation. The gums are useful in various applications like lamination of paper, wallpaper printing, for water-resistant formulations of pasting labels and other stationery applications.

Starchy Flour Extracted by Microbial Techniques

In order to facilitate the enzymatic cleavage of cell walls of cassava roots for starch separation, a simple low-cost technology using a mixed inoculum of micro-organisms was developed. This stable, self-sustaining, mixed-culture inoculum in the form of a mother liquor contains the following component micro-organisms: *Lactobacillus cellobiosus, Streptococcus lactis, Corynebacterium sp.* and *Pichia membranaefaciens.*

The mother liquor from an earlier lot, used to provide the mixed-culture inoculum, is kept in the refrigerator for subsequent fermentation. Half of the stored mother liquor is replaced with a fresh lot at intervals of 20 to 25 days. After a series of 25 to 30 sets of sequential fermentation, the inoculum is rejuvenated.

Peeled and washed cassava roots are sliced into 7-10 cm long cylindrical pieces and stacked in tubs. Water is added to immerse the root pieces completely with a surface column of 10-15 cm overhead. This requires about 100 liters of water for 100 kg of root pieces. While pouring the water, steeped liquor from an earlier fermentation supplying the mixed-culture inoculum is also added at 2% by volume of water with frequent stirring. The tub is then covered with a muslin cloth and incubated under ambient temperature (30-32°C) for up to 48 hours.

The root pieces are softened within 48 h making them easy to crush by hand. The extent of softening of the fermented roots is evidenced quantitatively from compressive strength tests which show 4.98 to 11.71 times reduction in comparison to their original compressive strength.

The pectinolytic and cellulolytic enzymes produced by the microbes in this process disintegrate the cell wall, thereby liberating the starch granules almost completely and enhancing the yield of starchy flour by 16-31%, depending on the variety of roots fermented . To produce sweet flour, the fermented pieces are mashed, sieved, allowed to settle in excess water (1:5), and then dried. The yield of sweet flour ranges between 17-23 kg per 100 kg of fresh roots (Mathew George *et al*., 1995).

LARGE-SCALE INDUSTRIES

Cassava Starch

Cassava is the raw material for large-scale starch extraction in Tamil Nadu, and currently around 1,100 factories are engaged in the manufacture of starch on a commercial scale. Two high-tech starch factories that have been established recently in the Erode and Namakkal districts in Tamil Nadu use a fully mechanized process for starch manufacture. The processing time from roots to dry starch is only 12 min. The high quality of the starch produced has brightened the prospects of cassava starch exports from India. Modernization of the age-old equipment used for starch extraction in traditional starch factories, brightened the color of starch/sago, and improved waste disposal by way of conversion to feed, fertilizers, biogas, etc.; this can help the starch manufacturer to increase product turnover through augmented internal demand and export opportunities.

Sago

Sago is a processed food starch marketed as small globules or pearls, manufactured in India from cassava starch. For the manufacture of sago, wet starch is dried in the sun to a moisture content of 40-45%. This is made into small globules by shaking in power-driven globulators. In small units, globulation is done with 10-15 kg starch. The globules vary considerably in size and are sieved through standard meshes. The next step is partial gelatinization which is carried out on shallow iron pans with oil. These are then heated over fire. The granules are stirred continuously for 15 min, and then dried in the sun or oven.

Sweeteners

1. Liquid glucose and dextrose

Cassava starch is a raw material for the production of liquid glucose and dextrose. Hydrolysis of starch to glucose is achieved mostly using hydrochloric acid. After neutralization with soda ash, the hydrolyzate is filtered, decolorized and concentrated in a triple effect evaporator. Finally, the decolorized syrup is vacuum-concentrated to obtain a product containing 43% dextrose, which is used by many confectionery industries in India.

Crystalline dextrose is obtained by further vacuum-concentration to 70-88% and crystallization in cylindrical crystallizers using the seeding technique.

2. Fructose syrup

Fructose syrup has gained importance in view of the fluctuating prices of sugars and the potential harmful effects of synthetic sweeteners. Glucose is isomerized to fructose using commercial glucose isomerase enzyme at 62°C in glass-lined tanks for 6 h at pH 8.0 . The fructose solution is decolorized and vacuum-concentrated to obtain a syrup containing 45% fructose, 50% glucose and 5% oligosaccharides. Though the technology is readily available, the Indian industry has yet to come forward to exploit it fully (Balagopalan *et al*., 1988).

3. Maltose

Maltose is obtained commercially from starch by enzyme treatment. There are three types of commercial maltose syrups, i.e., high maltose syrup, extremely high maltose syrup and high conversion syrups. The process for maltose manufacture involves two steps, i.e., liquefaction of starch by heat and a thermolabile α-amylase, and saccharification using microbial β-amylase. The maltose syrup is used in brewing, baking, soft drink manufacture, canning and confectionery industries (Moorthy and Balagopalan, 1996).

4. Modified starches

Cassava starch is modified by chemical or physical means to improve its functionality for industrial applications. The commercially converted starches are acid modified, oxidized and dextrinized starches. The undesirable properties of cassava starch, such as high breakdown in viscosity and cohesiveness of starch paste, can be modified through physical and chemical treatments. The physical treatments include heat, moisture, steam pressure and irradiation with γ-rays. For example, the gelatinization temperature is enhanced and viscosity is lowered but stabilized with steam pressure treatment. This starch has properties resembling fats, and hence can find use as fat-mimicking substances. The various chemical treatments which are used to modify starch include oxidation, esterification and cross-linking. Oxidation with hypochlorite gives a starch of lower viscosity suitable for the paper industry. It is expected that the paper industry is poised for tremendous growth in India. Esterification/etherification can lead to complete transformation in starch properties. The viscosities can be either lowered or enhanced and stabilized, and the pasting temperature can be altered. In fact, starch which gelatinizes in cold water, but does not gelatinize in boiling water, can be prepared by achieving the proper degree of substitution. Modified starch can find use in canned foods, frozen foods and as dusting powders in food and other industries. Cross-linking can stabilize viscosity and also provide various types of starch for food and industrial applications. Cross-linking agents include phosphate, epichlorhydrin and thionyl chloride.

CTCRI has developed laboratory-scale technologies for all these products, which can be scaled up for future applications. These products have wide applications in paper, textile and food industries. In addition, products like itaconic acid (Potty *et al*., 1982), lactic acid and citric acid can be produced from starch.

5. Biodegradable plastics

Annual production of plastics in India is about 1.26 million tonnes against a corresponding demand of around 1.83 million tonnes, about 32% of the requirements being met by imports. Agricultural and packaging sectors account for about 50% of the plastics consumed in India. Use of plastics now has accelerated to such an extent that the disposal of used products has become increasingly difficult. The global shortage and mounting price of petroleum have also led to severe competition between fuel for energy and feedstock for petrochemicals. In the search of alternative feedstocks for polymers, starch, a natural polymer as well as a renewable raw material, has captured the interest of academic and industrial researchers across the globe pursuing environmentally degradable polymers for easier disposal.

The process for producing starch-based plastics involves mixing and blending starch with suitable synthetic polymers i.e., low-density polypropylene (LDPE) and linear low-density polypropylene (LLDPE), as stabilizing agents, and suitable amounts of appropriate coupling, gelatinizing and plasticizing agents. Compounding of the blend prior to extrusion film blowing was adopted to attain proper melt mixing. Successful extrusion film blowing was possible with formulations containing up to 40% cassava starch and appropriate amounts of suitable gelatinizing, plasticizing and coupling agents.

The properties of these films relating to strength, stability and physico-chemical properties were studied to determine their limitations and potentials for different end-uses. Films from starch-based plastics can be blown as thin (39-96 µm), as those from LDPE or LLDPE. Films containing starch above 20% exhibited relatively higher vapor transmission rates. Starch-based plastic films showed hygroscopicity in proportion to their starch contents.

These starch-based plastic films were found to possess adequate mechanical strength and flexibility to make them suitable for various potential agricultural applications. The tensile strength of these plastic films containing 10, 25 and 40% starch was found to be 12.56, 17.34 and 10.67 Mpa, respectively. The elongation at break values for these films varied from 211% to 122% as the starch content varied from 10% to 40%. In comparison, the tensile strength and elongation values of the LDPE control films were 10.97 MPa and 384%, respectively. The storage stability of these films, with regard to changes in tensile strength and elongation, was almost equivalent to that of the ordinary polyethylene films, the granular form of the material being more stable than the film form.

The suitability of these films for potential areas of application in the field of agriculture and single-use disposable packaging was assessed through outdoor weathering and soil burial; this showed a drastic reduction in mechanical strength and elongation values resulting in brittleness and disintegration. Deterioration of strength and of flexibility were progressively greater with an increase in starch content of the film, and the duration of environmental exposure. More rapid biodegradation (in 2-6 months) of these films could also be achieved by incorporating a suitable catalytic agent into the film composition. Films of the latter type would be much more suited for making nursery bags. Relatively easier disintegration and absorption of starch-based biodegradable plastics by the soil after a specific time interval would make this an ecologically satisfactory mode of disposal of plastic waste.

Synthetic polymers filled, grafted or blended with starch, either in its native form or modified, have been reported to impart biodegradability to the fabricated plastic goods. Incorporation of low-cost starch into synthetic polymers also provides a potential method for expanding their applications as well as improving the economics for making the plastics. Their superior utility has been deployed in specific applications such as short-service lifetime agricultural mulch, single-use disposable packaging and for controlled release of agro-chemicals, such as pesticides, pheromones, growth regulators and fertilizers.

6. Cassava alcohol

Although the income elasticity of cassava is considered to be low, and in terms of ethanol production, crops like sugarcane enjoy a better competitive position at present, in the future cassava can also become an alternate raw material for ethanol production in India. CTCRI has perfected and patented the process for alcohol production from cassava. The process essentially consists in liquefaction, saccharification/neutralization and fermentation with yeast for 48-72 h at pH 4-4.5, followed by distillation to recover the alcohol (Vijayagopal and Balagopalan, 1978)

FUTURE THRUST AREAS FOR CASSAVA UTILIZATION

Extruded Food Products

Extrusion processing has become an increasingly popular procedure in food industries for the development of many successful products, including snacks and baby foods. Though extruded ready-to-eat food products based on cassava are common in many southeastern European countries, in the Indian market cassava-based extruded snack foods are not available. Once technology for extrusion cooking is standardized, ready-to-eat extruded snack foods will be readily available in the metropolitan areas and cities in India. Marketability of such products is foreseen to be possible without much effort.

Rural Processing Units

In order to ensure rural employment and adequate remunerative prices for the producers or growers, the concept of cassava-based rural processing units has to be implemented. Many food items can be made out of cassava with little technological inputs. Wafers, chips, *papads*, dried chips for animal feed, *rava*, porridge powders, etc. are ideal food items for village-based food industries. Similarly, the technology developed for the production of gums, adhesives, cold soluble starches, etc. may also promote rural industrial growth in Kerala, Tamil Nadu, Andhra Pradesh and the northeastern provinces. The target markets for such products are urban and semi-urban areas.

Cassava-based Large-scale Industrial Units

Novel products made out of cassava, such as biodegradable plastics, ethyl alcohol and modified starches, are ideally suited as ancillary industries in the sago and starch belts of Salem in Tamil Nadu and Samalkot in Andhra Pradesh, to cater to the needs of a wide spectrum of end-users.

Environmental pollution as a result of the extensive use of plastics is a serious concern of the government in India. CTCRI technology to produce biodegradable polymers incorporating cassava starch has given new hope to the country in tackling the problem effectively. The biodegradable nature of this polymer can to a certain extent control the pollution hazard. This patented technology has been purchased by four companies within the country. Besides the application filed for an Indian patent, a European patent has also been awarded for this product and process.

The scope of cassava alcohol in the potable alcohol sector has not been explored fully. High quality ethyl alcohol produced from cassava, besides serving as potable alcohol can also be channelled into the energy sector. CTCRI which owns a patent for this process has transferred this technology to two commercial firms.

The patent for the production of cold water soluble starches from cassava is under active consideration by the patent authorities and two or three firms have shown interest in the technology; in the near future this will also be transferred to industry. The target groups for these products are in the urban and semi-urban areas. Likewise, many modified starches find application in the paper, textile and food industries.

Cassava starch when subjected to hydrolysis with amylolytic enzymes and acids at low concentration can yield a variety of sweeteners, such as liquid glucose, dextrose, maltose and other saccharides, which have wide applications in the growing confectionery and pharmaceutical industries in India.

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PRODUCTION AND USE OF CASSAVA FLOUR: A NEW PRODUCT OF FUTURE POTENTIAL IN INDONESIA

Sri Widowati[1] and Koes Hartojo[2]

ABSTRACT

Cassava is a perishable commodity. Over-supply occurs every year during the peak harvest season, with varying severity. To overcome the above problem, processing cassava into flour can be an alternative solution. The cassava flour production system in Indonesia is designed as a nucleus-plasma model. Cassava flour can substitute for wheat and rice flours as well as cassava starch at varying levels according to the kinds of food products. However, there are still problems in its marketing and distribution. A study on consumer acceptance has been conducted in West Java (115 households) and East Java (100 households and 25 small-scale food industries). Three visits to each respondent were made to collect information on the socio-economic situation, cassava flour utilization, and the level of cassava flour used in the processing of traditional foods, cookies, cakes and crackers. In the various food industries cassava flour was mostly processed into cakes, traditional foods and noodles. Substitution levels ranged from 20 to 100%, depending on the product. The contribution of cassava to the total carbohydrate intake in the diet of urban and rural households was 2.5 and 23%, respectively.

INTRODUCTION

Rapid urbanization in Indonesia has increased the consumption of processed food and bakery products, as well as increased the demand for imported products. To reduce imports and to save foreign exchange, it has been proposed that wheat flour be substituted by local products, such as maize, rice, sorghum, cassava and sweetpotato flours.

In Indonesia cassava is grown on about 1.4 million ha annually and its roots are used for food, feed and as raw material for starch extraction (Damardjati *et al*., 1990). The cassava market is unstable, and there are no attractive economic incentives for farmers to produce more cassava. At present, the low price is associated with limited demand. Since 1990 there has been over-supply because no new marketing opportunities have been created. Wheat is not produced commercially in Indonesia, but is imported as grain. There are three big wheat-milling factories, located in Jakarta, Surabaya and Ujungpandang, to produce wheat flour. The consumption of wheat in Indonesia has increased sharply from 125,000 tonnes in 1972 to 2.995 million tonnes in 1996. Wheat-based products are important, even though they do not dominate the national diet. In 1988, average per capita wheat consumption contributed only 66 Kcal/day or 2.4% of the calorie intake, and 1.6 g/day or 2.7% of the protein intake of the total national consumption (CBS, 1990). 1996 statistics show that wheat consumption had increased sharply to 40.8 g/day, contributing 149 Kcal and 3.6 g of protein per day. The properties of cassava flour are rather similar to those of wheat flour, and therefore cassava flour can partially substitute for wheat flour in many wheat-based products.

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CASSAVA FLOUR PRODUCTION

Cassava flour production is divided into three distinct operations as follows (Damardjati *et al.*, 1990a):

1. Harvesting and Handling of Fresh Cassava Roots

This is conducted fully at the farm level to produce fresh roots for the market, for temporary storage, or for processing to semi-processed products.

2. Production of Dry Cassava Chips

This is conducted at the farm level, either by individual farmers or in a group. The production of dry cassava chips follows several steps, i.e. peeling, washing and soaking, shredding or chipping, pressing and drying. Dry chips and flour will have a good quality when the raw materials are fresh (processed not more than 24 hours after harvest).

Peeling

Simple peeling of cassava can be done manually, using a knife. This traditional method results in good quality peeled cassava, but needs more labor and time than when using a peeling machine.

Washing and Soaking

Peeled cassava should be washed immediately, and then soaked in water. The purpose of this step is to remove the mucilage and reduce released HCN. Soaking can be done in a washing tank or by flowing water.

Shredding or Chipping

Several prototypes of cassava chipping machines have been introduced. Some of the machines are:

1. Manual chipping machine (designed by Sukamandi Research Institute for Food Crops, SURIF)

The equipment has replaceable blades depending on the purpose: to slice, shred, chip, or rasp. The capacity of this machine is 30 kg fresh cassava/hour operated by two persons.

2. Pedal chipping machine (designed by SURIF)

The capacity of this machine, which has a feed hopper, is about 100 to 120 kg/hour operated by two persons. By using an engine of 0.5 hp its capacity can be increased to 200-250 kg/hour/person.

3. Power chipping machine (designed by Maros Research Institute for Food Crops, MORIF)

The CSM-1 and CSM-2 models are designed with an engine of 0.5 hp, and have capacities of 170 and 370 kg chips/hour/person, respectively.

4. Large-scale chipping machine

Mariza company, a private enterprise, produces cassava chipping machines on a large scale to meet the demand of five national companies. Its machines are distributed in five provinces. The Type M5 # 16 cm chipping machine has a capacity of 300-400 kg chips/hour. Using pedal power, its capacity is 150 to 200 kg. The Type M5 # 32 cm chipping machine, with an engine of 2 hp, has a capacity of 2 t/hour.

The purpose of shredding or chipping is to convert the whole root into thin slices, of approximately 0.2-0.5 cm width, 1-5 cm length and 0.1-0.4 cm thickness.

Pressing

There are two purposes to pressing, i.e. to increase the drying rate and to reduce the HCN content, especially in bitter cassava varieties. The drying time for unpressed chips is about 30-40 hours, while pressed chips require only about 14-16 hours.

Drying

Pressed chips have to be dried immediately. Sun-drying is preferred because it is cheap and simple. During the rainy season, drying can be done by using an artificial dryer. Drying is complete when the chip moisture content has reached 14% or less. Dry chips are packed in plastic bags and can be stored for up to six months.

3. Milling

The manufacture of flour is done in a factory managed by cooperatives or by private companies with a larger capital.

To produce cassava flour, dry chips are milled with a disk mill, usually used for rice flour production. In order to maintain its quality, cassava flour should be packed in plastic bags and kept in a good quality warehouse.

AGRO-INDUSTRIAL MODELS

The development of models places emphasis on the operation of the systems at the farm level. It is expected that these farm products will be absorbed by the industrial sector, giving added value to the farmers.

The cassava flour production system in Indonesia is designed as a nucleus-plasma model. The cassava flour agro-industry can be developed in any area which is able to supply about 10 tonnes of fresh roots per day for five months operation in a year.

In an area of 1,000 ha, producing 15,000-20,000 tonnes of cassava/year, 5% of this production can be used for the development of a cassava flour agro-industry. A production level of about 1,500 to 2,000 tonnes/year is equivalent to about ten tonnes roots/day processed over five months.

In such an area, three main models of agro-industry can be proposed, depending on farmer capability, capital and distribution/marketing of the value-added product.

Model I: Home agro-industry for individual farmers

A family consisting of 2-3 persons can process 200 kg of fresh cassava roots/day and produce about 70 kg of dry chips. The investment is about Rp 750,000[1] to buy one unit of a hand-chipping machine, washing tanks, and sun-drying equipment (Damardjati *et al*., 1992b). The dry chips produced can be absorbed by Model III.

If two tonnes of fresh cassava roots/day are available, ten families can be involved in Model I, producing about 700 kg of dry chips/day.

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[1] In 1992 the exchange rate was about Rp 2000 per US dollar.

Model II: Agro-industry for farmer groups

A group consisting of 10-12 persons can process 1 tonne of fresh cassava roots/day to produce about 300 kg dry chips. The investment is about Rp 5,500,000 for buying one unit of a pedal-operated chipping machine, washing tanks, and sun-drying equipment (Damardjati *et al*., 1992b). The dry chips can be absorbed by Model III.

If five tonnes of fresh cassava are available per day, five groups of farmers can be involved, resulting in a total production capacity of about 1.5 tonnes of chips/day.

Model III: Nucleus cassava flour agro-industry.

The plant requires about 20-25 laborers and has a processing capacity of 3-5 tonnes cassava flour/day. Dry chips and cassava flour are the end-products. This milling unit mainly processes dry chips from neighboring farmers. Model III is mainly to produce cassava flour, and is responsible for marketing. Investment for the equipment is estimated at Rp 90,000,000 to buy a power chipping machine, two units of pressing equipment, drying equipment, and two units of milling equipment (Damardjati *et al*., 1992b).

Model III can absorb 1 to 2 tonnes fresh cassava/day, to be processed into dry chips, as well as absorb about 2 to 3 tonnes dry chips/day produced by Models I and II

CONSUMER ACCEPTANCE OF CASSAVA FLOUR

Cassava flour, which is processed from dry chips or dry shredded cassava, is a relatively new product in Indonesia. Research has been conducted since 1990 (Damardjati *et al*., 1990). Case studies to gather information on consumer preference for cassava flour and its products have been conducted in West Java (Damardjati *et al*., 1992a) and in East Java (Martini, 1992). The study in West Java involved 115 respondents based on their income level and the women's education level. In East Java, the study involved 100 respondents, divided into two categories, i.e. rural and urban/city respondents. Each respondent was visited three times to collect the data.

Consumer Preference in Cassava Flour Utilization

All the cassava samples for the cooking trials, which were supplied by interviewers during the first visit, were utilized by the respondents to prepare snacks within two weeks. The different income levels of respondents tended to be associated with the different types of food preparations from cassava flour

Traditional foods were preferred by most of the respondents (ranging from 53 to 76%) in all income levels over other processed foods made from cassava flour. The consumers stated that preparing traditional foods was simpler, and that they were more familiar with the products. For the high-income group of consumers, 43% of respondents preferred to process cassava flour into cakes; this compared to 22% in the medium and 30% in the low-income groups. Preference for traditional foods by the high-income consumers tended to be less. Ingredients such as margarine, butter, flavoring agents and dried fruit may be added in the cake preparation. These ingredients are relatively expensive. Therefore, the highest percentage making cakes came from the high-income consumers. The interest in cakes among the low- and medium-income consumers was not much different (**Table 1**).

Table 1. Preference of 115 consumers of various socio-economic and educational classes for making various products using cassava flour samples supplied by the interviewers (West Java).

Respondent group	n[1)]	Choice of consumer (% of respondents) for: Traditional foods	Cookies	Cakes	Crackers *(krupuk)*
Income group					
-Low	39	67.6	16.2	29.7	2.7
-Medium	46	75.6	12.2	21.9	2.4
-High	30	53.3	13.3	43.3	0.0
Educational level					
-Elementary	55	76.5	3.9	23.5	1.9
-Junior high school	25	73.9	13.0	34.8	0.0
-Senior high school	35	47.0	29.4	32.4	2.9

[1)] sample size

Source: *Damardjati et al., 1992a*.

The consumer's education level also affected their preference for certain food products. However, in general all respondents tended to process cassava flour mainly into traditional foods. More than 70% of those with elementary and junior high school education processed cassava into traditional foods. The simple process involved might be the reason. Those with a higher education level seemed to use cassava flour in preparing more types of products.

The kinds of processed foods in the rural areas were slightly different compared to those from an urban/city area (**Table 2**).

Table 2. Preference of consumers in rural and urban areas for making various products using cassava flour samples supplied by the interviewers (East Java).

Processed Food	Rural respondent n*	Rural respondent %	Urban respondent n	Urban respondent %
1. Steamed	38	76	38	76
2. Fried food	33	66	38	76
3. Crackers *(krupuk)*	8	16	15	30
4. Traditional foods	20	40	42	84
5. Cakes	4	8	6	12
6. Meal *(tiwul)*	44	88	7	14

*sample size

Source: *Martini, 1992.*

Table 2 shows that in both rural and urban areas, cassava flour was mostly used for steamed and fried foods. Crackers and traditional foods which were preferred by urban respondents, were mostly used as supplementary food. In the rural areas, cassava meal is still widely used as a staple food, and most respondents (88%) processed cassava flour into meal (*tiwul*), considered as a source of carbohydrate equal to rice for rice eating people. As a staple food, cassava contributed 23 and 2.5% to the carbohydrate intake in the diets of rural and urban households, respectively.

In East Java, information on cassava flour acceptance was also collected from 25 small-scale food industries; these were for processing of traditional foods (36%), cookies (32%), cakes (4%), crackers (24%) and noodles (4%). Most of them used cassava flour as a partial substitute of wheat flour (Martini, 1992)

Consumer Acceptance of Cassava Flour for Long-term Consumption

On the second visit to the respondents, there were evaluations on the acceptance by consumers for the kinds of food products made from cassava flour and consumed over a long period. **Table 3** shows the consumer acceptance for different kinds of food products made from cassava flour.

Table 3. Consumer acceptance for food products made from cassava flour.

Acceptance	Consumer acceptance (% of respondents) for			
	Traditional foods	Cookies	Cakes	Crackers
Like very much	6.6	1.6	3.3	0.0
Like	50.4	9.9	20.5	1.6
Slightly dislike	3.3	0.0	0.9	0.0
Dislike	0.0	0.9	0.9	0.0

Source: *Damardjati et al., 1992a.*

Most of the respondents (more than 50%) mixed cassava flour with other flours such as wheat flour, cassava starch or rice flour when preparing traditional foods and cakes. Cassava flour was not utilized much for cookies and crackers. The reason might be the lack of knowledge or capability of the respondents in utilizing cassava flour in these forms. Damardjati *et al*. (1992a) reported that cassava flour substitution up to 60% resulted in high quality of various types of cookies. Cassava flour and starch mixed in a 1:3 ratio can also be used in making crackers, and the product was well accepted by panelists (Suismono and Wheatley, 1991).

A second cooking trial, conducted by 115 respondents, indicated that cassava flour was accepted by 84.4% of respondents, while 15.6% of the respondents rejected the flour. Cassava flour consumption by most respondents was about 4 to 7 kg/family/month. The highest consumption was recorded by consumers with medium income levels. Most consumers processed cassava flour into traditional food products (41.7%) and cakes (21.7%).

FOOD PREPARATION METHODS

Most respondents preferred to process cassava flour into traditional foods, cakes, cookies and crackers. The ingredients and processing methods are shown in **Table 4**.

Table 4. Composition of products processed from cassava flour.

	Traditional foods	Cookies	Cakes	Crackers
Basic ingredients	Wheat flour, Rice flour	Wheat flour	Wheat flour	Cassava starch
Additional ingredients	Margarine, Eggs, Sugar, Vegetable/s, Coconut milk	Margarine, Eggs, Sugar	Margarine, Eggs, Sugar	Sugar
Other ingredients	Salt, Artificial coloring	Leavening, Flavoring	Leavening, Artificial flavoring	Salt, Spices, Flavoring
Process	Steamed, fried or roasted	Oven-baked	Oven-baked	Steamed, prior to frying

Source: *Damardjati et al., 1992a.*

Traditional Foods

Several kinds of traditional foods, which are usually prepared from wheat flour, rice flour or maize starch, were made using cassava flour as a partial or total substitute for these ingredients. The traditional foods were *bala-bala*, *nagasari*, *cimplung* and *bika ambon* (**Table 5**).

Cakes

The basic procedure for cake preparation is mixing together sugar, eggs and a leavening agent. Composite flour and melted margarine are then added and mixed thoroughly into a dough. The dough is poured into a pan already swiped with margarine and coated with wheat flour, then baked for approximately 30 minutes. There are many flavors of cakes, such as coconut cake, palm sugar, pineapple, etc. There is also a type of roll called *bolu gulung*. Several respondents made cakes from 100% cassava flour, and others from 50% each of cassava and wheat flours.

Cookies

Three kinds of cookies were made by the respondents, i.e. cheese-sticks, *aster* cookies and *nastar*. Each was made from 100% cassava flour. Cheese-sticks were made by mixing cassava flour, egg yolks, salt, coconut milk and margarine. The homogenized dough was sheeted, cut and then deep-fried. *Aster* cookies were made by mixing refined sugar and margarine, then adding eggs one by one, followed by vanilla, baking powder and roasted cassava flour, and mixing thoroughly. The dough was molded then baked for approximately 25 minutes. The basic procedure for making *nastar* is similar to that for *aster* cookies.

Table 5. Percentage substitution by cassava flour in several types of traditional foods and their method of preparation in Indonesia.

Local name	% substitution by cassava flour	Other flours	Brief description of preparation method
Bala-bala	50	Wheat	- Mixture of flour, water, vegetables and spices - Fried
Cimplung	50	Wheat	- Mixture of flour, water, sliced jackfruit and salt - Fried
Nagasari	70	Maize	- Cassava flour mixed with coconut milk, salt, vanilla, maize flour, and cooked - Wrapped in banana leaf, stuffed with banana slices
Jongkong	50	Rice	- Dough mix of flour with coconut milk and salt, and cooked - Filled with sliced palm sugar, drenched with thick coconut milk, and wrapped in banana leaf - Steamed
Ongol-ongol	65	Wheat	- Flour mixed with water and sugar, then cooked - Formed, cooled and sliced - Served with grated coconut
Dodongkal or *awug*	100	-	- Cassava flour mixed with water and salt, then cooked - Dough filled with shredded palm sugar - Served with grated coconut
Biji salak	100	-	- Small balls made from cassava flour dough, and cooked - Served with sweetened coconut milk and sliced jackfruit
Bika ambon	35	Rice	- Flour mixed with egg, fermipan and coconut water, and worked into a dough (I) - Sugar and coconut milk cooked together until oily (II) - I and II mixed together - Baked

Source: *Damardjati et al., 1992a.*

Crackers

Crackers are processed by mixing eggs, sugar, salt, ground garlic, water and composite flour. The dough is wrapped and shaped into a solid roll, then placed on banana leaf and steamed. When the steamed dough has cooled, it is sliced, dried and deep-fried. The composite flour consists of 50% cassava flour and 50% cassava starch.

CONCLUSIONS

Cassava flour production in Indonesia represents an alternative means of diversifying cassava products. It has the potential to increase farmer's income, extend marketing, support food diversification and reduce wheat imports. Cassava flour processing involves the development of technologies and equipment for peeling, washing, soaking, chipping, pressing, drying and milling.

The cassava flour agro-industry system is designed as a nucleus-plasma model. Cassava flour was accepted by 84% of surveyed respondents. It can be processed into six groups of food products, i.e. traditional foods, cookies, cakes, crackers, noodles and cassava meal. Cassava flour can substitute for wheat and rice flours. The level of substitution ranges from 20 to 100%, depending on the product.

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NEW PRODUCTS OF FUTURE POTENTIAL IN THE PHILIPPINES: CASSAVA FLOUR AND GRATES

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ABSTRACT

In most parts of the Philippines, root crops have evolved from being mainly a source of energy-rich human food to a key commercial crop with high-value and marketable products in the form of flour and grates. Economic analysis indicates that cassava flour could be competitive, both in price and quality, with wheat flour. Allowing a 25% profit margin attained from production to processing, cassava flour may be sold at 75% the cost of wheat flour. This resulted in a reduction of 5% in the cost of bread using a composite flour mix of 80% wheat and 20% cassava. It also produced a special type of aroma, texture and distinct taste, especially if using the Golden Yellow variety released by the Philippines Root Crops Research and Training Center (PRCRTC; now renamed PhilRootcrops).

Cassava grates, on the other hand, is the main component of high-value food products like cassava cake, "pitsi-pitsi" and cookies. Initial studies indicate its wide acceptability in urban markets, resulting in increasing demand. It obtained a return on investment (ROI) of 50%, compared to cassava flour, which had only 20%. Both products have their own processing system and equipment developed by PhilRootcrops, the Univ. of the Philippines in Los Baños (UPLB), and a private manufacture, the ALMEDA. These plants have served as pilot projects in previous studies.

The economic impact can only be felt if these village-type plants go into commercial production with sufficient and sustained volume. As the demands for flour and grates grow, there should be a number of these village-type plants in each cassava production area. Moreover, research and development on system improvement and evaluation should be continuously pursued with full integration of all efforts from crop production to product development.

INTRODUCTION

Root crops are the third most important crop in the Philippines, after rice and maize. They are traditional crops that are easy to grow and are adapted to a broad range of agro-ecological conditions. In fact, many of these root crops are planted in marginal areas where other crops cannot grow well. Root crops are an important source of food, feed and starch among the Filipinos. About half a million ha of agricultural land are planted to root crops each year (NRRDEN, 1999).

Among the root crops, cassava leads in terms of area and production. Cassava roots can be processed into various products, and can replace various associated raw materials whose supplies are imported or, if locally produced, are unstable. These include maize in the manufacture of animal feed, molasses for production of sweeteners or alcohol, and wheat flour in various bakery products. Presently, the use of cassava as a feed ingredient is more accepted by feed millers than ten years ago. However, cassava for food use is still at a semi-commercial or subsistence level. One major disadvantage of cassava is the high perishability of the fresh roots when not handled and stored properly. Cassava roots starts to exhibit vascular streaking about 48 hours after harvest, rendering them unfit for human consumption. To increase the potential of using cassava for food and to increase the value of the roots requires transforming the product into a dried form.

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This paper thus presents the potential of cassava flour and grates in processing as a viable industry.

OVERVIEW OF CASSAVA UTILIZATION

The average volume of cassava production in the past 10 years (1989-1999) was close to 2.0 million metric tons. Of this, 35% was used for the manufacture of starch, 50% for food and 5-15% for feed. The largest percentage is utilized for food, especially in Muslim Mindanao (southern part of the country), where the people utilize cassava as their staple food. Utilization of cassava as a feedstuff is a growing industry; hence, there is potential growth in this sector.

1. Industrial Uses

Commercial use of cassava began only in 1956 with the establishment of starch factories in Mindanao and Pangasinan, triggering a rapid increase in the production of the crop. Since then, the growth of cassava production has been related to the growth of the starch industry. The use patterns for food, processing and animal feed have changed from 68-21-11, respectively, in the sixties to the ratio of 60-34-6 in the seventies where starch is the major industrial use (Roa and Orias, 1997).

Today, there are ten major cassava starch factories in operation; however, cassava production for starch is facing problems of cost increases, prices instability and sustainability. In a related development, some companies have ventured into other uses of cassava, such as alcohol production for human consumption, and using it as a binder in the food and paper industries. Some of these are now being put in place in Negros Occidental and Northern Mindanao. The long-term viability of such projects and other considerations are being looked into to determine how technology, social and economic factors interplay and affect one another.

2. Food Uses

Cassava is traditionally eaten as a staple or a staple supplement when cereals are not adequately available. It is boiled, steamed or fried (e.g. *kabkab*), or processed into local delicacies of various procedures, forms and taste. In Mindanao alone, there are at least 30 different preparations of grated cassava (Loreto, 1999). Among the local delicacies, cassava pie, pudding and cake are gaining popularity in the urban areas. These products are traditionally prepared using fresh grated cassava. However, fresh cassava and its grated form have high perishability; hence, market reach is constrained. Thus, consumption of the roots is virtually confined to the rural areas.

POTENTIAL PRODUCTS

In areas far from starch mills and chip traders, income and employment opportunities from cassava are limited. To increase market reach and to make cassava products more available in the urban areas (where disposable income is presumably higher), requires transforming fresh cassava roots into more stable and acceptable products. The products that seem to have most potential are cassava flour and dried grates.

1. Cassava Flour

Wheat grain is still the primary raw material for flour milling in the country. Like in other tropical countries, it is highly import-dependent with most wheat coming from the United States, Canada and Australia. The Philippines is the fourth biggest importer of wheat, next to Japan, Egypt and China. Since flour is produced from an imported raw material, locally produced alternatives are sought. Research by the Philippine Root Crop Research and Training Center, in collaboration with the Department of Agricultural Chemistry and Food Science, indicates that many bakery and other food products can be substituted with cassava flour without affecting their quality (**Table 1**).

Table 1. Acceptable level of substitution of cassava flour in selected food products.

Food Product	% Substitution	References
Paborita	50	Palomar *et al*., 1981 & Lauzon *et al*., 1987
Cheese crackers	50	Palomar *et al*., 1981 & Lauzon *et al*., 1987
Coconut cookies	50	Palomar *et al*., 1981
Doughnuts	50	Palomar *et al*., 1981
Gollorias	50	Palomar *et al*., 1981
Polvoron	100	Palomar *et al*., 1981
Pandesal	20	Palomar *et al*., 1981
Fried cheese sticks	50	Truong *et al*., 1983
Cinnamon rolls	50	Monserate *et al*., 1983
Muffins	50	Truong *et al*., 1983 & Lauzon *et al*., 1985
Cassava shrimp sticks	50	Lauzon *et al*., 1985
Chiffon cake	100	Lauzon *et al*., 1985
Butter cake	100	Lauzon *et al*., 1985
Cacharon	100	Lauzon *et al*., 1985
Hot rolls	20	Palomar *et al*., 1981
Loaf bread	10	Palomar *et al*., 1981

The flour used in these products had been dried to a moisture content of 10-12%, and milled to a particle size that will pass through the 180 µm mesh.

2. Dried Grates

On the other hand, the market for cassava cakes, pies and pudding is slowly developing. As mentioned earlier, the high perishability of fresh cassava roots and grates remains a challenge among post-harvest scientists. One possible solution is the use of dried grates. Dried grates are those products that underwent rasping and drying, and finally passed through a 140 µm mesh. Studies by Palomar *et al*. (1981) and Lauzon *et al*. (1985) show that cassava cakes, pies and pudding produced using dried cassava grates are comparable with those produced from fresh grates in taste, appearance and acceptability among consumers. Dried grates as a product form has certain advantages, such as: a) being as stable as flour; b) amenable to use in preparations of various local delicacies; and more importantly, c) have good market demand. Market testing shows a promising market potential for grates in convenient delicacy packs, not only for domestic distribution but also for Filipinos living abroad who long for this special product.

FLOUR AND GRATES PROCESSING

Processing of cassava into flour and grates is very simple. The fresh roots undergo primary processing such as sorting, washing and peeling prior to chipping or grating. Drying of the chips or grates is accomplished either through sun-drying or the use of mechanical dryers. Milling followed by sieving of the dried chips or grates is done to attain the final consistency of the product (**Figure 1**).

There are a few critical points in the process: a) cleanliness of the chipping/grating and drying activities; b) dryness of the chips/grates; and c) appropriate storage of the chips/grates. Moreover, the use of high quality roots is very important because it dictates the overall quality of the product.

Economic Analysis

Fine flour recovery from fresh roots is approximately 25-30%, depending on the maturity of the roots, variety and machine efficiency. Under the present price and cost structure for cassava and wheat, it is economically feasible to produce cassava flour at a competitive price. Allowing a profit margin for raw materials in processing, cassava flour may be produced at 75% the cost of wheat flour. Hence, cassava flour can be sold at 18.00 pesos/kg, while wheat flour costs 25.00 pesos/kg. The resulting cost of bread made from a wheat-cassava composite flour mix of 80: 20 will be lower.

For cassava grates, net returns are relatively higher because they can be sold at a price 25% higher than that of cassava flour due to their special use. This results in an improvement of ROI (returns on investment) of up to 50%, compared to a maximum of only 25% for cassava flour.

Pilot Production of Flour and Grates

One of the projects assisted by PhilRootcrops belonged to the Mabagon Rootcrop Cooperative Association (MARCA) in Hindang, Leyte. It is a cooperative comprising mostly female members and managed by a male member. Most of the members are also producers of cassava, generally on a semi-commercial or subsistence level. The variety commonly planted in their farms is Golden Yellow with a yield range of 5-18 t/ha with no fertilizer input (Tan *et al*., 1996).

Housewives of cassava growers who are also members of the cooperative carried-out processing of cassava chips. Quality dried cassava chips were made by washing the roots, peeling them into thin cylindrical strips, and sun-drying on mats. The process is a traditional practice of women in the area. The quality of dried chips passed the quality specifications for flour.

The project then introduced a chipping and milling machine for flour processing. When the production of flour stabilized, the idea of utilizing cassava flour was introduced to bakeries and other food processors. Later, the project expanded into the production of dried grates due to the demand from food processors in Manila.

The project was successful, both in terms of acceptance by bakeries and profitability. This continued until the co-op leader resigned from the cooperative due to political and family reasons, leading to a vacuum in the leadership of the cooperative. No

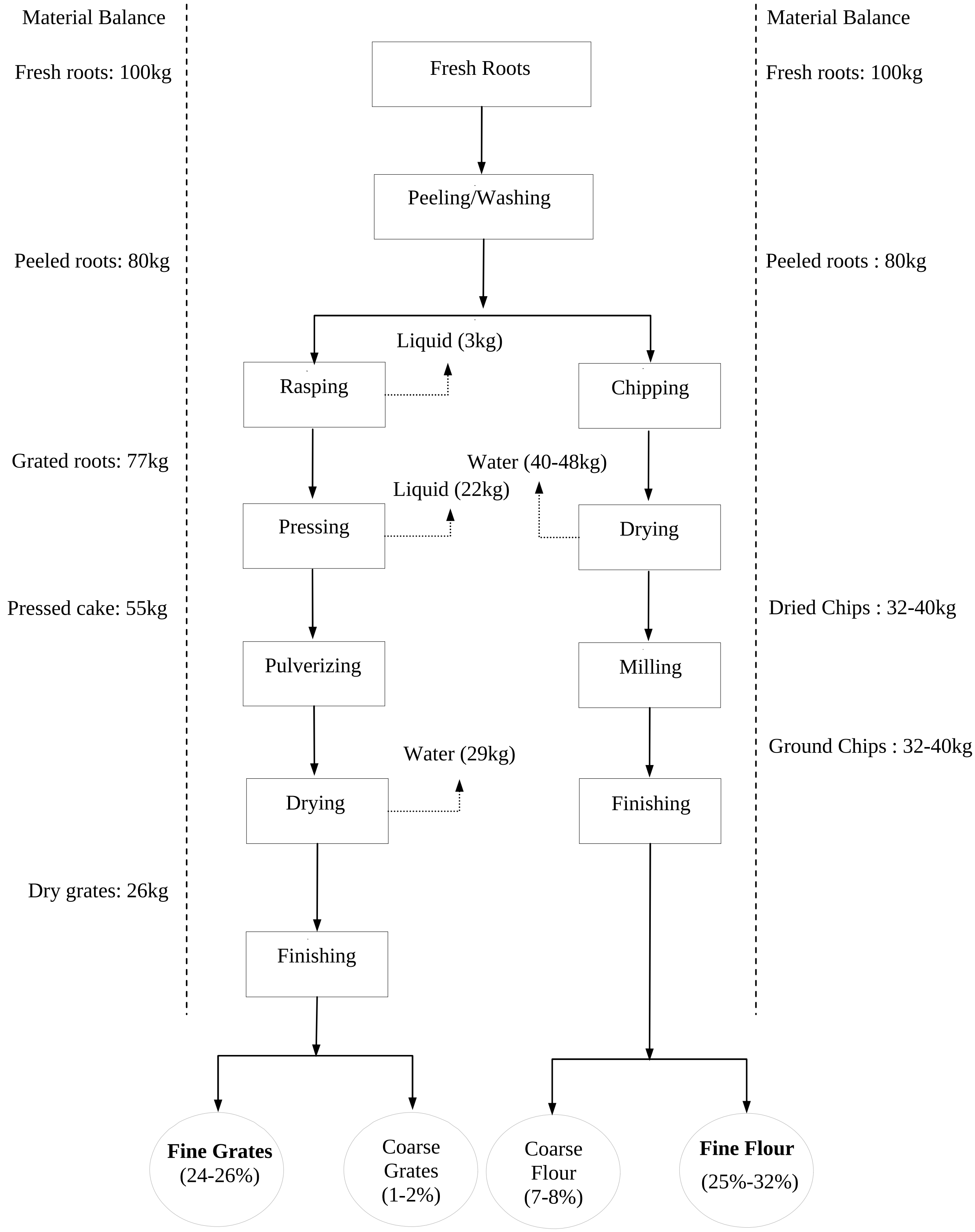

Figure 1. Cassava flour and grates processing flow and estimated recovery (in percent) from fresh roots.

one among the members was willing to take on the responsibility. Consequently, the supply of cassava flour to bakeries became irregular, forcing bakery owners to switch back to 100% wheat flour. Similarly, the market for dried grates switched to other suppliers due to the unstable supply from the cooperative.

CONCLUSIONS AND RECOMMENDATIONS

Cassava flour has yet to evolve into a commercial product, and be produced on a commercial scale. It must succeed at a smaller entrepreneurial scale, but with a larger collective production capacity from a number of established mini-plants. Cassava flour may find a market niche, not as bread flour alone but as specialty flour, similar to sweetpotato flour, which is marketed as gluten-free flour for those suffering from celiac disease. The processing of dried grates, on the other hand, should be passed on to processors that can strongly market the product, both domestically and abroad. It is in this new direction that we see brighter prospects for cassava flour and dried grates in the near future – they are competitive in both price and quality.

From the extension activities done by PhilRootcrops, there seems to be a need to really examine the framework for commercializing products such as flour and grates. Finally, the question remains: "Should processing (value addition) and sales be done by cassava growers, or should growers benefit solely from the increased demand of roots?"

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GLOBAL CASSAVA STARCH MARKETS: CURRENT SITUATION AND OUTLOOK[1]

Guy Henry[2] and Andrew Westby[3]

ABSTRACT

Current global starch production is approximating 50 million tonnes. While the starch production growth rate steadily continues to surpass average population growth figures, the make-up by starch source and production regions have been changing. The world share of cassava-based starches may range between 4-6%. While Southeast Asia continues to lead as the foremost cassava starch production (and utilization) region, both within this region and in other continents the cassava starch industry and market patterns are changing. Starting in the late 1980s and accelerating during the 90s, Latin-American and (to a minor extent) African cassava starch processing has expanded. It is most likely that this basic trend will continue into the beginning of the 21st century. However, the new century brings with it both new threats as well as additional opportunities that will greatly impact on the competitiveness of cassava as a major starch source.

The paper firstly summarizes the principal global trends of starch production, utilization and markets, paying special attention to the role of cassava. In addition, individual starch regions (US, EU, Asia) and their main players will be discussed. Secondly, the foremost global and regional technical, political and economic conditions that are currently coming about will be reviewed concerning their potential impact on global starch markets. Thirdly, a synthesis is formulated as to what the most probable implications are for cassava sector researchers and developers.

INTRODUCTION

Cassava utilization has, especially during the early 1990s, accelerated outside of the traditional regions with already high cassava utilization, i.e. Thailand, Indonesia and India. Most of this renewed emphasis has been taking place in the so-called " newly opened economies " of China, Vietnam, etc. These dynamics regard especially cassava starch processing. Moreover, traditional cassava starch producers, like Thailand and Indonesia, are further expanding their industries and product portfolios. To a lesser extent this has also been the case in Latin America. However, in Africa this trend has only just started to take initial shape.

Given these recent dynamics and given the scarcity of reliable and updated information about the starch industry in general, and the cassava starch industry in particular, this Workshop offers an opportunity to present new information and highlight global cassava starch trends.

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[1] The initial (presented) paper was modified to accomodate more recent information that was generated through a consultancy of the European Group on RTB for FAO-ESCB (March 1998). The main authors for the consultancy were Guy Henry (CIRAD), Andrew Westby (NRI) and Chris Collinson (NRI), referenced as Henry *et al.*, 1998.

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Cassava starch industry aspects cannot be analyzed in isolation. Two principal forces dictate the industry, in its input and in its output markets. The first is the cassava chip and pellet industry, that compete for the same raw material as the starch industry. The second is the output market with competing starches based on potato, maize and wheat. Hence, this paper will give due attention to these two additional sectors, in its attempt to shed more light on trends in the global cassava starch market.

PAST AND FUTURE TRENDS OF END-USES, BY CONTINENT

Current global cassava utilization is estimated at 166 million metric tonnes (t). A recent paper (FAO, 1997) analyzed past cassava utilization trends. The paper, based on the results of econometric modelling, in addition, projects utilization growth rates to the year 2005. **Table 1** shows that the annual global utilization rate is projected to slow down to 1.8%, from the past 2.4%. This is mainly caused by a relative slowdown in African utilization, while growth rates in Asia and in Latin America and the Caribbean (LAC) are projected to increase. Starch utilization is included in the group of "other uses". While this group showed a global past growth rate of 4.7%, it is projected to decrease to 3.1%, but this still represents the highest growth rate compared to food and feed use. Especially for Asia and LAC, the growth rates of "other uses" will continue to be significant. The same table also shows the relative shares of the different uses in time. As such, it is projected that both the food and feed share will decrease, while "other uses" will gain in terms of global utilization share. To a large extent, this is a reflection of the dynamic global future outlook for cassava starch.

Table 1. Global cassava utilization growth rates (past and projected) and shares among various uses in 1983-1993 and 1993-2005.

Region:	World (%)	Africa (%)	Asia (%)	LAC[1)] (%)	Share of total use (%)
Total use					
1983-1993	2.4	4.3	1.6	0.2	**100**
1993-2005	1.8	2.4	2.5	1.5	**100**
Food					
1983-1993	2.4	3.9	0.1	0.2	**59**
1993-2005	2.2	2.5	2.0	0.8	**58**
Feed					
1983-1993	1.1	7.6	4.7	0.2	**24**
1993-2005	-0.2	1.8	2.5	1.3	**22**
Other use					
1983-1993	4.7	5.3	6.8	0.4	**17**
1993-2005	3.1	2.3	5.4	3.4	**20**

[1)]LAC = Latin America and the Caribbean

Source: *FAO, 1997.*

Starch, or cassava starch in the context of this paper, can be classified according to end-use or to processing technique. A practical classification used by Roper (1996) and by Sansavini and Verzoni (1998) includes four main classes: *native starch*, *hydrolyzates, modified starch, and others*. The industries utilizing starch can be basically divided into: food and non-food sectors. As such, starch (lysine, ...) for the animal feed sector, is included as a non-food. The list of industries that are currently using starch is very large since it is being used in thousands of end-products. Useful references for extensive listing of the sectors are Ostertag (1996), Leygue (1993), Roper (1996) and Gottret *et al*. (1997). Besides, the internet home-pages of major starch multinationals (like Cargill, ADM, Purac, Cerestar, CPC) list all possible derived products. Furthermore, a substantial number of modified starches are labelled with codes rather than names (as is the case of cationic starches for the quality paper industry). For the sake of efficiency on the one hand, and data availability on the other hand, this paper will mainly deal with starch used in the following sectors (including a non-exhaustive sample of end-products):

(a) Food Sector:

Food processing industries:
- bakery and pastry products
- noodles, vermicelli, ...
- soups, sauces, ...
- ice creams, yoghurts, lactic drinks, puddings, ...
- processed meats, ...
- sweets, chocolates, candy, chewing gums, ...
- marmalades, jams,...
- canned fruits, juices, ...
- soft drinks, beers, ...
- snack foods,...
- taste enhancers, color enhancers, ...
- fat substitutes for dietary products
- alternative protein sources
- sweeteners, ...
- .....

(b) Non-Food Sector:

Paper, cardboard and plywood:
- carton, high quality papers, different plywoods, ...

Textile industry:
- fillers, stiffeners, ...
- leather goods

Chemical and pharmaceutical industry:
- glues, paints, cements, ...
- soaps, detergents, bleaches, insecticides, ...
- explosives
- oil drilling materials
- biodegradable plastics, polyesters, etc.
- industrial alcohols
- combustibles, ethanol, oils,...
- pharmaceuticals,vitamin C and B12, antibiotics,..
- cosmetics, ...
- water treatment agents

- …

Feed industry: - protein substitutes
- carbohydrate sources

As mentioned before, very few updated and consistent reports exist regarding starch markets. Roper (1996), based on 1991-92 data, refers to a European starch market of 6.1 million tonnes. Information from the International Starch Institute in Denmark (Thomson, 1997) mentions the EU producing 7 million tonnes, which is consistent with AAC (1997), but a Cerestar source notes 6 million tonnes. Ostertag (1996), using largely 1992 data, calculates a global market of 33.2 million tonnes, with shares for the US and Canada of 41%, the EU 18%, and Asia 34%. A recent (still unpublished) study by Sansovini and Verzoni, using 1993 data, estimates the world market at 33.7 million tonnes.

The cassava share of global starch production is estimated by Ostertag (1996) at 6%, but by Sansavini and Verzoni (1998) as high as 10-11%. These conflicting estimates do not contribute much to a clear understanding of the global cassava starch situation. However, it seems more pertinent to analyze the cassava starch actual and potential markets at the disaggregated or country level.

II. African Cassava Starch Production and Utilization

The availability of data on household level starch production is very limited. Household level starch production does exist, as demonstrated by the data from COSCA, but is probably mainly for local food use.

There used to be a number of cassava starch factories operating in Africa, including in Uganda, Tanzania and Madagascar. Few of these are now operational and little data is available on their production. An African starch experience comes from Malawi (CFC, confidential report, 1997), where the local paper and cardboard industry is willing to buy up to 1.5 tonnes of cassava starch (for adhesives) a day, while the confectionary, plywood and food processing industries have also expressed interest to use (local) cassava starches. Similarly, one report from Uganda (CFC, confidential report, 1997) evidences the opportunity for cassava flour to partially substitute for wheat in the manufacturing of baby premixes, biscuits, ethanol and dextrins. The other report, from the same source, describes the possibility for refurbishing an old starch factory for future production of starch, glucose and dextrin for use by the pharmaceutical, food-processing and textile industries. The factory is envisioned to produce daily 15 tonnes of starches, using cassava and maize as the source crops. Following are some summarized case studies to further highlight the African starch situation.

Market opportunities in Zimbabwe

Kleih (1994; 1995) estimated the potential level of commercial/industrial use of cassava in Zimbabwe. There is currently little cassava grown in Zimbabwe, but there is a lot of interest because of recent poor maize harvests. By analysis of the future markets and rapid rural appraisals in potential production areas, the future supplies and demands for cassava were estimated. Kleih (1995) estimated a starch demand equivalent to 7,700 tonnes of chips. Demand is not certain and may only occur in the medium to long term. The major manufacturer indicated that they will concentrate on maize for the next five years. Dry raw materials are the preferred input. Furthermore a demand for ethanol was estimated to an equivalent of 240,000 tonnes of fresh roots. Demand is not certain and may only occur in the long term once a large-scale cassava economy is established. Cheaper processing technologies would be required. 240,000 tonnes of the roots could produce 40 million liters of ethanol, equivalent to 13% of current gasoline consumption.

Domestic market potential for cassava starch in Ghana

Graffham *et al.* (1997) surveyed producers and users of starches and flours in Ghana between February and April 1996. The market for starch within Ghana comprises a number of end users who make use of maize, cassava and potato starches, which are mostly imported. The current market is approximately 4,200 tonnes per year, which compares well with figures in a survey carried out by Glucoset Limited of Ghana (Anonymous, 1994). The Glucoset survey also predicted that demand will increase to 5,600 tonnes by the year 2000. Most users have very high quality specifications with 60% of the market being for modified starches.

The use of starch from locally grown cassava would mean that less material has to be imported. Further work is required to determine whether small-scale processors can produce starch of a high enough quality, or whether there are opportunities for large-scale processing plants using cassava as a raw material.

Market potential for cassava starch and alcohol in Nigeria

Bokanga (1997) made some estimates of the potential use of cassava for alcohol and starch in Nigeria. He predicted that one factory consuming 30 tonnes of cassava chips per day for alcohol could save US$2.06 million in foreign exchange, with net returns to processors of US$1.5 million and US$0.5 million to farmers. Use of cassava for starch (based on an annual production estimate of 200,000 tonnes) would have no foreign exchange savings, but would result in US$30.12 million net income to processors and US$12.5 million to farmers.

Trade in starch

A stage beyond the use of cassava starch by the domestic food and non-food industries is the export of starch. Data for cassava starch exports are available from FAOSTAT (FAO, 1997); these show that starch to the value of only US$16,000 was exported in 1995. The major exporting countries were Kenya and the Democratic Republic of Congo. Over the period 1992-1995 Africa was a very minor exporter of cassava starch. The only significant quantity was exported by Egypt in 1993. Since Egypt is not a major cassava producing country, this may have been produced elsewhere.

By contrast with its exports, Africa was more of an importer of cassava starch between 1992 and 1995 (9,000-6,000 tonnes). Only a small quantity of African imports could have come from African countries because total exports from these countries were very low. With appropriate development, African countries with potential comparative advantages in cassava starch production may in the future be able to supply themselves or other African nations. However, the extent to which intra-African cassava starch trade is possible will crucially depend on the cost of intra-African transport. This potential is worthy of investigation. In terms of imports of other types of starch, north African countries tend to be the largest importers of EU starch. This may reflect their greater level of industrialization. According to data taken from the US Department of Commerce, the US is not a major starch exporter to Africa. No types of starch, other than those that appear in the tables, were exported from the US to African countries during 1996 and 1997. Cassava starch exports from Thailand to African destinations (non-specified), between 1993 and 1996, fluctuated between 2,167 and 3,200 t/year (TTTA, 1996).

Although some data have been identified on the current supply and demand for starches in Africa, more are required before recommendations can be made on the future of starch processing. Specifically, more data are required on the demands for modified starches and hydrolysis products. An important criterion in the assessment of this market potential will be the ability to produce starches of the appropriate quality for various commercial applications.

III. Asian Cassava Utilization and Markets

Chips and pellets

As extensively reported by Hershey *et al.* (1997a), Henry and Gottret (1996) and Henry *et al.* (1994; 1995), Thailand has been the principal cassava[4] chip and pellet producer and exporter for more than three decades. As the result of a series of trade policy changes throughout the late 1980s and 1990s, Thai pellet production and exports have steadily decreased from 7.2 million tonnes in 1990 to 3.6 million tonnes in 1996 (TTTA, 1996). Furthermore, the share of Thai chips has become negligible compared to that of pellets. Pellet export prices, as the cause of reduced exports, have behaved irregularly. While at the end of the 1980s and start of the 1990s the CIF Rotterdam pellet price was in the 145-165 US$/tonne range, as EU coarse grain prices started to slide so did Thai pellet prices. While in 1995, average EU pellet prices rebounded to a US$ 140/tonne level, they have since slid to a current 1998 price level of less than US$ 100/tonne (FOB price European port of DM 170-177/tonne). Hence, the Thais have not been able to satisfy their annual export quota to the EU. This is also due to competition for cassava roots from the domestic starch industry. The future potential of cassava for the domestic feed industry and its competitiveness *vis-à-vis* domestic or imported maize, needs further study.

Indonesia, as the second largest chip/pellet[5] exporter has experienced a similar export erosion trend, although with much smaller volumes. As will be further elaborated in

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[4] It needs to be noted that a large share of the solid residue from the Thai cassava starch processing industry is used as raw material for the cassava pelleting industry. However, no exact figures on its utilization rate are available.

[5] Unlike Thailand, Indonesia still ships large volumes of cassava chips. Currently, exports are equally divided between chips and hard pellets. The relatively cheaper chips have been used, at times, by other Asian countries for starch processing.

the discussion on starch in Indonesia, the domestic market for Indonesia is of primary importance, especially for starch. While Indonesia has profited from its EU pellet/chip exports until the early 1990s, it has actively diversified its market, which currently is almost equally divided between the EU and Asia (Taiwan, Japan, Hong Kong, China,..) and others. Future processing emphasis in Indonesia will further shift to starch rather than chips and pellets. Little hard information is available regarding future potential of cassava for domestic feed utilization. This needs further attention.

Starch situation in Thailand

Thailand is the largest cassava starch producer, manufacturing approximately 2 million tonnes of native and modified starches, of which less than half is exported. Sriroth (1997), reports that the industry currently is made up of 52 factories, down from 96 in 1974. **Table 2** shows the domestic cassava starch utilization, by industry, as a percent of the total 1994 production of 1,121,625 tonnes of starch for domestic use.

TTTA (1994) estimates the annual starch export growth rates for the main starch products between 1987 and 1992 as follows: native 10.5%, modified 33.8%, sorbitol 48.9%, monosodium glutamate (MSG) 12.8%, glucose syrup 9.4% and sago 8.3%. These figures speak for themselves regarding the dynamics of the Thai starch industry. As the industry becomes more competitive and hence, more secretive, traditional information sources in Thailand are becoming very reluctant to share their latest data. The latest (1996) TTTA Annual Yearbook only mentions exports, but gives no national utilization information.

Starch exports in 1996 are estimated at 800-900,000 tonnes. Principal destinations are foremost Japan and Taiwan, followed by USA, Mexico, China, Singapore, Hong Kong, the Netherlands, Philippines and Indonesia. It is interesting to note that even with the very steep EU tariffs, 28,577 tonnes of starch were exported to the Netherlands! It is yet another indication[6] of the competitively low price of Thai starch, which during 1996 averaged US$ 280-300/tonne *versus* EU potato starch at US$ 600; the latter dropped to US$ 550/tonne during the year, due to favorable EU export subsidies (while US maize starch was US$ 300/tonne). The latest Thai starch industry information (May, 1999) mentions a "Super High Grade Starch" price of US$ 200/tonne FOB Bangkok (TTTA, 1999).

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[6] The current financial and economic crisis in Thailand (and in SE-Asia as a whole), has many serious negative implications for the country, its economy and its people. However, as regards cassava product exports, the huge devaluation of the Baht (currently 37Baht= 1US$, compared to 25 Baht two years ago), should have significant positive repercussions for the international competitiveness of Thai cassava based products, such as starch. Since most of cassava starch production and processing inputs are non-imported, domestic factors (land, labor), that have risen only marginally in price, cassava product prices have become relatively cheaper, allowing for higher profit margins (for exporters, if at same export prices) and/or increased export market expansion (at lower prices).

Table 2. Domestic utilization of starch in Thailand in 1994, as a percent of total domestic starch use.

Chemically modified starches	25.41%
MSG (80%) and lysine(20%)	12.10%
Glucose/fructose syrup	11.97%
Food processing	11.87%
Paper	11.49%
Physically modified starches	7.37%
Sago pearl	3.56%
Plywood	2.14%
Textile	1.86%
Sorbitol	1.55%
Adhesives	1.19%
Others	9.49%

***Source**: Thai Tapioca Flour Industries Association, 1994.*

The TTTA (1996) source also notes a 1997 (starch) export target of 955-970,000 tonnes, of which 30% are dextrins and modified starches, and 70% native starch (p.37). Internal TTTA activities point towards a growing export market interest for the Soviet Republic and China. Additional export opportunities for Japan are totally policy dependent, and as yet, unclear to predict.

While traditionally, the export market has constituted the primary Thai objective, several reports (Titanapawatanakun, 1997) point out the growing importance of the domestic market (as another means for market diversification). The author estimates that for the food sector, MSG and lysine demand will grow fastest, while in the non-food sector, it will be paper and other industrial uses (p.63). However, with the current financial crisis, these earlier assessments may need to be revised.

Several Thai research groups with government and private industry support, have undertaken considerable amounts of research on new cassava starch-based product formulations (ethanol, SCP, food colorants, starch-based plastics, etc) starch waste valorization, improved cassava varieties, etc. (Sriroth, 1997; Ratanawaraha *et al*., 1997). Furthermore, Maneepun (1997) mentions the following “new promising uses for tapioca starch”, as: (i) improved quality and cheaper maltose syrups for brewery industry, (ii) malto-dextrins manufactured from physically modified starch (rather than chemically modified), for use as fat replacers, and (iii) cyclo-dextrins for food and pharmaceutical uses (p. 81).

Starch situation in Indonesia

Traditionally, Indonesia’s primary starch market has been the domestic market (Henry *et al*., 1995), principally being used for the manufacturing of food snacks such as *krupuk*. However as the industrial and economic development has steadily increased, other uses (also in the non-food industries) have become important. A study by Gunawan (1997) notes that in 1992, "direct" cassava consumption was only 21.5% of total supplies (p.35), and that about 34-35% of total cassava available was processed in medium- and large-scale processing industries, and 45% was used in households, mini- and small-industries, and non-formal sectors (p.36).

Cassava processing includes animal feed (chips/pellets) and starches. Due to decreased EU cassava prices, and increased domestic (and foreign) cassava demand, Indonesia's chip/pellet exports have decreased from 1.2 million tonnes in 1990 to 600,000 tonnes in 1996 (FAOSTAT, 1997). Gunawan (1997) notes that "...*domestic demand has increased tremendously because cassava products have many different (domestic) uses, such as feed, plywood industry, and glucose and fructose industries*" (p.39). In addition, information from the US private industry (personal communications, E. Tupper, 1997) reports that currently the Indonesian annual per capita paper consumption is at 12 kg, with an estimated annual growth rate of 14%[7]. At an average inclusion rate of 35-45 kg of modified starch per ton of paper, this presents a significant derived demand growth potential for cassava (modified) starch in Indonesia. Currently, the larger share of the "more sophisticated" starches is being imported in Indonesia, mainly from the US and Thailand. However, during 1995-97 (up to the financial crisis) significant new investments (both foreign and national) have been made in the construction of large-scale vertically-integrated factories for manufacturing of modified starches (personal communications, P. Temprom, 1997), indicating a trend towards increased self-sufficiency regarding up-scale starch production. The bottom line is that currently no reliable and updated data exists regarding Indonesia's starch production, nor its starch utilization shares, by industry.

Starch situation in Vietnam

Cassava starch production in Vietnam, before the start of the 1990s consisted largely of small household-level processing units in addition to several state-owned (run-down) larger-scale units (Dang Thang Ha *et al*., 1996; Dao Huy Chien, 1997), mainly producing dry and wet native starch (for noodles, cakes, alcohol, etc.) and to a lesser extent maltose (for candy manufacturing, ...). Starting in the 1990s, following "the run for cheap local labor and inputs, coupled to expanding domestic markets", large-scale modern cassava starch processing factories were constructed in the major cassava production areas of southern Vietnam. While in the beginning these were largely joint ventures with Japanese, Korean and Taiwanese multinationals (Vedan, Ajinomoto, AAA etc.), during the second half of the 1990s, local Vietnamese private factories sprung up, in addition to joint ventures with major European and Thai starch companies (PROAMYL, 1997-98; Henry *et al*., 1995). Limited and ad-hoc information (personal communications, J. Wang, 1996) points to the fact that from the start MSG has been the primary product market objective of the these new factories (for both national and export markets). However, the product

[7] Compared to the US with 332 kg (2% growth) and Japan with 230 kg (6% growth).

portfolio seems to have changed since the mid-1990s. This needs to be investigated since no new data exists.

During the early 1990s a cassava starch market assessment was conducted (Dang Thang Ha *et al*., 1996), showing that the 1992 national cassava starch production was around 90,000 tonnes and projected to reach 200,000 tonnes by the year 2,000 (mainly due to increases in MSG production[8]). If Vietnam would follow similar industry trends as in Thailand and China, one would expect increased productions of, especially, hydrolyzed and modified starches in the future.

Starch situation in China

Data on cassava starch in China before the 1990s are, at best, sketchy and mostly in Chinese. A first post-1980s assessment, though still in Chinese, was written up by Jin Shu Ren and Henry (1993), followed by English and up-dated versions by Jin Shu Ren and Henry (1994) and Jin Shu Ren (1996). These publications report that in 1992, cassava starch production in South China was estimated at slightly over 200,000 tonnes, based on a regional availability of 1.2 million tonnes of chips[9]. For the major ten factories in Guangxi alone, an annual starch output of 80,000 tonnes was calculated. At that time, the cassava starch product portfolio included native starch, fructose, sorbitol, mannitol, maltol, alcohol, MSG, citric acid, denatured starch, glucose and glucose syrup. For 1996, Henry (1996b) reports that the Guangxi (as the most important cassava starch producing province[10]) starch industry was made up of 150 factories with an installed capacity of 3,000 tonnes/day, producing 280,000 tonnes/year (**Table 3**). The industry output consisted of roughly 10% modified and hydrolized starches, and 90% native starch. The same source reports that the industry's annual growth rate estimation was >16%, especially regarding the chemically modified starch supplies.

As referred to in earlier sections, during the last five years the Chinese cassava starch industry has enjoyed significant attention from national and especially foreign investors. Henry and Howeler (1996) already noted the industry's trend towards new or

[8] MSG industry information points out that Taiwan is the world's largest MSG consumer, (1 kg/year/cap). Even at a conservative rate of 0.5 kg/year/cap, the domestic Vietnamese MSG consumption could be 60-70,000 tonnes per year by the year 2,000 (personal communications, J. Wang, 1995).

[9] It is pertinent to point out that, contrary to most other countries, Chinese (and to some extent, Vietnamese) cassava starch processing depends to a large extent on dried cassava chips as raw material. For further information on this, see Henry and Howeler (1996).

[10] For additional more detailed 1994 primary information on the cassava processing industries of Guangdong, Guangxi and Hainan, see the report of a RRA in South China by Henry and Howeler (1996).

refurbished large-scale factories at a cost regarding small-scale units and old-fashioned large state-owned factories. A report by Howeler (1997) mentions the construction of a series of five large-scale new starch factories for the production of bio-degradable plastics. Four of these are already in operation in the provinces of Guangxi, Shandong, Jiangsu and Xinjiang. A fifth is being constructed in Hainan. At least two of these factories will use cassava as the principal raw material (p.4). More recent, but still unpublished, information validates the continuation of this upscaling trend. Unfortunately, this latter information does not include a quantification of the industry's product utilization shares, nor expected growth rates.

Starch situation in other parts of Asia

In the Indian state of Tamil Nadu, there exists a large concentration of small- to medium-scale cassava starch and sago producers (Shegaonkar, 1995). Salem district alone, with roughly 720 units, represents 80% of the state's output. Total Indian cassava starch and sago output is estimated at 200,000-300,000 tonnes. The share of sago *versus* starch is unknown, neither the utilization rates for food and non-food sectors. Additional information is needed. Apart from India, the Philippines has some cassava starch extraction operations. However, most starch is imported from the US, Thailand and the EU. Contradicting sets of information exist about new cassava starch investments (by San Miguel) and the success of these. Again, better information is required.

IV. Starch Production and Utilization in Latin America and the Caribbean (LAC)

Starch situation in Brazil

Cassava starch production increased from 200,000 tonnes in 1990 to approximately 300,000 tonnes in 1997 (Vilpoux, 1997; 1998). Roughly 70% of Brazil's starch utilization is based on domestic maize starch, bringing the total industry, currently, at an estimated 1 million t/year (Vilpoux, 1998). Hence, Brazil's starch expansion has been typically maize-based. Maize starch manufacturing is concentrated with two large international (of US origin) companies: CPC International/Refinacao de Milho Brasil, and Cargill, both based in Southern Brazil. The cassava starch industry represents small- to medium-sized companies, distributed in the states of Sao Paulo, Minas Gerais, Sta. Catarina, Parana (and lately also moving into Mato Grosso do Sul).

Table 3. Comparison of key economic and technical parameters of the cassava starch industry in China (Guangxi), Thailand and South Brazil (Sta Catarina, Parana states), 1996.

Parameter :	Thailand	Guangxi, China	South Brazil
Cassava yield (t/ha)	14	13	20
Starch content in roots (%)	12-28 (Av.22)	25-27	28
Rural labor cost ($/day)	4.0	1.25	7
Cost of root production ($/t)	30-35	27.5	-
Labor cost for root production($/ha)	-	19.6	-
Cost 50 kg of 15-15-15 fertilizer ($)	16	12.5	-
Land rent/ha crop cycle ($)	200	20	200

Harvesting time	70% in 5 months	100% in 4 months	100% in 10 months
Months of (major) harvests	Nov-March	Nov-Feb	May-Oct; Feb-May
No. of starch factories	41	150	75
Total installed capacity (t starch/day)	6,000	3,000	1,500-2,000
Total production (t starch/year)1995	1,800,000	280,000	350,000
Annual growth rate (%)	10	>16	-
Modified starch from cassava (t/year)	540,000 (30%)	30,000 (<10%)	<10%
Conversion rate roots to starch (%)	25	25	25
Factory labor cost ($/day)	5.0	1.87	-
Factory gate cassava root price ($/t)	40	37-41	45-55
Water use per t starch (m^3)	15-30	40	18
Cost of water ($\$/m^3$)	0.28	0.003	-
Starch production cost in factory ($/t)	210-220	225-250	350-400
Tax (VAT) (%)	7	20-22	10
Price of starch at factory gate ($/t)	225-250	325	400
Waste water treatment	39 oxidation ponds; 2 biogas	mostly oxidation ponds; dumping	anaerobic; ponds
Starch content of residue (% dry weight)	50	35-40	70
Residue utilization	export as feed or local animal feed	ethanol prod. or animal feed	animal feed
Peel utilization	compost or mushroom prod.	compost	-

Source: *Internal data from industry association and key informants in Brazil (10/96) and China (11/96).*

Current utilization of starch is detailed in **Table 4**. This shows 69% of total starch for the food sector, 16.7% for the paper industry, and 5% for the textile industry. It also shows that 43% is native, 46.2% is hydrolyzed (sweeteners), and 11% is (other) modified starch. Vilpoux (1998) notes that in 1997, the food industries that increased their starch utilization the most were the frozen and dehydrated foods sectors (with 18.2%). Furthermore, the same source notes that the future starch demand growth (modified and native) in the food sector will be mainly in the ready and semi-ready product lines. Other US private sector information (PROAMYL, 1996) notes the potential increasing demand for cationic starches for the high-quality paper industry.

Starch situation in Venezuela

Little hard data exists regarding the cassava starch situation in Venezuela. Scattered first hand information reports that there are currently two large-scale integrated (with root production) starch factories. One of these operates a 7,000 ha cassava farm, partly irrigated, with an average productivity of 25-30 t/ha/year. The roots are processed into native starch and glucose syrup. While the latter represents still a small share, the immediate objective is to increase this product output. The primary market is Venezuela, but native starch exports for the Colombian paper industry have also been reported (at a very competitive price *vis-à-vis* Colombian starches).The main starch source in Venezuela remains maize starch, mostly imported from the US.

Starch situation in Colombia

The main cassava starch products in Colombia are sour starch and native starch. Some sketchy information reports about recent investments in the department of Cauca for a cassava-based glucose syrup factory (Gottret *et al*., 1997). However, no data are available on production or capacity figures. The cassava sour starch production is mainly concentrated in the Cauca Department with a total average production of 13,000 tonnes from approximately 200 small-scale processing units. Several larger units producing native cassava starch operate in the Atlantic Coast region. Colombian starch utilization is principally (still) satisfied by starch imports from the US (maize), Venezuela (cassava), Brazil (cassava/maize), and sometimes from Ecuador (cassava). Several maize-based starch factories (Maizena) have existed, but these seem to be in the process of closing down (needs to be confirmed). Gottret *et al*. (1997) reports the relatively high prices of Colombian cassava starch. Colombian native starch was priced in 1996 at US$500-550/tonne *versus* imported maize starch at US$ 450-480/tonne. At these prices, Thai and even Brasilian starch could possibly be imported at a significant profit. It needs to be noted that the Colombian starch market is in the hands of only a very few operators, dictating imports and market prices.

Starch situation in Paraguay

Very little hard data on cassava starch is available for Paraguay. Henry and Chuzel (1997) have noted that small volumes of cassava starch have traditionally been manufactured in small-scale household processing units for the manufacturing of "*chipas*", a typical snack. However, more recently, growing interest exists from Brazilian starch manufacturers,

Table 4. Brazilian starch and starch derivatives utilization (tonnes), by industrial sector, in 1997.

Starch type	Food sector				Paper sector		Textile sector	Other sectors	Total
	Sweeteners	Bakery pastry	Powder products	Others	Paper	Cardboard			
Native	2,100	26,500	93,000	109,100	66,300	43,500	20,000	77,000	**437,500**
Modified									**113,250**
Acid modified	2,600			1,500	29,900	4,300	30,000		68,300
Cationic					1,800	200			2,000
Anfoteric					24,300				24,300
Dextrins/pregel.			100	300	100	50	100	18,000	18,650
Hydrolyzed									**472,200**
Glucose syrups	141,200	800	3,100	30,400			200	1,000	176,700
Glucose powder	200	100	300	5,100			100		5,800
Maltose syrups				271,500					271,500
Malto-dextrins	400	300	2,800	14,400			300		18,200
Total	**146,500**	**27,700**	**99,300**	**432,300**	**122,400**	**48,050**	**50,700**	**9,600**	**1,022,950**

Source : *Vilpoux, 1998.*

across the border in Parana and Mato Grosso do Sul, for joint-venture investments in large-scale cassava starch manufacturing, taking advantage of relatively lower land and labor prices (this information needs to be confirmed and quantified). Most starch utilized in Paraguay currently originates from Brazil, and to a lesser extent from the US (maize starch).

V. Starch Situation in the European Union (EU)

EU starch production in 1994 was estimated roughly at 6 million tonnes. By 1997, this is estimated at 7 million tonnes (AAC, 1997). According to the same source, the principal starch source crops are maize (51.5%), wheat (25.5%) and potato (23%). During the last 3-4 years, the share of maize has increased significantly. A recent private industry source, noted by Sansavini and Verzoni (1998), estimates that the EU starch output includes 52% sugars, 28% native starch and 20% modified starches. This seems roughly in accordance to Roper's 1994 and AAC's 1997 (51%, 27.5% and 21.5%, respectively) estimates. The three sources are in agreement about the EU starch utilization, by industry, as:

Sweets and drinks:	*33-34%*
Processed foods:	*21-22%*
Chemicals and pharmaceuticals:	*15-16%*
Paper and corrugated card board:	*27-28%*
Feed:	*2%*

Through import tariffs and quotas, the European starch market is highly protective of its national industries from foreign competition. Nonetheless, there exist an ACP-countries quota of 25,000 tonnes; this includes Thailand, which annually exports 10,000 tonnes to the EU.

Export data series from the US (USDA-ERS, 1997) show that small volumes of US maize starches (3-4,000 tonnes/year) are imported to the EU, mainly to the UK and the Netherlands. In addition, as noted in a previous section, Thailand exports considerable volumes of cassava starch above its allotted (10,000 tonnes) quota, especially to the Netherlands.

Total EU starch exports in 1996 are estimated at 1.1 million tonnes (AAC, 1997). The shares of native, sweeteners and modified starches of total exports were 45, 25 and 30%, respectively. EU potato starch exports increased from 122,981 tonnes in 1990 to 292,142 tonnes in 1996, an increase of 42%. The estimated starch exports value over the same period increased by 31%. 1996 EU potato starch exports were valued at 121.2 million ECU (EUROSTAT, 1998). Principal destinations of EU potato starches were: US, Mexico, Thailand, Japan, Taiwan, Hong Kong and South Korea. Especially the SE-Asian countries import increasing volumes.

While European starch multinationals are relatively well protected from cassava starch imports from Asia (although they still want higher import protection plus higher export refunds...), they all are increasingly involved in both vertical and horizontal integration[11] with cassava and maize starch based industries in Asia, and to a minor extent in LAC. Countries of particular interest are Thailand, Indonesia, China and Vietnam (and Cambodia). Hence, executives of Avebe, Roquette, Amylum, and others have been seeking to learn more about the basics of cassava in the past few years (PROAMYL, 1997-98; CERAT) and to analyzing the comparative advantages of starch factory construction in north vs. south Vietnam vs. South China vs. Thailand (vs. Brazil vs. Venezuela). While most emphasis has been on cassava as the "hot new" starch source crop, new maize starch joint-ventures[12] in Asia are also being considered. Besides, starting in the early 1990s, an increasing number of joint ventures of molasses/cassava sourced starch manufacturing are occurring between Japanese, Taiwanese, Korean and Thai multinationals with local investors in China and Vietnam, i.e. Ajinomoto, Vedan, AAA, Vethai, ... (Henry, personal observations, 1996-97).

VI. Starch Situation in the United States (US)

While the US (and Canada) do not use cassava as a starch base, but mainly maize (or molasses), some understanding of its industry is important for the following reasons: (i) US maize starch makes up the largest global volume of starch (and derivatives), directly competing with potato, wheat and cassava starches; and (ii) the fact that there is evidence of increasing horizontal integration of US traditionally maize-based starch companies, through joint-ventures, into (national) cassava-based starch companies in SE-Asia and LAC. This trend is similar to what is happening with the major European starch multinationals (PROAMYL, 1997-98).

The main US maize-based starches and derivatives include native starch, modified starches, sweeteners (HCFS), ethanol, industrial alcohol, citric acid, lactic acid and lysine. USDA-ERS (1997) data (**Table 5**) shows the US market demand for some of the "hottest" product groups.

The US is a net exporter of maize starch and starch derivatives. The major products (for food processing) in 1996 were: starch, glucose, glucose syrup (<20% fructose), pure fructose, glucose syrup (20-50% fructose), fructose syrups + solids, dextrins, and modified starches (US Department of Commerce, 1997). The most important volumes are exported to NAFTA members Canada and Mexico, Asia (Japan, Malaysia, Korea, Philippines, Indonesia, Taiwan,...), LAC, EU (UK, Netherlands,...), and Israel. 1997 US maize starches exports have increased by 8% over 1996.

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[11] Information has also been found about a major joint-venture of Cargill with Purac (daughter of Dutch-based CSM) in Nebraska, US, for the production of lactic acid (USDA-ERS, 1997), evidencing a US-European integration as well.

[12] Sansavini and Verzoni (1998) cite a Cerestar source regarding a new 350,000 tonne maize starch factory in Jilin province of China, as a joint venture between the Jifa Group and Cerestar, for a total investment of US$ 100 million. Production of native starch, modified starch, malto-dextrins, maltose, protein powder, glucose, isomaltose, vitamin C, ... are to be envisioned (Jifa Group Corporation, home-page, 1998).

Table 5. Volume, value and future growth of the major starch-derived products for domestic utilization in the USA in 1996/97.

Product	1996/97 volume ('000 tonnes)	1996/97 value (million US $)	Future growth (%)
Sweeteners (HCFS)	14,900		2-3% annually
Ethanol	2,580		4-6% (depends)
Citric acid	240	340-380	8-10% annually
Lactic acid	27	25-30	4-9% annually

***Source**: USDA-ERS, 1997; Sansavini and Verzoni, 1998..*

The US Department of Commerce (1997) report details of US imports of cassava starch. In 1997, total import volume was 12,000 tonnes at an average value of US$ 309/tonne (most maize starches exported from the US are valued at US$ 450-650/tonne). US cassava starch imported in 1997 originated mainly from Thailand (97%), but also included very small imported volumes from Brazil, Colombia, Costa Rica, Philippines and Ghana. Data for these latter countries can not be accessed for individual country cassava starch exports.

FUTURE OUTLOOK FOR CASSAVA STARCH UTILIZATION

Previous sections leave a clear impression that increasing and strong starch demand is driving the industry to novel partnerships and novel sources of raw materials. While it seems that Asia is the current " hotspot " for both supply (cheap production factors) and demand (bullish future economic development expectations in spite of the current financial crises), LAC is increasingly showing a profitable market as well. Future lowering of import regulation levels in high starch demand countries, especially in Asia (Japan) and EU, may further boost demand for cassava starches. It is, however, dependent on cassava starch industry's technology adopters to successfully compete with potato and maize starches in the emerging markets (especially requiring modified and hydrolyzed starches). It will be necessary to first identify which will be the most appropriate starch market segments for subsequent targeting. Because of the competitiveness of the market, the leading starch companies have this information, smaller companies can only follow these leaders, but will therefore lag behind. Increasingly, economies of scale and internationalization form the key elements towards the highest profit margins in this industry.

Competition between starch sources are based on a variety of factors. The principal ones have been included in **Table 6** for comparison. The relatively low productivity of cassava is due to the lack of research (and technology transfer) in comparison with that of other raw materials. Hence, while maize, potato and wheat are already near their potential

Table 6. Qualitative comparison[1)] of starch from different raw materials.

Parameters	Maize	Wheat	Potato	Waxy-maize	Cassava
Raw material productivity	***	***	***	***	*
Raw material price competitiveness	***	**	*	***	***
Starch conversion efficiency	***	**	*	***	**
Valueof byproducts	**	***	*	**	*
Cost of waste disposal	*	*	**	*	***
Starch price competitiveness	***	**	*	**	***
Food industry application	**	**	***	***	***
Non-food industry application	***	***	**	**	**
Sweeteners application	***	**	*	***	**
Relative R&D advance	***	***	***	***	*

1) The following scoring scheme is used for the importance of various factors: *** high, ** intermediate, * low

yield ceilings, cassava still has a vast potential for additional yield increase. An important limiting factor for cassava as a starch source is the issue of waste management and by-products. The former is relatively expensive, while the latter is highly undervalued. From this table, one could argue that, *ceteris paribus*, the future competitiveness of cassava as a starch source seems to be technology dependent. However, the cassava starch situation is even more dependent on global and regional trade policies and the future changes of these. Current starch market prices (**Table 7**) do show that cassava starch can compete with other sourced starches. However, as earlier discussed, the major production/consumption markets of the US, EU and Japan are highly protected by trade policies. For example, the EU compensates its (wheat, potato) starch producers' high costs with export refunds (**Table 8**).

Africa seems to have various potential markets for cassava starches. The small starch volumes that are currently consumed, are largely imported from the US and EU. Although these volumes are small, the EU and US multinationals keep a very firm grip on their markets (monopolistic!). Furthermore, near future cassava market expansion, in the short-run, will be undoubtedly satisfied by the multinationals. Current local interest for cassava starch manufacturing seems mostly limited to relatively small-sized cases. However, the interest is growing in almost all major cassava producing countries (Uganda, Nigeria, Ivory Coast, Ghana, ...), as local investors observe growing starch demand on the one hand, and a cheap starch source crop, i.e. cassava, on the other hand. However, while on paper it may be relatively easy to demonstrate that cassava starch production is feasible in many countries of Africa, significant technical, financial, institutional and organizational constraints need to be overcome. Nonetheless, the opportunities seem to be present. Significant further technical, sector and starch market analyses are required in Africa to validate this theoretical local supply potential. An in-depth analysis regarding appropriate scale of starch processing units, is also most needed.

Table 7. Comparison of selected starch prices, 1996 – 98 (US$/t).

	Avg.	Avg.	Jan-Mar

	1996	1997	1998
US maize starch (food use)	607	748	780
US maize starch (non-food use)	475	445	425
US maize gluten meal	366	381	326
EC potato starch (food use)	488	467	431
EC potato starch (non-food use)	503	380	307
EC wheat starch (food use)	708	669	517
EC wheat starch (non-food use)	335	366	349
EC wheat gluten	743	623	621
Thai cassava starch (native)	361	319	297
SE-Asia MSG	1,170	1,190	1,100
SE-Asia citric acid	1,150	1,070	1,010
US lysine	2,280	2,470	2,160
US ethanol	362	317	293
US sorbitol	920	950	860

Source : *Adapted from LMC International, various issues, 1998.*

Table 8. EU starch refunds on selected commodities (in ECU and US $).

	New minimum price	Compen-sation	Total refund	New minimum price	Compen-sation	Total refund
	ECU			US$		
Potatoes[1)]						
92/93	241.2	40.0	281.2	277.6	46.0	323.7
93/94	208.0	40.0	248.0	245.6	47.2	292.9
94/95	192.0	56.0	248.0	239.8	69.9	309.8
95/96	176.0	72.0	248.0	226.7	92.7	319.4
Maize[2)]						
Jun/97	126.9	7.6	134.5	144.3	8.7	152.9
Wheat[2)]						
Jun/97	119.2	-	119.2	135.5	-	135.5

Source: [1)] *CAP monitor, July 1, 1997.*
[2)] *Agra Europe, April 1, 1997.*

While in Latin America, during the last decade, foreign investments have helped in pushing the starch industry development, it is still unable to compete with Asian cassava starches. As **Table 3** shows, several basic factors of production and processing are too costly. Further investment outlays will be needed to better equip and concentrate the industry. In addition, the industry's marketing activities need considerable improvements.

The cassava starch future outlook remains positive, since upcoming future global trade negotiations are expected to further decrease trade restrictions, benefiting cassava starch market potential. The major challenge remaining is to fully benefit from cassava's technology gap.

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GLOBAL CASSAVA STRATEGY FOR THE NEW MILLENNIUM: CIAT'S PERSPECTIVE

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ABSTRACT

The economies of many Latin American countries have opened up to the global markets in recent years. These changes have had drastic effects on the agriculture of those countries. For instance, whereas Colombia did not import maize in 1990, ten years later it was importing more that 2 million tonnes per year. The same situation is true for many other tropical countries. As a result, agribusiness attention has recently focused on cassava as a source of raw material. In response to these changes in the markets, the CIAT cassava breeding project has directed its efforts to develop competitive cassava production for several different industries. The main goal is to increase yields and reduce costs. Dry matter yields as high as 15 t/ha have been obtained by combining outstanding germplasm with adequate agronomic practices. Dry matter productivity is the main goal for the development of these "industrial clones". Other strategies for increasing yields and/or reducing production costs are mechanization of planting and harvesting, development of herbicide-resistance in cassava, improved fertilization techniques with animal manure, etc. The inclusion of cassava foliage in animal feed is also under analysis. Genetic transformation protocols are currently being fine-tuned so different desirable traits can be readily incorporated into elite cassava clones. The availability of molecular markers and a saturated genetic map will also contribute to an efficient selection of key traits in the breeding process.

Sexual seeds from three large diallel crosses are currently being produced for genetic studies. The trials will be planted in the field early in 2001. In addition to producing a large segregating population, the study will allow us to better understand the genetics of the inheritance of several traits of agronomic value. The breeding scheme has been modified to speed up the selection process and to reach as soon as possible the stage of replicated trials. Collaborative research with IITA has been outlined to determine heterotic patterns between Latin American and African cassava gene pools. The germplasm bank collection is currently under evaluation for several traits of agronomic importance, including starch quality traits and vitamin content. There is an ongoing collaborative research project with the University of Bath (England) for elucidating the biochemical pathway leading to post-harvest physiological deterioration (PPD) of the roots. Parallel studies are underway to determine the genetic basis for reduced PPD, and sources of resistance have been identified (MDom 5 and MPer 183) and crossed with susceptible clones.

In the area of integrated pest management an excellent source of resistance to whiteflies has been identified (MEcu 72) and antibiosis, as its mechanism of resistance, was determined. This genotype has been crossed with a susceptible clone and the segregating progeny is currently being analyzed for their reaction to the insect in the field; their molecular fingerprinting is also underway. ACMD (African Cassava Mosaic Disease) resistance will be incorporated into Latin American germplasm, using a recently identified molecular marker.

INTRODUCTION

Until a few decades ago, cassava was a little known crop outside the tropical environment where it had been grown for centuries. Because cassava products were not exported, and the crop was relatively unknown in temperate countries, very little attention was paid to this remarkable plant. However, upon the creation of the International Center for Tropical Agriculture (CIAT) and the International Institute of Tropical Agriculture

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(IITA), in Colombia and Nigeria, respectively, coordinated efforts were begun in the late 1960's for a scientifically based improvement of the crop (Cock, 1982; 1985). In addition, several countries have developed successful cassava programs. In tropical countries, cassava is the fourth most important crop as a source of calories for human consumption. In many cases it is one of the most reliable sources of food and feed energy that can be obtained from the low-fertility soils and drought-prone areas frequenty found in the tropics.

In spite of the rusticity of the crop, high yield potential and reliability, and diversity of uses, cassava has failed to realize its full potential. Several factors have influenced this situation:

a. Influence of technology from temperate regions

The evolution of agriculture and agriculture-based industries in tropical countries frequently benefited from the developments achieved in temperate regions. Maize was, and still is, one of the main sources of energy and starch for temperate environments. For human consumption wheat and rice are also very important. Most of the technology, machinery, industrial processes, formulations for animal feed, etc. introduced to tropical countries were, therefore, adjusted to, and based on those crops that are prevalent in temperate regions. This was a disincentive to the development of industries based on cassava.

b. Lack of genetic materials specifically developed for the industry

In many countries dual-purpose cassava varieties (materials that could equally be used for human table consumption or the industry) prevented the development of cassava-based industries. If prices for fresh consumption were high, then the farmer would sell their roots to this market; otherwise, roots would be sold to the industry. In fact, this strategy prevented the industrial uses of cassava because there was no reliable supply of raw material. In addition, dual-purpose genotypes frequently produce materials that are neither: they are not outstanding for table consumption, nor do they fit the needs of the industry. The case of maize, on the other hand, offers a contrasting situation with two totally independent activities: sweet corn (basically a horticultural crop) and field corn, with very little interaction between them.

c. Length of selection cycles and low reproductive rate

Breeding cassava is a lengthy process. Whereas a typical full-sib recurrent selection cycle for any cereal can be completed in a year, cassava requires five years. Two factors influence this: cassava is usually harvested at about ten months after planting, and the reproductive rate is low. Whereas one ha of maize can produce enough seed to plant more that 100 ha, in the case of cassava it produces only for about 7-10 ha. Therefore, the speed of varietal development and adoption is considerably slower in cassava, compared with other traditional staple food crops, particularly cereals.

d. Government policies

Because of a conjunction of factors, governments, in general, have not paid adequate attention to cassava. Data on research investment by commodity are extremely difficult to obtain. However, Judd *et al*. (1987) in a very detailed study, found that "several commodities---specifically cassava, sweetpotato and coconut --- receive little research attention anywhere in the world". In a different study, research expenditures in developing countries for maize and cassava were estimated to be 29 and 4 million dollars, respectively, in 1975. According to CIMMYT (1994) a total of 372 maize breeders were counted in Latin America (224 and 148 in the public and private sectors, respectively) in the year 1992. On the other had, no more than three full-time cassava breeders were working in the same region at that time (C. Iglesias, personal communication). That is less that one percent of human resources allocated to cassava *vis-a-vis* maize.

e. Bulkiness and short shelf life of roots

Cassava roots have two limiting constraints for extensive commercialization: their bulkiness (about 65% of the weight is water) and the short shelf life after harvest (less than three days, although there is considerable variation in this regard) due to a process called post-harvest physiological deterioration.

f. *Poorly developed markets*

There has always been a problem for the industrial uses of cassava, similar to the chicken-egg paradox: there was no industry because there was no availability of raw material (i.e. cassava roots), and there were no roots because there was no industry to buy them.

The problems related to marketing are more pronounced in cassava than in other crops because: cassava is mostly grown by smallholders, requiring greater marketing coordination for industrial uses, and they are often located in areas with poor infrastructure. In addition, the low-input practices tend to increase environmental variability, and hence variability in root quality. There is also the difficulty of gearing up quickly for large-scale production due to the low multiplication rate. Lack of credit is another constraint.

WORLD's AGRICULTURE BEYOND THE YEAR 2000

A mayor and generalized economic trend across the world during the last decade has been the globalization of the economies. Agricultural markets were not an exception. As a result, trade barriers for agricultural products have been reduced, gradually and consistently. For instance, whereas in 1990 Colombia did not import any significant amount of maize (32 thousand tonnes), by 2000 the country consumed more than 2 million tonness of imported maize, with an annual growth of 79.5% between 1988 and 1998. The situation is similar in many tropical countries, where local maize production is not competitive against maize from temperate regions: the annual growth of maize importation in developing African and Asian countries were, respectively, 5.53 and 4.58% (FAOSTAT, 2000) during the same time period. Because of its generalized use in animal feed and starch industries, maize usually has an important effect on cassava production and processing.

There are several reasons for the lack of competitiveness of tropical *vis-à-vis* temperate maize. As stated by Pandey and Gardner (1992): "Maize yields are primarily limited in the tropics by the intercepted radiation to heat unit ratio. The ratio is much lower in the lowlands compared to high altitudes, and is lower in the tropics compared to temperate latitudes. Relatively less light is intercepted during the rainy season in the tropics, which coincides with the grain-filling period of the crop. Light interception is further reduced by lower plant densities. Extreme weather variations, erratic rainfalls, high temperatures, particularly during nights, and low temperatures at high altitudes also reduce yields". Other limiting factors for maize productivity in the tropics are: 1) low fertility of most tropical soils; 2) lower grain yield potential of tropical maize cultivars; 3) high pest pressures and suboptimum moisture supply; 4) diseases that frequently reduce production by 30-40%; 5) weeds that can account for up to 50% of yield losses under low-input conditions; and 6) poor crop management practices, limited resources, application of inadequate and improper inputs, and a lag in technology transfer.

It is clear that many of the limiting factors for maize competitiveness in the tropical environments are very difficult or impossible to overcome. Therefore, if the trend for opening the markets continues, there will be fewer opportunities in the future for competitive local production of maize in the tropics. That has been the case in Colombia, and as a result, for the first time, both the government and private sector are turning their attention to cassava as a reliable, competitive, local source of raw materials for the starch, animal feed and processed human food industries.

THE PRESENT AND FUTURE OF CASSAVA IN THE WORLD

World cassava production has been growing at an annual rate of 2% during the last decade (1987-1997), slightly faster than during the previous decade (1977-1987), when it grew at an annual rate of 1.7%. Area expansion has generally driven the growth in cassava production during the last decade (1.7% annual growth rate in area and only 0.3% in yield). Projections for the 1993-2020 period expect a growth rate between 1.93-2.15% per year, of which more than 1% is expected to come from yield increases, while the rest (0.74-0.95) from area expansion. Therefore, cassava production will continue to grow at almost the same rate, but more due to increases in yield than before (CGIAR, 1999).

The use of cassava roots as a rural/urban starchy staple, and the leaves as a protein source, are of great importance, particularly for Sub-saharan Africa, and its demand will continue to grow mainly due to population growth. In this case the main beneficiaries of research will be the poor farmers and consumers, and this will contribute to the CGIAR mission in terms of food security and income generation. Stability in marginal areas, increased yields, improved processing techniques and adequate policy decisions are required to fulfill the needs of this particular market. The use of cassava as an urban vegetable will continue to be important in metropolitan areas close to production zones. The driving force for this growth in demand will be the urbanization process, but this market will require a high quality and more convenient product as well as a good marketing strategy. The main beneficiaries of research will be farmers from income generation and consumers from lower prices.

Cassava use as a substitute of grains for the starch, flour and animal feed industries will be a major market, and demand will increase as a consequence of income growth, particularly in Asia and Latin America. Specific research needs to take advantage of this market are yield efficiency, soil management, processing, marketing, and appropriate policies. The main beneficiaries will be farmers, industry and non-farm labor, fulfilling the CGIAR mission of contributing to increasing incomes. However, the possibility to benefit poor farmers and contribute to poverty alleviation (equity aspect of impact) will depend on the organizational model adopted and the possibility of linking small farmers to these growing markets.

Cassava research has benefited greatly from IITA, CIAT and National Programs' scientific contributions. These institutions working independently, or through many successful joint projects, have provided valuable information, technologies, and germplasm, to support a renewed competitive agricultural system based on cassava. As a result, many of the constraints listed in the introduction of the paper have been or are currently being resolved. Many of the developments listed below will benefit both the more traditional production, processing and uses of cassava as well as the industrial markets. In general, there is a clear trend for increased use of cassava in the starch industry, particularly in the area of modified starches.

Why cassava will become more important for world agriculture beyond the year 2000

The effect of globalization has stimulated a renewed (or in most cases a truly new unprecedented) interest in cassava from the policy makers, donors and investors in cassava for the tropical environments. There are some stimulating efforts to increase the importance of cassava in the agriculture of tropical countries:

- The Colombian Government, jointly with the Colombian Poultry and Swine Growers Associations, have been actively supporting research and development of cassava for industrial uses, particularly for the feed industry.
- CLAYUCA (Latin American Consortium for Cassava Research and Development) was created in April 1999. The consortium made up of both the government and private sectors of several Latin American countries is supporting research and development of cassava through a research agenda determined by the members of the consortium: mechanization, artificial drying, mechanical harvest of roots and foliage, herbicide resistance in cassava, integrated pest management issues (mainly biological control of insects and pests), and cassava fertilization with chemical and organic products.

During the next fifty years the world population will increase by three billion people according to conservative estimates. Most of this growth will concentrate in developing tropical countries, where cassava is particularly relevant in food security. Furthermore, since cassava is well adapted to marginal environments, which are the only prevalent ones remaining to be incorporated into production, this crop will play a fundamental role in providing food for these additional people.

It is also strategic for mankind to widen the number of crops on which it feeds. There has been a growing concern by scientists and policy makers regarding the continuous reduction in crops (and genotypes representing each crop) during the 1900's (Witt, 1985).

It is advisable, therefore, to widen the crops on which we depend for food and other human needs. Cassava is a reliable crop on the one hand, and can be used in several industrial pathways on the other.

How to make cassava more competitive

With the active support of both the government and private sector, several studies are underway for developing technologies, specifically adapted for cassava, that will facilitate cultivation and processing of cassava roots and leaves. New planting and harvesting machinery have been developed, evaluated and perfected recently. Mechanical planting, for instance, requires significantly less labor (reduced costs of production), allows for large areas to be planted under optimal environmental conditions (stable production); and means a better physiological status for the stakes (increased yields). Also, there is already a diversity of equipment for the mechanical harvest of roots, and different alternative machines are currently evaluated for the harvest of fresh foliage.

Breeding cassava varieties is now particularly oriented to produce varieties for either industrial use or human consumption. New varieties will better fit the needs of their target market. An industrial variety must have high dry matter yield potential (t/ha), combined with high dry matter content (%). Other traits, such as color of the root or pulp, are secondary, depending on their specific industrial use. On the other hand, fresh consumption generally requires very specific root quality traits, which may be more important than yield potential: color of the root, low cyanogenic potential, intermediate dry matter content (depending on the region), and most of all, good cooking quality. In general, good progress has been made in developing fresh market varieties around the world and a new generation of industrial clones is now also available for most of the cassava growing areas. At CIAT, varieties specifically adapted for the acid-soil savannas, the sub-humid tropics, and mid-altitude environments have been developed; they have already demonstrated their potential, and have also helped the consolidation of industrial processes. In each of these three environments, commercial yields above 40 t/ha of fresh roots can be achieved with the use of adequate technology (not necessarily with high inputs). Higher commercial yields can be achieved (and will be available in the near future) with the advent of new germplasm and the introduction of new technologies (Velez, 2000). Different research programs in South and Southeast Asia should be credited for their pioneering work in the development and promotion of industrial clones, which have been fundamental in the successful use of this crop in these parts of the world.

Cassava development has been severely hampered by the lack of established markets. Several reasons prevented the development of those industrial cassava markets, as already pointed out in this document. However, because of a diversity of reasons different independent strategies have been implemented for different industries. To illustrate this point the case of *Ingenio Yuquero del Cauca* (Cassava Mill of Cauca, Colombia) will be described. This enterprise was legally created in 1999 and should become fully operational by the year 2001.

The mill is a drying facility (based on artificial or mixed drying processes) supplied with cassava produced in about 6000 ha around it. Production is concentrated in a region no farther than 30 km from the drying facility. Mechanized planting and harvest, bulk transportation coordinated by the mill, implies a great reduction of production costs. Integrated disease and pest management, possible for this size of operation, is also coordinated and managed by the mill. Further reduction of production costs, as well as the implementation of sound, environmentally friendly, cultural practices are possible within this context. Of the 6000 ha of cassava, approximately 1/6th belongs to the mill, the remaining 5/6th are contracts with individual farmers, thus guaranteeing a minimum supply of raw material. Associated with the drying facility, are poultry and/or swine industries that will consume the dried cassava products. The harvest of foliage is an integral part of the strategy, but demands careful soil fertility practices to guarantee the sustainability of the system. Poultry and swine manure, in this context, becomes also an integral part of the strategy, particularly when commercial exploitation of the foliage (when the roots are harvested), becomes a common practice. The system, therefore, minimizes transport costs both ways (fresh products from the field to the drying facility, and of dried cassava from the mill to the poultry or swine industries); bulk transportation will further reduce the costs. The marketing of the product is greatly facilitated by this arrangement. Technology transfer to the farmers associated with the system is carried out by personnel paid by the mill. It includes the provision of seed of new industrial clones, information on the implementation of new cultural practices aimed at reducing production costs and protecting the environment, and the provision of credit.

Biotechnological tools will contribute to increase cassava’s competitiveness by different means. Breeding cassava will be faster through the use of molecular markers, and the technology already exists for the transfer of genes between cassava’s clones and/or wild relatives. Tissue culture is becoming an economic alternative for the rapid multiplication of elite clones, particularly at the early stages of diffusion.

How to make the crop even more reliable

Cassava is known for its rusticity, with excellent tolerance to different biotic and abiotic stresses. Cassava is particularly tolerant to drought and acid or low-P soils. It also grows well in the humid tropics where the rainfall can exceed three meters per year. Cassava yields are quite stable compared with those of other crops. The *El Niño* phenomenon at the end of the 1990’s induced drastic climatic changes around the Pacific Ocean. Cassava yields, however, remained relatively unchanged, both in Asia and America (FAOSTAT, 2000).

Integrated pest management has greatly contributed to the stability of cassava production. Genetic resistance or tolerance to major diseases and arthropod pests has been incorporated in the breeding programs of the world.

A landrace from Ecuador (MEcu 72) has been found to possess excellent levels of resistance (antibiosis, in fact) against the whitefly, *Aleurothrachelus socialis*. This is one of the first reports of resistance against whiteflies found in cultivated crops. In some cases where resistance or tolerance has not been found, environmentally-friendly biological control methods have been successfully deployed. Yet in other cases, cultural practices can reduce both biotic and abiotic stresses.

Molecular marker techniques are currently used to better understand the dynamics of pathogen populations. Cassava bacterial blight (CBB) disease (induced by *Xanthomonas axonopodis* pv. *Manihotis),* has been characterized and different strains have been identified. The knowledge of virulence patterns in the pathogen's populations facilitates and improves the efficiency of host genetic resistance. Thermotherapy has been successfully implemented to clean stakes from bacterial and fungal pathogens. Serological and PCR-based diagnostic methods have been developed for a range of pathogens, including bacterial blight, geminiviruses, and other viruses affecting cassava. These methods assure the safe movement of cassava germplasm. A PCR method is currently under development for the detection of frog skin disease.

How to add value to the crop and boost profitability

The development of new varieties also includes the incorporation of particular quality characteristics needed in particular markets:

- For instance, the development of high-carotene cassava germplasm (yellow – orange roots) for the poultry industry is currently in the pipeline. High carotene cassava roots also have a huge potential as a source of vitamins for those areas in Africa where chronic deficiencies result in severe human health problems.
- Novel starch types are sought in the germplasm bank collection (made up of more than 6000 accessions). This also includes visiting wild related species in search for new starch types (i.e. high amylopectin).
- The introduction of the "waxy" gene into cassava is now technically possible (Munyikwa, 1997).

Taking advantage of the fact that cassava chips absorb less fat than potato chips a new product for the snack market (flavored or unflavored fried cassava chips) is being developed. These processes require particular types of cassava. One important factor for the development of these new varieties is the demand of the processing sector; a demand that had seldom expressed itself before. The interaction between the research, farmer and processor sectors are proving to be extremely successful in promoting the use of cassava for competitive industrial uses.

The bulkiness of cassava roots can not easily be avoided. One strategy has already been mentioned: increasing the dry matter content of the roots. However, there is a limit to the increase in dry matter content that can be achieved. The most relevant strategies for reducing the inconveniences derived from the high water content of the roots, are locating drying plants close to the production sites, and the development of efficient artificial drying plants.

Cassava leaves have excellent nutritive characteristics. They are sometimes used (after processing) in Africa and Asia for human consumption and in Asia for animal feed. The protein content of dried foliage exceeds 20% and the mean concentration of carotene from a sample of 544 accessions was 48.3 mg/100 g of fresh weight (ranging from 23.3 to 86.2). Furthermore, carotene seems to be relatively stable since from 40 to 60% of original levels were recovered after three different processing methods: boiling, sun-drying, and oven-drying (Chávez *et al*., 2000)

With respect to more basic research, CIAT has a joint project with the University of Bath (England) to study the biochemical and molecular basis of the post-harvest physiological deterioration process. The project benefits from the valuable support of DFID (Department for International Development, England). Though the outcome of this research is not likely to result in practical applications in the immediate future, eventually this research may offer solutions with significant positive effects on cassava handling and marketing.

How to create new cassava products through improved processing

There have been interesting developments in the area of cassava processing. Dry cassava chips have been extensively produced through natural drying. While this is a very cost-effective procedure, it requires relatively long dry periods, which are not necessarily found throughout the tropics. Novel, cost-effective artificial drying procedures are currently under development, so dried cassava roots can be produced in large volumes and without the need of long dry spells. The first pilot plant at CIAT-Colombia will become operational in mid-2000. Artificial drying of cassava, should also allow for the production of a mycotoxin-free product, a trait that would be very attractive for the feed industry.

The private sector is currently developing a series of new value-added products for human consumption. The snacks markets benefit with a series of increasingly popular products. Precooked, frozen cassava croquettes are a commercial success in Colombia and Venezuela. Furthermore, several different brands have come on to the market and their products are currently being exported to the USA and Europe. Here, again, there is a fundamental integration between research, production (farmer) and processor that is consolidating the initial progress. CLAYUCA is playing a fundamental role in this integration.

Improved designs for small-scale native and/or fermented starch factories have been developed (Alarcón and Dufour, 1998). The design increases efficiency of extraction and reduces cost of production. More than 200 such processing facilities have been created in Colombia, providing employment to many rural families.

How to put biotechnology to work for cassava

Biotechnology has proven to offer a set of very useful tools for cassava improvement and development. Tissue culture can greatly accelerate the multiplication rate of cassava, so massive volumes of relatively inexpensive propagules can be produced in a short period of time. Shall a new disease appear, or the need for seed of a new industrial variety be critical, the system can now provide what was not available a few years ago. If the industrial uses of cassava become more and more common, there will be a need for the continuous production of pathogen-free propagules, and tissue culture will play an important role in this process. High through-put technologies for tissue culture-based mass propagation are necessary for cassava, as well as for other vegetatively propagated crops. Recent promising developments include techniques using automatic temporary immersion systems, like the RITA system (*Récipient á immersion temporaire automatisé*) developed at CIRAD, France.

The molecular map developed recently allows the cassava breeding programs in the world to carry out their tasks in a much more efficient, fast, and (for some traits) cost-effective way. For instance, it is now possible to select for resistance to the African Cassava Mosaic Virus (ACMV) disease in the absence of the pathogen. Using this technique a joint CIAT-IITA project, supported by the Rockefeller Foundation, will introduce and identify resistance in segregating progenies from elite Latin American clones. The disease is not found in Latin America but it was considered strategic to introduce the resistance in case it eventually appeared. The feasibility of genetic manipulation allows for the transfer of native cassava (or wild relatives) genes from one variety to another.

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CASSAVA BIOTECHNOLOGY RESEARCH AT CIAT/COLOMBIA

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ABSTRACT

Cassava is probably the most efficient producer of carbohydrate per unit land area under tropical conditions. The high productivity of cassava makes it an attractive source of renewable industrial raw material, provided ways are found to reduce production costs and solve constraints. Cassava has a long growth cycle, anywhere from 8-24 months, which means that it is visited by many pests that may also transmit diseases. It is vegetatively propagated, and securing sufficient and healthy planting material can be a problem for many small farmers. Biotechnology can contribute to solutions of these problems and realize great benefits for cassava farmers. Since the 1980s CIAT has worked to realize the potential of biotechnology for cassava, especially to solve those problems that can not be dealt with effectively through conventional approaches. Cassava biotechnology research at CIAT falls into three broad areas, namely: genetic transformation, molecular marker development/marker-assisted breeding, and the rapid multiplication of healthy planting material.

Genetic transformation projects include the engineering of cassava with the bt gene for resistance to the cassava stem borer (*Chilomina clarkei*), and other pests susceptible to the bt protein; the production of herbicide resistant cassava, Round-up ready cassava; and the bio-engineering of cassava for the production of novel polymers.

The CIAT molecular genetic map of cassava --- the first such map to be constructed entirely at a CGIAR center --- is being applied to dissect complex traits, such as early bulking, and to realize earlier unachievable goals, such as breeding for resistance to the African Cassava Mosaic Disease (ACMD) in Latin America. ACMD is not only the most serious constraint of the crop in sub-Saharan Africa, but is also a potential threat in tropical America and Asia. The whitefly biotype that serves as the virus's vector has already been found in the Caribbean and in Brazil, and it is a matter of time before the virus appears as well. Simple sequence repeat (SSR) markers from the map have also been employed in the characterization of genetic diversity, towards a definition of heterotic patterns in cassava.

The rate of spread of a successful variety continues to remain slow. Rapid propagation of cassava, using the continuous media cycling method (RITA), is being tested to provide large quantities of disease-free material to farmers or to commercial producers of planting material. The CIAT cassava biotechnology team also works in partnership with the Latin American and Caribbean Cassava Consortium (CLAYUCA) to apply biotechnology to overcome constraints of cassava, and to make the crop more competitive, both as a source of food and as raw material for animal feed and other industrial uses. Such alliances between the public and private sectors to solve problems of mutual concern, are the best hope for increasing the income of millions of poor producers and consumers through cutting-edge science.

INTRODUCTION

Cassava is probably the most efficient producer of carbohydrate per unit land area under tropical and small farmer conditions. The high productivity of cassava makes it an attractive source of renewable industrial raw material. But cassava suffers from several production constraints, which can reduce yield considerably, and make the crop less profitable in the highly competitive carbohydrate market. Salient amongst the constraints are the long growth cycle, anywhere from 8 to 24 months, which means it is visited by

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many pests that may also transmit diseases. The long period to harvest also hinders the flexibility of availability, a trait required by an industrial crop, while it also lengthens considerably the gestation period for new improved varieties. Cassava is vegetatively propagated, and securing clean and healthy planting material can be a problem for poor farmers. Biotechnology can contribute to the solution of some of these constraints, and to realize great benefits for small farmers. Since the 1980s, CIAT has worked to realize the potential of biotechnology for cassava, especially to solve the problems that can not be dealt with effectively through conventional approaches. Cassava biotechnology at CIAT falls into three broad areas, namely: molecular markers for cassava breeding, genetic transformation for pest resistance and starch quality, and tissue culture for rapid multiplication of healthy planting material. This presentation is a brief overview of each area, going into more details with one example; the paper finally concludes on how these biotechnology tools can be applied to cassava research and development in Asia.

A. Molecular Markers for Cassava Breeding

1. An overview

Molecular markers have been employed in crop improvement primarily to make breeding more efficient, and thus reduce the cost and time required for the production of new varieties. Markers, on a genome wide basis, have also been used to characterize germplasm collections, to identify new sources of genetic variation for faster progress in breeding. Markers associated with traits of agronomic interest, have also been used to provide an accurate picture of the breeding value of genotypes, by eliminating the confounding influences on the phenotype of other deleterious loci and the environment. At CIAT genetic markers have been used to characterize genetic diversity of both the cultivated and wild relatives, and to identify new sources of genetic variation. Markers have also been used to map resistance genes, for use in negative marker-assisted selection of disease resistance in the absence of the pathogen (elimination of susceptible genotypes); markers are also the start-off point for the cloning of these resistance genes. Finally, associations between molecular markers and traits of agronomic interests, which are mostly quantitatively inherited, are being employed to elucidate the genetics of these traits.

2. A Molecular Genetic Map of Cassava

With funding from the Rockefeller Foundation, a molecular genetic map of cassava was constructed from an intra-specific cross between TMS30572, an improved line from IITA, Ibadan, Nigeria, and CM2177-2, an elite line from CIAT, Cali, Colombia. The F_1 mapping progeny consists of 150 individuals. Traits of agronomic interest present in the parents and expected to segregate in the cross include: resistance to African cassava mosaic disease (ACMD), resistance to cassava bacterial blight (CBB), and early harvestability in the female parent, TMS30572. In the male parent, traits include: good cooking quality, resistance to CBB, and a high photosynthetic rate. The map which was published in 1997 (Fregene *et al*.,1997) has a total of 300 RFLP, RAPD, SSR, and isozyme markers; more than 70% are RFLP markers. The 1997 map is estimated to cover 80% of the cassava genome and requires saturation. Efforts are currently geared to placing another 300-400 molecular markers on the map. To make the genetic map of cassava widely available, especially to cassava breeders and researchers in national agricultural research and extension systems (NARES), it was decided that the new markers to be added should be easy to use, while maintaining the same level of information as RFLP markers.

With support from the Swiss International Center for Agriculture, and the participation of a NARES cassava breeder from Nigeria, a project was initiated to generate 300-400 simple sequence repeat (SSR) markers for the genetic map of cassava. SSR markers are simple motifs of di-, tri-, or tetra-nucleotides repeated several times. The regions flanking the repeat sequences are usually conserved, and suitable for the design of PCR primers. They are, therefore, PCR-based, meaning they are easy to use, and co-dominant markers, having the same level of information as RFLP markers. SSR markers also have the unique advantage of ease of automation. In cassava, SSR markers were developed using several genomic libraries enriched for SSR sequences, followed by the sequencing of more than 500 positive clones. About 450 primer pairs have been designed and 200 tested so far, while 90 SSR markers have been mapped. At the moment, the search for SSR markers has turned to looking in non-enriched cDNA, and small fragment genomic libraries, to reduce the high level of duplication found with enriched libraries, and to convert the RFLP markers to SSR ones using BAC (Bacterial Artificial Library) library clones.

3. Characterizing Genetic Diversity and Defining Useful Variation

Progress in crop improvement depends upon the skillful exploitation of crop genetic diversity. The success story of maize hybrid production, and the green revolution wheat and rice varieties are probably the best illustrations of this fact. Cassava breeding has existed at CIAT for the past 27 years, and a group of parents with excellent general combining ability has been identified from a large germplasm collection that represents land races from the crop's center of diversity. Sixty four SSR markers, with a broad coverage of the cassava genome, were employed in an automated fashion, to analyze the parental genotypes, including others from IITA, a collection from Tanzania, and a randomly selected set of land races from the world cassava collection at CIAT. A total of 315 genotypes were analyzed, resulting in a large data matrix of more than 20,000 data points. Principal component analysis (PCA) based on genetic distances was performed on the SSR allele data. Analysis reveal clustering in the cassava genotypes according to region but the high GCA formed did not form any clear cluster in relation to other genotypes. Like maize, cassava appears to have highly differentiated gene pools, and has a large percentage of dominant/recessive gene action loci, two key characteristics required for heterosis. Existing yield data, from crosses between individuals from certain clusters, suggests that this may be so, and molecular markers can be used to predict heterosis, but evidence for this is at the moment being confirmed.

Several studies have revealed that cassava was domesticated from populations of the wild *Manihot* species, *M. esculenta*, sub spp *flabellifolia*. Other studies have also shown that the amount of genetic variation present in the natural population of this wild species are significantly more than that found in cassava. These findings suggests a founder's effect, or a genetic bottle neck, at the domestication of cassava. If this is the case, useful alleles for yield, and yield components may yet exists in the cultivar primary gene pool. We have initiated an advanced back cross quantitative trait loci (QTL) mapping scheme to mine favorable alleles for root quality, canopy strength, harvest index, and pest and disease resistance, aimed at broadening the genetic base with exotic alleles. The advanced back cross scheme has been used successfully in tomato, rice and maize to transfer favorable alleles to cultivated germplasm. In cassava, an allogamous crop, the scheme has been modified to reflect this. Basically, it involves making F_1 crosses of about 100 individuals each between four genotypes of sub spp *flabellifolia*, that best represent genetic diversity, and eight elite lines representative of the CIAT cassava gene pools. All F_1 individuals that flower are back-crossed to the respective parents to produce BC_1 families. Negative selection is performed at the seedling stage on the BC_1 families, and remaining progenies are back crossed to produce the BC_2 families, which are clonally evaluated in replicated single row (6 plants) experiments. The best four BC_2, with the highest phenotypic variation for the traits in question will be evaluated in replicated trials and also genotyped with markers. QTL analysis should identify new alleles from the wild donor and provide a tool for further breeding. The best BC_2 lines are then tested in a marker-assisted scheme as parental genotypes for improving the selected traits. For a closely related species such as *M. esculenta*, sub spp *flabellifolia*, QTL mapping is performed at the F_1 stage and identified QTLs are used directly in breeding. This second scheme is being used to identify QTLs for high dry root yield and starch content for introgression into good Asian varieties such as KU50.

4. Marker-assisted Selection for Disease Resistance in the Absence of the Pathogen

CIAT has several gene tagging projects for resistance to pests and diseases; they include African cassava mosaic disease (ACMD), cassava white fly (*A. socialis*), cassava bacterial blight (CBB), and cassava root rot (*Phytophtora* spp) with an aim of improving the efficiency of breeding for pest and disease resistance. Only gene tagging for ACMD resistance is discussed here. ACMD is the number one production constraint in sub-Saharan Africa, and a potential risk to Latin America and Asia, given the recent accidental introduction of the vector, the B biotype of the white fly. ACMD also complicates the exchange of germplasm between endemic areas and other parts of the world.

Breeding for ACMD resistance at CIAT is limited by an absence of the pathogen in Latin America, and also by the need to breed for resistance to at least three different strains of the virus. With funding from the Rockefeller Foundation, a project to tag all known sources of resistance to ACMD was initiated by CIAT and IITA. The female parent of the cassava map population (TMS30572) has resistance to ACMD, and also represents the currently deployed source of resistance from the *M.glaziovii* source. A BC_1 mapping population was developed by back crossing five F_1 progeny to TMS30572; these progenies were established *in vitro* from embryo axes and shipped to IITA.

A second mapping population was developed at IITA involving the new source of resistance from TME 3, a Nigerian land race. The new source of resistance shows near immunity to the West and the East African strains of the virus. Classical genetic studies show that the currently deployed source is recessive and the new source is a single dominant gene in the heterozygous state. Both ACMD resistance mapping populations were evaluated over two seasons for disease resistance in replicated trails in two high disease incidence sites in the field; they were also genotyped with molecular markers from the genetic map. A simple regression of disease response on marker genotypic classes revealed that a region of chromosome D explained about 50% of phenotypic variance for resistance from the *M.glaziovii* source, while a region on chromosome R explained more than 70% of phenotypic resistance of the new source of ACMD resistance.

A scheme has been initiated to use the marker in a marker-assisted scheme to breed for resistance to CMD in Latin America. At the same time a map-based cloning effort has also been initiated to clone the resistance gene for faster deployment via genetic transformation. The scheme involves fine mapping the gene, creating a contig of large DNA fragments around the gene, genetic transformation with candidate DNA fragments that carry the gene, and sequencing. Fine mapping of the region is ongoing, and a bacterial artificial chromosome (BAC) library of large DNA fragments has been constructed for contig mapping. The cassava BAC library which was constructed by CIAT scientists through a visit to the Clemson University Genome Institute (CUGI) in Clemson, South Carolina, has a total of 55,000 clones, of average size 80kb, and a 5X coverage of the cassava genome.

5. Dissection of the Genetics of Complex Traits

The map of cassava has also been employed to elucidate the genetics of agronomic traits that are quantitative in nature, with low broad sense heritability, such as dry matter yield, starch content, and early bulking (early harvestability). Only early bulking is discussed here; it is an important breeding objective in all cassava producing regions, and a key requirement for the transition of cassava from a traditional to an industrial crop. Combining a high starch yield, high dry root yield and early bulking is not an easy breeding objective. Identification of markers associated with the trait can be employed to eliminate inferior genotypes in a large number of breeding populations and thus increase selection efficiency for earliness.

One of the parents of the cassava map population, TMS30572, is an early bulking genotype: 80-90% of maximum yield is attained at eight months, making the cassava map population an excellent one for gene tagging for early bulking. Sixty plants of the 40 best and 40 worst genotypes (from two years of multi-locational replicated trials and harvest) for early bulking were planted in 6x10 m plots, with two replications at CIAT, Cali, Colombia; four internal plants were harvested every three weeks, beginning at six weeks after planting (WAP), until 30WAP. The dry root yield, dry foliage yield, harvest index, number of roots, and size of roots (diameter) where measured. A very early bulking clone from Brazil was included as control. A multiple regression analysis showed that dry foliage weight, and harvest index (HI), were the most important yield components in this experiment. A simple regression of dry foliage weight, and HI across the period of the experiment, on marker genotype class revealed QTLs that explained between 18-35% of phenotypic variance. Marker fidelity studies to confirm the use of these markers in breeding continues.

B. Genetic Transformation for Pest Resistance and Root Quality

CIAT has developed robust protocols for the regeneration and genetic transformation of cassava. The method is based on the *Agrobacterium tumefaciens* transformation of friable embryogenic callus. Transformation efficiencies of 10-15% have been obtained. The transformation protocol is being employed to engineer resistance to an important pest of cassava, the cassava stem borer (*Chilomima clarkei*), which is endemic in the Colombian North Coast. The stem borer can cause losses of 50-100% of cassava stakes and result in a severe shortage of planting material. Resistance is being created by the insertion of a construct containing the Bt gene, pBIGCry, and two reporter genes, the gus and npt II genes.

A second transformation project, which is about to begin, is the genetic engineering of cassava to produce waxy starch in cassava (100% amylopectin) This is via the down regulation of the granule bound starch synthate gene (GBSSII), via anti-sense down regulation of the gene. The gene has been cloned from cassava, in collaboration with the Wageningen Agricultural University (WAU) in the Netherlands; constructs for transformation will soon be available. Another project, awaiting funding, is the genetic engineering of cassava for biodegradable polymers, polyhydroxy alkanoates (PHA). The genes for the production of PHAs have been cloned from bacteria and shown to express specifically to organs of plants with the key fatty acid biosynthesis pathway, required to produce the polymers. PHAs have been successfully produced in seeds of arabidopsis, and soybean. The genes required are ketothiolase, polyhydroxylase B, and polyhydroxylase C.

C. Tissue Culture for Rapid Multiplication of Healthy Planting Material

Cassava yields can be affected considerably by diseased, or poor quality planting material. Securing clean and healthy stakes can be a problem for small farmers. For the same reason, the rate of spread of successful varieties continues to remain slow; rapid propagation of cassava by small farmers in rudimentary conditions have been proposed as a means of increasing the rate of spread in Colombia. CIAT has joined hands with a NGO in southern Colombia to help farmers acquire the rapid propagation technique, via the use of simple and widely available materials. The continuous media cycling technique (RITA) is also being tested by CIAT for the production of cassava planting material on a larger scale, by bigger companies and by NARES labs.

CONCLUSION

Cassava biotechnology research at CIAT can contribute to cassava research and development in Asia. Expertise in tissue culture has been transferred to NARES in the region in the past. But maybe the greatest potential for impact exists in cassava breeding. Success in cassava breeding relies heavily on:

1. Parental genotypes: crosses between different pairs of genotypes have a varying degree of success, and good genotypes do not always give good progenies
2. Size of progenies: between 1983 and 1997 the Thai-CIAT breeding program released three improved genotypes selected from 327,000 genotypes from 4130 crosses (Kawano *et al*., 1998)
3. Selection scheme: selection at the second cycle of evaluation, the single row trial (SRT) is the most crucial for success; more than 95% of the progenies are eliminated at this stage.

Markers can be used to:

1. Increase selection efficiency by a marker-assisted negative selection for root dry matter content, disease and pest resistance, and harvest index, at the seedling trial stage to accurately eliminate inferior genotypes and increase the selection efficiency at the single row trial (SRT) stage. Potential for increasing the selection efficiency is greatest at that stage.
2. Choice of parental genotypes: Molecular markers can provide a quantitative estimate of genetic variability, and help in choosing parents that maximize genetic variation. Markers associated with traits of interest can also be employed to identify parents with highest breeding value.

Application of marker technology to plant breeding has become economically feasible, thanks to high through-put technologies, but marker development and application requires considerable investment of resources to begin. Marker development and application for Asian cassava breeding is best achieved through a regional network of labs with funding from a regional donor. An Asian cassava biotechnology network, modeled on the successful Asian rice and maize networks should be considered. A project to test the application of markers in Asian cassava breeding is a worthy venture, given the potential of such technologies, and should be pursued.

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CLAYUCA: LATIN AMERICAN AND CARIBBEAN CONSORTIUM TO SUPPORT CASSAVA RESEARCH AND DEVELOPMENT

Bernardo Ospina[1]

ABSTRACT

During the last 25 years, cassava research in Latin America and the Caribbean (LAC) has been the responsibility of the Centro Internacional de Agricultura Tropical (CIAT) in collaboration with national programs, and has been financed mainly with public-sector funds. At the end of the 1980s, this model was not longer viable due to changes in the world's socio-economic situation, forcing institutions and countries to organize and establish strategic alliances to continue cassava-based research and development activities. The cassava sector in Latin America and the Caribbean also felt this need.

To solve this situation, it was necessary to identify and establish new models for financing and supporting cassava research and development to attend to the interests and needs of different groups of end-users of the technology from both the public and the private sector. It was proposed to form a Consortium to finance and support research and development of cassava, to strengthen the transfer of improved technologies, and to enhance the exchange of experiences, information and technologies among LAC countries. Thus, CLAYUCA was established.

The mission of CLAYUCA is to contribute to improving living standards and sustainable natural resource management in regions of LAC where cassava plays an important role in agricultural production systems, through the generation, transfer and exchange of technologies, information and scientific knowledge among public and private sector institutions and farmers in the region.

The main objectives are:

1. The organized participation of public and private sector institutions, including universities, non-governmental organizations and farmer groups, in the discussion and identification of priority issues and the definition of a regional research and development agenda for the cassava crop.
2. Execution of collaborative cassava-based research and development activities, with participation of diverse institutions in each member country.
3. Seeking additional financial support to implement research and development activities that could benefit all member countries.
4. Strengthening national capacity in each member country to execute research and development activities at the national level and to participate in activities at the international level.

Founding members of the Consortium are Colombia, Cuba, Bolivia, Ecuador and Venezuela, the International Center for Cooperation in Agricultural Research for Development (CIRAD) and CIAT. In each country, the group of participants in activities promoted by the Consortium are composed of institutions from the public and private sector, universities, non-governmental organizations, farmer groups and other sectors involved in cassava production, processing, commercialization and utilization, training, research and technology transfer. Potential members are all cassava producing countries in LAC, which have the capacity to help finance and execute activities of the Consortium.

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CLAYUCA will be self-financed. Each participating institution will pay an annual membership fee. Resources contributed by each member country will be administered and spent only on activities defined collectively by members of the Consortium. The Consortium's operational budget will be defined in agreement with the workplan established for each year. Moreover, the Consortium will seek additional funding to execute specific projects.

BACKGROUND

Cassava originated in Latin America and the Caribbean (LAC), where it has been cultivated since prehistoric times. Its adaptation to diverse ecosystems, its high production potential and the versatility of its markets and end uses have transformed the crop into a basic food for rural populations and a commercialization alternative for urban markets.

Today, the crop has extended to nearly 90 tropical and subtropical countries, with estimations that its starch-rich roots and protein-rich leaves are feeding about 500 million people. LAC is responsible for about one fifth (34 million) of the 170 million tonnes of fresh cassava roots that are harvested in the world every year.

During the last 25 years, cassava research in the region has been the responsibility of the International Center for Tropical Agriculture (CIAT), with the collaboration of diverse entities and national programs, and has been financed mainly with public-sector funds. At the end of the 1980s and all throughout the 1990s, this model was not longer viable, mainly because many public sector institutions have been undergoing change and reform as part of the region´s structural adjustments, including decentralization and privatization. Countries and institutions interested in cassava in the region felt the need to organize and establish strategic alliances that could lead to the establishment of new models for financing and supporting cassava research and development activities. These new alliances were meant to involve different groups of end users of the technology, from both the public and the private sector.

It was proposed to form a Consortium to finance and support research and development of cassava, strengthen the transfer of improved technologies, and enhance the exchange of experiences, information and technologies among LAC countries. That this type of regional mechanisms could function is shown by the Consortium in LAC for irrigated rice: the Latin-American and Caribbean Fund for Irrigated Rice (FLAR), which was formed in 1995 and of which CIAT and CIRAD are also founding and active members. After five years of work, FLAR has a membership of 12 countries and expect to invest annually nearly half a million dollars in rice-based research and development activities.

Based on these considerations, it was proposed to create the Latin American and Caribbean Consortium to Support Cassava Research and Development, CLAYUCA.

RATIONALE

The establishment of a mechanism through which the public and the private sector could jointly support research and development activities is justified on the grounds that it will allow countries to have more control over the research agenda and the benefits obtained. The investors control and assume responsibilities for parts of the agenda, which becomes a regional agenda. Each sector contributes with its own capacities and strengths, and the work is planned and conducted based on common interests and prioritized problems. For the International Centers the benefits accrue from the help that Consortium activities can give in filling the vacuum left by de Centers in regional research. This vacuum has increased considerably in the last decade due to the Center's financial constraints.

The work of the Consortium goes beyond the traditional research domain and becomes a regional forum. This is an additional benefit for the International Centers that allows them an active presence, at a relatively low cost, in a regional research and development agenda. Finally, private and public sector institutions obtain improved access to technologies generated by International and Advanced Research Centers.

JUSTIFICATION FOR CLAYUCA IN LATIN AMERICA AND THE CARIBBEAN

The newly born Consortium appears a viable mechanism for the LAC region considering the following opportunities and challenges that have arisen during recent years:

1) The dynamic growth of the cassava starch market, both for foodstuff and for industrial use.
2) Increased growth in cereal imports as raw material for balanced animal feed rations, in tandem with recent technological developments in the use of dried cassava chips as a partial substitute for cereals in animal feed.
3) Important advances in the development of improved technologies for manipulating the genetic potential of cassava germplasm (e.g. biotechnology and molecular biology).
4) Important advances in the development of improved technologies for sustainable, integrated management of the cassava crop.
5) A need to increase the crop's competitiveness through higher productivity, reduced processing costs and improved efficiency in the use of cassava, its products, and byproducts.
6) Predominance of cassava as an associated crop in small-farmer production systems found in marginal zones, thus representing an alternative agricultural policy to stimulate the socio-economic development of this sector.
7) Interest of the public and private sector in supporting cassava research and development activities aimed at generating improved technologies for production, processing, utilization and commercialization.

CLAYUCA´s MEMBERSHIP

Founding members of the Consortium are Colombia, Cuba, Ecuador and Venezuela, the International Center for Cooperation in Agricultural Research for Development (CIRAD) and CIAT.

In each country, the group of participants in activities promoted by the Consortium are composed of institutions from the public and private sector, universities, non-governmental organizations, farmer groups and other sectors involved in cassava production, processing, commercialization and utilization, training, research and technology transfer. Potential members are all cassava producing countries in LAC, which have the capacity to contribute financially and execute the activities of the Consortium.

CLAYUCA´s MISSION

To contribute to the improvement of living standards and sustainable natural resource management in regions of LAC where cassava plays an important role in agricultural production systems, through the generation, transfer and exchange of technologies, information and scientific knowledge among public and private sector institutions and farmers in the region.

CLAYUCA´s OBJECTIVES

To establish a self-financing, sustainable regional mechanism to facilitate:

1. Organized participation of public and private sector institutions, including universities, non-governmental organizations, and farmer groups, in the discussion and identification of priority issues, and the definition of a regional research and development agenda for cassava.
2. Execution of collaborative cassava-based research and development activities, with participation of diverse institutions in each member country.
3. Seeking additional financial support to implement research and development activities that could benefit all member countries.
4. Strengthening the national capacity in each member country to execute research and development activities at the national level and to participate in activities at the international level.

CLAYUCA´s FINANCING

CLAYUCA will be self-financed. Each participating institution will pay an annual membership fee. This annual fee is calculated based on each country's annual production (see Annex 1). Resources contributed by each member country will be administered and can only be spent on activities defined collectively by members of the Consortium.

The Consortium's operational budget will be defined in agreement with the workplan established for each year. Additionally, the Consortium could seek additional funding to execute specific projects.

The four founding member countries of CLAYUCA have already committed an annual budget of nearly US $ 100,000. Currently, CIAT´s contribution is about US $ 100,000 and CIRAD is offering scientific expertise upon request. The goal, when the Consortium is fully operating, is to reach US $ 340,000 per year.

CLAYUCA´s ORGANIZATIONAL STRUCTURE

The organizational and operational structure of the Consortium is to be maintained as flexible and light as possible. The main decision-making structure is the Executive Committee composed of one representative from each country and one representative from each International Center. Each one of these members will have voting power. This Committee is responsible for defining the procedures, norms and orientation that the Consortium will follow to conduct its activities.

The second decision-making structure is the Technical Committee composed of up to three members from each country. These representatives are to be selected with participation of all the members of the Consortium in each country. Each International Center will have one representative in this Committee. The main responsibility of the Technical Committee is to define the working agenda, making sure that the interests and needs of each country are included and accounted for.

The organizational structure of CLAYUCA also includes the Executive Director, appointed by the Executive Committee. His/her principal responsibility is to act as the representative and coordinator of all technical and administrative activities implemented by the Consortium.

CLAYUCA´s WORK PLAN

An initial workplan has been defined and approved for the year 2000. It includes topics and issues that were prioritized by the members. Activities will include:

- **Transfer of cassava germplasm with high yield potential to member countries**

  This activity will be conducted with all interested countries and institutions. Shipment of cassava germplasm will include different forms: *in-vitro*, stakes (Colombia) and poly-crossed sexual seed. Initial shipments of sexual seed have been sent to Ecuador and Venezuela.

- **Post-harvest handling of cassava**

  Processing technology for cassava flour for animal feeding is a request that has appeared as top priority in all countries. Options that are being evaluated and adapted to each country's specific characteristics include natural, artificial and mixed (natural + artificial) drying systems.

  Cuba and Venezuela are interested in small-scale cassava starch processing technologies. CIRAD and the Rural Agroenterprises Project at CIAT have a wealth of knowledge and accumulated experience in this type of technology, and CLAYUCA will try to negotiate their support and collaboration to implement technology transfer activities.

- **Technical Assistance and Promotion**

  These activities will be conducted in the five member countries, coordinated by the CLAYUCA group of each country. Based upon each specific request, CLAYUCA will try to coordinate support from researchers at CIAT, CIRAD, and the member institutions in each country.

- **Research and Development**

  CLAYUCA's initial agenda for cassava-based research and development activities is aimed at supporting member institutions in each country in the process of transforming cassava into a competitive, efficient and profitable agricultural commodity. The areas defined are (in priority order):

  1. Mechanization

  There are available, in various countries of Asia, Europe and Latin America, some prototypes for mechanized planting and harvesting of cassava, with potential to reduce production costs considerably. CLAYUCA has initiated activities aimed to a) identify more viable options (technical and economic), b) purchase and validate the prototypes, and c) make recommendations on the more suitable options according to each country's specific characteristics. This work area will also include mechanized fertilization of cassava.

2. Cassava Drying (Artificial or Mixed)

The potential of cassava flour to be used in the animal feed industry has grown considerably in Latin America during the last decade. These opportunities are based on the dependency that most of the countries in the region have established on the importation of cereals (maize, soybean) for their balanced animal feed rations. To consolidate this potential, besides the basic condition of producing cassava roots at competitive prices (high productivity, low costs), it is necessary also to develop drying systems (artificial or mixed), that allow the final cost of the raw material (cassava flour) to be competitive with that of imported cereals. CLAYUCA will be implementing activities to achieve this goal.

3. Fertilization

Fertilization practices, and especially the issue of soil fertility management, is closely related to the Consortium's general objective of supporting member countries in their search for more efficient, profitable and sustainable cassava production, processing and utilization systems. Based on information and accumulated experiences at CIAT and at some of the institutions affiliated to CLAYUCA (INIVIT-Cuba and Almidones Nacionales de Colombia), the Consortium will develop practices and recommendations based on the use of conventional and non-conventional fertilizers, such as poultry and pig manures, mycorrhizas, azotobacter, phosphorin and others.

4. Integrated Pest and Disease Management

An analysis of strengths existing at CIAT, and in some of the member countries, has shown the importance of implementing research and development activities that could facilitate the validation of technologies based on the use of bio-pesticides, for controlling most of the pest and diseases that affect the cassava crop. In Cuba, for example, during the last five years, the use of chemical pesticides in cassava production has been avoided and the use of biological products such us V*erticillium, Metarrizium, Bauveria bassiana, Bacillus thuringiensis and Thrichrograma* has been intensified. CLAYUCA will be implementing activities based on these technological alternatives that could be important in reducing costs and diminishing the use of chemical products.

5. Genetic Modification of Cassava

Although this activity will not be executed directly by CLAYUCA, there have been some discussions about the strategic importance of maintaining the Consortium linked with research projects that are being formulated at CIAT to produce transgenic cassava plants. Some of the possibilities being analyzed include working with genes that will confer Round-up and pests resistance, or that will modify the amylose/amylopectin ratio. The possibility of developing elite, genetically-modified clones of cassava with some of these characteristics could be an important breakthrough in large-scale cassava plantations and could also be important in small-scale systems in which farmers could grow premium varieties and obtain better prices.

6. Production and Utilization of Cassava Foliage

This activity is also related with the potential of cassava leaves to be used in animal feeding. The cassava top part (leaves and stem), represents an important protein source, that, with very few exceptions, is unused in Latin America and the Caribbean. CLAYUCA will implement activities to validate and adapt existing technologies for the production and utilization of cassava foliage. The aim is to generate reliable technical information on the nutritional value and potential of cassava leaves to be used in animal feeding.

CONCLUSIONS

The promotion of joint ventures between public and private sector institutions and enterprises, with the aim of supporting research and development activities for a specific crop is not a process that develops overnight. A good solid initial thrust has to be developed based on clearly specified objectives, methods, and operational procedures. Thus, private sector investors recognize the importance of sharing risks and responsibilities in supporting and financing research activities, but at the same time, are able to clearly recognize the benefits they will get.

The presence and participation of the public sector is essential in this type of arrangements. Although they usually lack the necessary funds, their importance is based on the wealth of knowledge and information they have about the appropriateness of specific technologies at the local level. They also have a strong capability to facilitate the implementation of activities.

International and Advanced Research Centers are key players in these Consortiums. Over the years they have accumulated knowledge, information and experiences related to technology generation and dissemination. In most cases, problems prioritized by member countries already have technological alternatives tested or in the process of generation. The close participation and joint efforts of the private and public sector helps to speed up the final process of fine tuning these promising technologies.

Experiences developed throughout the last five years by the irrigated rice sector in Latin America, represented by FLAR, and promising results that the cassava sector is starting to obtain, represented by CLAYUCA, indicate the potential of promoting joint ventures of private and public sector institutions, with scientific backstopping from the International and Advanced Research Centers, with the common objective of increasing competitiveness, efficiency and profitability of specific agricultural sectors.

TWO EXAMPLES OF COLLABORATION

Two examples help to illustrate the potential of this Consortium and the type of activities that could be implemented:

1. Institutions conducting research on cassava in Cuba have made important progress in the use of biological control methods for some of the principal pests and diseases that affect the crop. These technologies are relatively unknown in other LAC countries.

One important activity of the Consortium could be the realization of training events through which Cuban researchers could transfer this knowledge to other cassava researchers in LAC. Training activities, as an instrument to strengthen collaboration among research and technology transfer institutions in LAC countries, could be one of the most important work areas for CLAYUCA.

2. In South Brazil (States of Sao Paulo, Paraná, Santa Catarina), there are many cassava starch processing factories, both small- and large-scale. These factories face strong competition from corn-based waxy starches, mostly imported, that were developed with scientific support from universities in the USA. These regional factories have complained about the lack of research on improved cassava varieties that could yield starch of competitive quantity and quality. According to researchers at the Biotechnology Unit of CIAT, there are currently some advances in the manipulation of the genetic characteristics of cassava varieties that could enable the obtention of genetically-modified varieties with higher amylopectin content, which could make them very attractive for industrial purposes. The immediate benefits of this technological advance could be very important: cassava farmers could harvest cassava varieties with improved industrial quality, thus receiving better prices; conversely, cassava processors could elaborate more competitive products and establish more profitable market opportunities.

The Consortium could help turn these technological possibilities into reality.

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ANNEX 1. MECHANISM FOR FINANCING CLAYUCA

To finance CLAYUCA's activities, a mechanism has been established based on quotas paid by each member country. The criterion used to determine this quota is the annual cassava production for each country. The mechanism is as follows:

a. Annual affiliation quota

- Countries with an annual production of fresh cassava roots of less than 350,000 tonnes will pay US $ 15,000 per year

- Countries with an annual production between 350,000 and 700,000 tonnes will pay US $ 20,000 per year.

- Countries with an annual production between 700,000 and 1 million tonnes will pay US $ 25,000 per year

b. Annual additional quota

An additional quota has also been established as follows:

- Countries with an annual production of more than 1 million and less than 3 million tonnes will pay an additional quota of US $ 5,000 per year , and

- Countries with an annual production of more than 3 million tonnes will pay an additional quota of US $ 10,000 per year.

Based on these considerations and using production data from FAO, the quotas currently established for affiliation to CLAYUCA are as shown in **Table 1**.

Table 1. Cassava production in Latin America and the Caribbean and the annual financial contribution to CLAYUCA.

Country	Annual production[1] (tonnes)	Annual quota (US $)
Brazil	24,551,534	35,000
Paraguay	2,925,477	30,000
Colombia	1,800,066	30,000
Peru	661,996	20,000
Haiti	350,000	15,000
Venezuela	344,238	15,000
Bolivia	316,664	15,000
Cuba	252,500	15,000
Argentina	157,500	15,000
Costa Rica	131,000	15,000
Dominican Republic	123,823	15,000
Ecuador	76,688	15,000
Nicaragua	51,375	15,000
Guyana	35,100	15,000
El Salvador	34,920	15,000
Panama	31,600	15,000
Guatemala	15,683	15,000
Honduras	8,900	15,000
Suriname	6,000	15,000
TOTAL		**340,000**

1) Average of four years, 1993-1997

***Source*: *FAO, 1999* .**

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APPENDIX

Results of Soil Analyses in Asia 1995-2000

Reinhardt H. Howeler

The following tables present the analysis results of soil samples taken in various countries in Asia, mainly in soil fertility maintenance experiments and in FPR trials in farmers fields. To facilitate interpretaion of the results, **Table 1** indicates the approximate classification of soil chemical characteristic according to the nutritional requirements of cassava.

Table 1. Aproximate classification of soil chemical characteristics according to the nutritional requirements of cassava.

Soil parameter[1]	Very low	Low	Medium	High	Very high
pH	<3.5	3.5-4.5	4.5-7	7-8	>8
Org. matter (%)	<1.0	1.0-2.0	2.0-4.0	4.0-8.0	>8.0
Al-saturation (%)			<75	75-85	>85
Salinity (mmhos/cm)			<2	2-10	>10
Na-saturation (%)			<2	2-10	>10
P (µg/g)	<2	2-5	5-20	20-50	>50
K (me/100g)	<0.10	0.10-0.15	0.15-0.25	>0.25	
Ca (me/100g)	<0.25	0.25-1.0	1.0-5.0	>5.0	
Mg (me/100g)	<0.2	0.2-0.4	0.4-1.0	>1.0	
S (µg/g)	<20	20-40	40-70	>70	
B (µg/g)	<0.2	0.2-0.3	0.3-1.0	1-2	>2
Cu (µg/g)	<0.1	0.1-0.2	0.2-1.0	1-5	>5
Mn (µg/g)	<5	5-10	10-100	100-250	>250
Fe (µg/g)	<1	1-10	10-100	>100	
Zn (µg/g)	<0.5	0.5-1.0	1.0-5.0	5-50	>50

[1]pH in H_2O: OM by ethod of Walkley and Black;
Al saturation = 100 x Al (Al + Ca + Mg + K) in me/100g;
P in Bray II; K, Ca, Mg and Na in 1<u>N</u> NH_4-acetate; S in Ca-phosphate;
B in hot water; and Cu, Mn, Fe and Zn in 0.05 <u>N</u> HCI + 0.025 <u>N</u> H_2SO_4
Source: *modified from Howeler, 1996.*

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[1]CIAT Cassava Office for Asia, Dept. of Agric., Chatuchak, 10900 Thailand.

Table 2. Soil samples taken in China, 1997-2000.

Sample no.		Sample location and description	Date
Hainan	-1	Danzhou, CATAS; NPK trial befor planting 6 th cycle, $N_0P_0K_0$	Mar 97
	-2	Danzhou, CATAS; NPK trial befor planting 7 th cycle, $N_0P_0K_0$	Dec 97
	-3	Danzhou, CATAS; NPK trial befor planting 9 th cycle, $N_0P_0K_0$	Jan 00
	-4	Danzhou, CATAS; NPK trial befor planting 10 th cycle, $N_0P_0K_0$	Dec 00
	-5	Danzhou, CATAS; NPK trial befor planting 6 th cycle, $N_2P_0K_2$	Mar 97
	-6	Danzhou, CATAS; NPK trial befor planting 7 th cycle, $N_2P_0K_2$	Dec 97
	-7	Danzhou, CATAS; NPK trial befor planting 9 th cycle, $N_2P_0K_2$	Jan 00
	-8	Danzhou, CATAS; NPK trial befor planting 10 th cycle, $N_2P_0K_2$	Dec 00
	-9	Danzhou, CATAS; NPK trial befor planting 6 th cycle, $N_2P_2K_0$	Mar 97
	-10	Danzhou, CATAS; NPK trial befor planting 7 th cycle, $N_2P_2K_0$	Dec 97
	-11	Danzhou, CATAS; NPK trial befor planting 9 th cycle, $N_2P_2K_0$	Jan 00
	-12	Danzhou, CATAS; NPK trial befor planting 10 th cycle, $N_2P_2K_0$	Dec 00
	-13	Danzhou, CATAS; NPK trial befor planting 6 th cycle, $N_2P_2K_2$	Mar 97
	-14	Danzhou, CATAS; NPK trial befor planting 7 th cycle, $N_2P_2K_2$	Dec 97
	-15	Danzhou, CATAS; NPK trial befor planting 9 th cycle, $N_2P_2K_2$	Jan 00
	-16	Danzhou, CATAS; NPK trial befor planting 10 th cycle, $N_2P_2K_2$	Dec 00
	-17	Danzhou, CATAS; NPK trial befor planting 6 th cycle, $N_3P_3K_3$	Mar 97
	-18	Danzhou, CATAS; NPK trial befor planting 7 th cycle, $N_3P_3K_3$	Dec 97
	-19	Danzhou, CATAS; NPK trial befor planting 9 th cycle, $N_3P_3K_3$	Jan 00
	-20	Danzhou, CATAS; NPK trial befor planting 10 th cycle, $N_3P_3K_3$	Dec 00
	-21	Tunchang county, Nankun town, FPR erosion trial, poor rocky soil	Aug 97
	-22	Tunchang county, Nankun town, FPR erosion trial, check plot, good soil	Aug 97
	-23	Danzhou county, Panja town (FPR diagnosis), cassava+rubber	July 98
	-24	Baisha county, Kongba village, Mr. Ju Yong Quan, check in NPK trial	Aug 97
	-25	Baisha county, Kongba village, ZM 93274 with clear N deficiency	Aug 99
	-26	Baisha county, Kongba village, FPR variety trial Mr. Tan Yin Chai	Dec 99
	-27	Baisha county, Kongba village, FPR variety trial Mr. Zhou Yong Ming	Dec 99
	-28	Baisha county, Kongba village, FPR variety trial Mr. Fu Yong Cheng-high yield first year, no fertitizers applied	Dec 99
	-29	Baisha, Kongba, variety trial Mr. Yong Cheng, small top growth after 6 years of continuous cassava	Dec 99
	-30	Baisha county, Kongba village, variety trial Mr. Jhou Wensheng	Dec 99
	-31	Baisha county, Kongba village, variety trial Mr. Liu Huangcheng	Dec 99
	-32	Baisha county, Kongba village, variety trial of Mr. Jhou Wensheng (on mountain)	June 00
	-33	Baisha county, Tapuling village, Mr. Shou Wen Lin, check in NPK trial	Aug 97
	-34	Baisha county, Tapulin village, erosion trial, poor growth	Aug 99
	-35	Baisha county, Tapulin village, above erosion trial, good growth SC205	Aug 99
	-36	Baisha county, Tapulin village, FPR variety trial Mr. Fu Jiabang	Dec 99
	-37	Baisha county, Tapulin village, FPR variety trial Mr. Fu Yu Ming	Dec 99
	-38	Baisha county, Tapulin village, FPR variety trial Mr. Fu Yonggen	Dec 99
	-39	Baisha county, Tapulin village, FPR variety trial Mr. Fu Jia Yu (50% slope)	Dec 99
	-40	Baisha county, Tapuling village. variety trial of Mr. Fu Chang	June 00
Guangdong	-1	Qing Yuan county, check plot in NPK on-farm trial	Aug 97
	-2	Gaozhou Agric. College, check plot in NPK trial on campus	Aug 97
	-3	Gaozhou county, on-farm NPK trial before ‘98 planting	Dec 97
	-4	Yunan county, on-farm NPK trial before ’98 planting	Dec 97

Table 2. Soil samples taken in China, 1997-2000. (continued)

Sample no.		Sample location and description	Date
Guangxi	-1	Wuming county, Xinglian village, FPR site; red soil, 30% slope	Aug 99
	-2	Wuming, Xiawang village, ZM 8634 with Zn and B deficiency symptems	June 00
	-3	Near Pingguo town, Zn+Fe deficiency in limestone-derived soil	June 00
	-4	Near Pingguo town at foot of limestone mountain, field of GR 911	June 00
Yunnan	-1	Honghe district, Pingbian county, Pingbian Prod. Base near Vietnam border	Aug 97
	-2	Honghe district, Pingbian Production Base; variety trial	Nov 00
	-3	Honghe district, Jinping county, large cassava plantation on black clay	Aug 97
	-4	Honghe district, Yuanjang county, Si-jiao Tian village, cassava on 80% slope	Aug 97
	-5	Jianshai county, Chenguan town (north of Jiangshui), red clay eroded soil	Aug 97
	-6	Jinping county, Dazhai town, Michang village, Machaokou Production Base, black soil with banana	Aug 99

Table 3. Chemical and physical characteristics of cassava soils in China, 1997-2000.

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Hainan	-1	5.4	1.0	18.6	0.52	0.95	0.21	0.09	29	-	-	-	-	-	-	-	-	-
	-2	4.7	0.8	17.9	0.83	0.45	0.15	0.08	55	0.13	0.35	12.1	0.15	19.7	58.4	17.6	24.0	s.c.l.
	-3	5.2	0.8	12.0	0.62	0.39	0.06	0.09	53	0.20	0.61	10.7	0.13	14.7	58.8	27.2	14.0	s.l.
	-4	5.4	0.8	9.1	0.62	0.52	-	0.10	-	-	-	-	-	-	-	-	-	-
	-5	5.1	1.0	15.4	0.52	1.00	0.20	0.10	29	-	-	-	-	-	-	-	-	-
	-6	4.8	0.9	17.1	0.73	0.41	0.14	0.10	53	-	-	-	-	-	-	-	-	-
	-7	5.2	0.9	10.6	0.62	0.36	0.07	0.13	53	-	-	-	-	-	-	-	-	-
	-8	5.0	0.9	6.2	0.73	0.50	0.07	0.12	51	-	-	-	-	-	-	-	-	-
	-9	4.9	1.0	25.2	0.52	0.80	0.18	0.09	33	-	-	-	-	-	-	-	-	-
	-10	4.8	0.9	35.8	0.73	0.52	0.14	0.06	50	-	-	-	-	-	-	-	-	-
	-11	5.3	0.8	24.3	0.62	0.46	0.07	0.09	50	-	-	-	-	-	-	-	-	-
	-12	4.9	0.9	30.4	0.52	0.66	0.07	0.10	38	-	-	-	-	-	-	-	-	-
	-13	5.0	1.0	41.2	0.52	0.73	0.18	0.12	33	-	-	-	-	-	-	-	-	-
	-14	4.8	0.9	27.4	0.73	0.43	0.15	0.08	52	-	-	-	-	-	-	-	-	-
	-15	5.4	0.8	41.9	0.52	0.54	0.06	0.10	43	-	-	-	-	-	-	-	-	-
	-16	5.3	1.0	53.7	0.52	0.71	0.07	0.12	37	-	-	-	-	-	-	-	-	-
	-17	4.9	1.1	35.6	0.52	0.92	0.20	0.13	29	0.29	0.48	17.9	0.15	19.1	56.7	18.6	24.7	s.c.l.
	-18	4.8	1.0	43.8	0.83	0.52	0.14	0.11	52	0.16	0.28	15.5	0.17	22.4	58.4	16.3	25.3	s.c.l.
	-19	5.1	1.1	30.6	0.62	0.57	0.08	0.11	45	0.19	0.80	11.4	0.34	13.6	61.2	26.0	12.7	s.l.
	-20	5.0	1.0	48.3	0.52	0.85	0.09	0.12	33	-	-	-	-	-	-	-	-	-
	-21	5.0	2.4	5.9	1.04	1.50	1.00	0.13	28	0.24	0.53	32.2	0.17	24.5	65.9	11.9	22.2	s.c.l.
	-22	5.1	3.5	10.0	1.25	2.80	2.80	0.14	18	0.30	0.56	50.2	0.21	21.0	49.7	22.5	27.8	s.c.l.
	-23	4.3	3.2	9.9	0.62	0.38	0.28	0.14	44	0.67	0.57	15.0	0.16	50.6	71.0	8.8	20.2	s.c.l.
	-24	5.0	2.7	28.3	0.83	1.30	0.38	0.08	32	0.31	0.66	74.8	0.13	18.8	53.0	14.5	32.5	s.c.l.
	-25	4.5	2.1	15.2	2.29	0.33	0.12	0.10	81	0.49	0.44	9.4	0.25	38.1	48.8	15.2	36.0	s.c.
	-26	4.8	3.8	6.7	2.29	0.73	0.24	0.18	67	0.71	1.07	30.3	0.24	30.5	49.2	16.4	34.3	s.c.l.
	-27	4.7	3.3	31.6	2.50	0.67	0.16	0.12	72	0.66	0.81	24.1	0.37	36.6	49.3	17.7	33.0	s.c.l.
	-28	4.6	2.4	15.0	2.29	0.66	0.24	0.10	70	0.64	0.75	58.9	0.15	20.8	49.5	15.1	35.4	s.c.
	-29	4.7	2.4	28.0	1.77	0.74	0.23	0.10	62	0.60	0.87	51.9	0.21	19.7	50.6	16.4	33.0	s.c.l.
	-30	5.2	1.0	29.4	0.10	1.14	0.32	0.07	6	0.54	0.95	79.8	0.18	11.4	71.3	15.5	13.2	s.l.

[1)] s.c.l. = sandy clay loam; s.l. sandy loam

Table 3. Chemical and physical characteristics of cassava soils in China, 1997-2000. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
	-31	5.1	4.3	15.4	0.52	2.80	1.12	0.12	11	0.68	3.06	66.5	0.39	14.8	56.1	15.6	28.3	s.c.l.
	-32	4.5	6.0	7.8	4.06	0.52	0.27	0.41	77	0.75	1.28	15.6	0.22	32.2	39.7	19.7	40.6	clay
	-33	4.4	3.7	12.6	1.87	0.49	0.26	0.14	68	0.16	0.83	47.1	0.12	28.1	50.1	12.4	37.5	s.c.
	-34	4.7	1.4	10.6	1.04	0.32	0.18	0.08	64	0.52	0.93	41.2	0.33	9.6	66.8	10.0	23.2	s.c.l.
	-35	4.8	1.7	78.3	0.83	0.84	0.29	0.09	40	0.51	1.21	51.9	0.39	12.5	68.9	11.3	25.8	s.c.l.
	-36	5.0	1.1	6.6	0.94	0.42	0.14	0.08	59	0.39	0.85	41.3	0.25	10.0	67.6	9.2	23.2	s.c.l.
	-37	4.7	2.2	5.3	1.87	0.40	0.20	0.11	72	0.48	0.87	50.0	0.22	19.9	53.3	10.6	36.1	s.c.
	-38	4.6	2.6	4.4	1.87	0.36	0.16	0.12	75	0.50	1.06	53.8	0.28	37.2	49.7	14.4	35.9	s.c.
	-39	4.5	4.5	5.6	4.20	0.38	0.34	0.18	82	0.59	1.31	19.7	0.27	25.2	43.3	14.4	42.3	clay
	-40	4.7	2.5	10.6	1.46	0.42	0.27	0.20	62	0.99	1.30	57.6	0.32	17.8	60.7	13.1	26.2	s.c.l.
Guangdong	-1	5.0	1.0	16.2	0.24	0.40	0.14	0.04	42	0.21	1.70	1.9	0.35	19.3	77.3	8.1	14.6	s.l.
	-2	4.9	12.2	82.0	0.42	1.10	0.26	0.10	22	0.16	1.18	25.3	2.35	135.2	-	-	-	-
	-3	4.7	1.6	146.0	0.62	1.00	0.26	0.23	29	0.17	3.10	19.9	2.54	193.0	59.4	16.4	24.1	s.c.l.
	-4	5.0	3.0	53.0	0.31	3.40	0.75	0.23	7	0.19	4.03	17.3	1.45	213.2	30.7	17.9	51.4	clay
Guangxi	-1	4.8	0.7	10.0	2.29	0.36	0.13	0.12	79	0.35	0.42	57.9	0.42	9.4	1.9	9.0	89.1	clay
	-2	5.1	3.3	16.5	1.87	2.16	0.37	0.42	39	0.91	0.76	9.6	0.37	12.2	15.7	13.3	71.0	clay
	-3	7.1	3.6	0.3	0	14.99	0.58	2.61	0	0.79	0.02	1.2	0.14	0.1	36.0	34.5	29.6	c.l.
	-4	7.3	3.0	28.0	0	21.54	0.67	0.77	0	0.72	1.16	94.3	0.17	2.2	37.4	33.8	28.8	c.l.
Yunnan	-1	4.6	6.1	6.5	4.40	0.50	0.52	0.25	78	0.34	0.92	53.5	0.66	19.7	20.3	35.2	44.5	clay
	-2	5.0	5.5	6.3	1.30	2.54	1.09	0.11	26	0.71	2.89	30.2	0.49	21.9	40.8	32.1	27.1	loam
	-3	4.3	5.3	16.0	5.40	0.40	0.18	0.13	88	0.26	0.47	6.3	0.86	49.3	33.4	23.6	43.0	clay
	-4	7.0	1.4	4.9	0	11.64	1.36	0.16	0	0.40	0.53	47.5	0.41	14.0	58.1	22.1	19.8	clay
	-5	5.6	0.3	0.5	1.04	2.80	1.30	0.08	20	0	0.83	38.5	0.33	19.4	2.7	1.9	95.4	clay
	-6	4.3	3.3	9.7	5.72	0.65	0.25	0.28	83	0.39	0.54	12.0	0.58	30.5	21.6	23.0	55.4	clay

[1)] s.c.l.=sandy clay loam; s.c = sandy clay; s.l. = sandy loam

Table 4. Soil samples taken in Indonesia and East Timor, 1997-2000.

Sample no.		Sample location and description	Date
Lampung	1-12	Tamanbogo, NPK trial, at harvest 6th year, T_1-T_{12}	Oct 97
	13-21	Tamanbogo, erosion trial, after harvest 6th year, T_1-T_9	Dec 97
	22-33	Umas Jaya farm, NPK trial, after harvest 10th year, T_1-T_{12}	May 98
	34	Tamanbogo, in Experiment Station, very poor cassava with K deficiency	May 99
	35	Tamanbogo, in Experiment Station, very good cassava	May 99
Yogyakarta	-1	Playen, farmers field near cassava-soybean trial	Feb 98
	-2	Playen, cassava variety trial	Feb 98
	-3	Playen, plot next to variety trial, severe Fe/Zn deficiency symptoms	Feb 98
	-4	Playen, top part of erosion control trial	Feb 98
East Java	-1	Blitar, Ringin Rejo, Mr. Jaido for demonstration plot	Aug 97
	-2	Blitar, Ringin Rejo, Mr. Hardy FPR variety trial, sticks red clay	Feb 98
	-3	Blitar, Ringin Rejo, Mr. Katamin, FPR erosion trial, poor cassava	Feb 98
	-4	Blitar, Karang Bendo-Forestry Dept., cassava under coconut, volcanic ash soil	Feb 98
	-5	Blitar, Ringin Rejo, FPR erosion trial, Mr. Mat Dasuki, black clay soil	June 98
	-6	Blitar, Ringin Rejo, FPR erosion trial, Mr. Tamami, red clay soil, good cassava	June 98
	-7	Blitar, near Ringin Rejo, land of Forestry Dept., mahoganey+cassava, red soil	May 99
E. Kalimantan	-1	Sepaku II, near house Mr. Suharto	Mar 98
	-2	Makroman, near meeting hut, yellow clay	Mar 98
	-3	Makroman, cassava on steep slope	Mar 98
	-4	Makroman, cassava field intercropped with *Andropogon*	Mar 98
East Timor	-1	Baucau, Fatomaca Technical School-field of dark brown limestone derived soil	Nov 00
	-2	Ailey, before Maubisse, 80% slope, purple brown clay soil with shale, after burning	Nov 00
	-3	Ailey, after Maubisse, at 1300 masl; yellow clay loam with limestones	Nov 00
	-4	Ailey, after Maubisse, same site, lower field, brown-red clay soil	Nov 00

Table 5. Chemical and physical characteristics of cassava soils in Indonesia and East Timor, 1997-2000.

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Lampung	-1	4.5	2.2	5.1	1.35	0.60	0.45	0.09	54	0.23	0.62	11.6	0.33	30.9	51.7	11.4	36.9	s.c.
	-2	4.6	2.8	26.0	1.46	0.95	0.45	0.36	45	-	-	-	-	-	-	-	-	-
	-3	4.5	2.4	13.9	1.56	0.71	0.34	0.24	55	-	-	-	-	-	-	-	-	-
	-4	4.4	2.7	14.4	1.87	0.56	0.29	0.31	62	-	-	-	-	-	-	-	-	-
	-5	4.2	2.3	14.2	1.66	0.42	0.22	0.38	62	-	-	-	-	-	-	-	-	-
	-6	4.0	2.5	9.8	1.56	0.88	0.34	0.24	52	-	-	-	-	-	-	-	-	-
	-7	4.5	2.6	19.8	1.87	0.44	0.26	0.23	67	-	-	-	-	-	-	-	-	-
	-8	4.5	2.5	42.1	1.77	0.66	0.29	0.19	61	-	-	-	-	-	-	-	-	-
	-9	4.3	2.7	33.8	1.77	0.60	0.40	0.11	61	-	-	-	-	-	-	-	-	-
	-10	4.4	2.7	10.2	1.98	0.35	0.24	0.28	69	-	-	-	-	-	-	-	-	-
	-11	4.5	2.5	10.9	1.26	0.41	0.25	0.47	53	-	-	-	-	-	-	-	-	-
	-12	4.3	2.9	22.0	2.08	0.54	0.26	0.31	65	0.39	0.52	26.3	0.61	33.1	-	-	-	-
	-13	4.6	2.4	6.1	1.04	0.74	0.49	0.17	43	-	-	-	-	-	-	-	-	-
	-14	4.4	2.2	5.4	1.56	0.46	0.34	0.18	61	-	-	-	-	-	-	-	-	-
	-15	4.5	2.2	6.4	1.35	0.66	0.41	0.21	51	-	-	-	-	-	-	-	-	-
	-16	4.6	2.3	9.9	1.25	0.64	0.38	0.23	50	-	-	-	-	-	-	-	-	-
	-17	4.4	2.6	21.1	1.87	0.49	0.27	0.16	67	-	-	-	-	-	-	-	-	-
	-18	4.3	2.2	30.9	1.56	0.49	0.22	0.15	64	-	-	-	-	-	-	-	-	-
	-19	4.3	2.2	15.3	1.35	0.45	0.32	0.15	59	-	-	-	-	-	-	-	-	-
	-20	4.6	2.3	24.6	0.94	0.69	0.59	0.21	39	-	-	-	-	-	-	-	-	-
	-21	4.6	2.5	19.1	1.04	0.89	0.57	0.35	36	-	-	-	-	-	-	-	-	-
	-22	4.2	2.2	6.6	2.50	0.40	0.30	0.12	75	0.62	0.64	3.4	0.73	58.7	-	-	-	-
	-23	4.3	2.6	22.5	1.98	0.64	0.41	0.22	61	-	-	-	-	-	-	-	-	-
	-24	4.1	2.1	18.5	2.18	0.58	0.24	0.16	69	-	-	-	-	-	-	-	-	-
	-25	4.1	2.7	26.9	2.08	0.60	0.26	0.28	65	-	-	-	-	-	-	-	-	-
	-26	4.1	2.6	27.0	2.39	0.58	0.31	0.15	70	-	-	-	-	-	-	-	-	-
	-27	4.0	2.4	7.4	2.18	0.37	0.30	0.21	71	-	-	-	-	-	-	-	-	-
	-28	4.0	2.5	8.9	2.29	0.46	0.19	0.15	74	-	-	-	-	-	-	-	-	-
	-29	4.1	2.4	45.7	2.18	0.64	0.27	0.18	67	-	-	-	-	-	-	-	-	-

[1)] s.c.l. = sandy clay loam; s.c. = sandy clay

Table 5. Chemical and physical characteristics of cassava soils in Indonesia and East Timor, 1997-2000. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1]
Lampung	-30	4.0	2.4	18.6	2.18	0.63	0.30	0.10	68	-	-	-	-	-	-	-	-	-
	-31	3.9	2.5	26.4	2.29	0.64	0.23	0.15	69	-	-	-	-	-	-	-	-	-
	-32	4.1	2.4	28.4	1.87	0.64	0.33	0.30	60	-	-	-	-	-	-	-	-	-
	-33	4.0	2.6	33.0	2.18	0.62	0.27	0.20	67	0.49	0.49	4.0	0.52	70.1	43.5	16.6	39.9	c.l.
	-34	4.7	2.3	6.8	2.70	0.25	0.09	0.06	87	0.40	0.47	10.1	0.41	59.8	42.0	14.0	44.0	clay
	-35	4.4	2.0	25.9	2.18	0.42	0.18	0.08	76	0.43	0.42	15.1	0.46	43.7	44.7	14.0	41.3	clay
Yogyakarta	-1	6.5	2.4	28.0	0	54.65	1.85	0.74	0	0.63	0.16	16.1	0.14	0.8	7.3	17.9	74.8	clay
	-2	7.2	1.2	10.4	0	59.86	2.31	0.26	0	0.58	0.04	1.5	0.13	0.3	16.5	11.0	72.5	clay
	-3	7.5	1.6	9.7	0	60.16	2.31	0.21	0	0.68	0.04	1.0	0.16	0.2	15.8	11.6	72.6	clay
	-4	7.5	1.5	14.4	0	60.67	2.81	0.23	0	0.36	0.10	5.6	0.13	0.2	14.1	9.0	76.9	clay
East Jaya	-1	7.0	2.2	10.8	0	38.90	0.96	0.21	0	0.28	0.17	8.2	0.10	0.2	23.6	17.0	59.4	clay
	-2	5.6	0.7	9.6	0.10	38.00	4.70	0.05	0	0.48	0.33	22.4	0.82	9.7	-	-	-	-
	-3	5.7	1.0	3.3	0.10	34.60	4.20	0.07	0	0.61	0.23	19.2	1.25	11.3	18.5	25.8	55.7	clay
	-4	6.3	0.8	36.6	0	0.89	0.07	0.10	0	0.20	0.35	3.9	1.39	21.8	79.3	7.3	13.4	s.l
	-5	6.1	2.2	4.8	0	36.34	7.53	0.17	0	1.01	0.32	60.5	0.29	0.8	12.2	13.8	74.0	clay
	-6	5.5	1.8	4.6	0.33	32.59	8.55	0.07	1	1.07	0.81	87.4	2.01	13.4	11.4	17.8	70.7	clay
	-7	5.1	2.7	21.5	0.31	12.36	3.53	0.48	2	0.66	2.59	127.9	2.14	9.5	9.1	15.1	75.8	clay
E. Kalimantan	-1	4.6	3.1	4.0	3.30	0.87	0.58	0.20	67	0.31	0.54	8.9	0.35	169.2	33.5	33.4	33.1	c.l.
	-2	4.3	3.2	7.6	3.00	0.88	0.74	0.21	62	0.32	1.28	10.2	0.31	169.4	36.0	29.6	34.4	c.l.
	-3	4.5	2.3	3.9	3.10	0.84	0.59	0.16	66	0.19	0.36	7.5	0.31	166.2	37.3	29.6	33.1	c.l.
	-4	4.3	2.3	5.4	2.40	0.55	0.44	0.09	69	0.30	0.46	2.2	0.34	137.9	59.1	14.3	26.6	s.c.l.
East Timor	-1	5.6	3.3	6.2	0	15.41	0.98	0.28	0	0.48	0.32	209.7	0.24	0.6	20.0	25.0	55.0	clay
	-2	6.5	6.0	28.5	0	15.39	3.20	0.84	0	2.00	2.75	140.2	1.01	4.4	64.2	16.7	19.1	s.l.
	-3	6.6	3.1	2.4	0	16.17	5.40	0.51	0	0.56	1.78	95.0	1.31	8.8	21.0	36.4	42.6	clay
	-4	6.6	3.3	2.3	0	16.18	5.51	0.47	0	0.56	1.87	126.7	1.57	15.2	26.3	33.7	40.0	c.l.

[1]s.c.l. = sandy clay loam; c.l. = clay loam; s.l. = sandy loam

Table 6. Soil samples taken in Thailand, 1995-2000.

Sample no.		Sample location and description	Date
N. Ratchasima	1-6	HuayBong, TTDI Center, soil erosion demontration I_1-I_6	July 96
	7-12	HuayBong, TTDI Center, soil erosion demontration II_1-II_6	July 96
	13-18	HuayBong, TTDI Center, soil erosion demontration I_1-I_6	June 98
	19-24	Huay Bong TTDI Center, soil erosion demontration II_1-II_6	June 98
	-25	Road Paak Chong to Huay Bong, right side, severe Fe def. in cassava	July 96
	-26	Road Paak Chong to Huay Bong, left side, severe Fe def. in cassava	Apr 97
	-27	Road Paak Chong to Huay Bong, same field without Fe def. symptoms	Apr 97
	-28	FCRS-Banmai Samrong, NPK trial, 21st year, $N_0P_0K_0$	July 95
	-29	FCRS-Banmai Samrong, NPK trial, 21st year, $N_1P_0K_0$	July 95
	-30	FCRS-Banmai Samrong, NPK trial, 21st year, $N_1P_1K_0$	July 95
	-31	FCRS-Banmai Samrong, NPK trial, 21st year, $N_1P_0K_1$	July 95
	-32	FCRS-Banmai Samrong, NPK trial, 21st year, $N_1P_1K_1$	July 95
	-33	FCRS-Banmai Samrong, NPK trial, 21st year, $N_1P_1K_1$+compost	July 95
	-34	FCRS-Banmai Samrong, NPK trial, 21st year, $N_1P_1K_1$+stalks incorp.	July 95
	-35	FCRS-Banmai Samrong, NPK trial, 21st year, $N_0P_0K_0$+stalks incorp.	July 95
	-36	Daan Khun Thot, Huay Bong; TTDI plot 3/8	May 98
	-37	Daan Khun Thot, Huay Bong; TTDI plot 4	May 98
	-38	Daan Khun Thot, Huay Bong; TTDI plot 14	May 98
	-39	Daan Khun Thot, Huay Bong; TTDI plot 28	May 98
	-40	Daan Khun Thot, Huay Bong; TTDI plot 55	May 98
	-41	Daan Khun Thot, Huay Bong; TTDI plot 60	May 98
	-42	Thepharak; Mrs. Durian Fisantia to plant vetiver, white sandy soil	Aug 00
	-43	Soeng Saang, Sapphongphoot; plowed after cassava, red grey soil	Aug 00
Khon Kaen	-1	FCRC-Khon Kaen, NPK trial, 22d year, $N_0P_0K_0$	June 97
	-2	FCRC-Khon Kaen, NPK trial, 22d year, $N_1P_0K_0$	July 97
	-3	FCRC-Khon Kaen, NPK trial, 22d year, $N_1P_1K_0$	July 97
	-4	FCRC-Khon Kaen, NPK trial, 22d year, $N_1P_0K_1$	Jully 97
	-5	FCRC-Khon Kaen, NPK trial, 22d year, $N_1P_1K_1$	July 95
	-6	FCRC-Khon Kaen, NPK trial, 22d year, $N_1P_1K_1$+compost	July 97
	-7	FCRC-Khon Kaen, NPK trial, 22d year, $N_1P_1K_1$+stalks incorporated	July 97
	-8	FCRC-Khon Kaen, NPK trial, 22d year, $N_0P_0K_0$+stalks incorporated	July 97
Kalasin	-1	Sahatsakhan district; field selected for demonstration plots	Apr 97
	-2	Sahatsakhan district; FPR demonstration plots	June 97
	-3	FPR erosion trial #1 Mr. Tar Poommak 1-15cm	May 98
	-4	FPR erosion trial #2 Mrs. Joom Tong Bhutakom 1-15cm	May 98
	-5	FPR erosion trial #3 Mrs. Noopis Bhutakom 1-15 cm	May 98
	-6	FPR erosion trial #4 Mrs. Noodong Bhutakom 1-15 cm	May 98
	-7	FPR erosion trial #5 Mr. Somnuk Boonvasna 1-15 cm	May 98
	-8	FPR erosion trial #6 Mr Kunti Aimprasert 1-15 cm	May 98
	-9	FPR erosion trial #7 Mr. Tongbai Bookost 1-15 cm	May 98
	-10	FPR fert. trial #1 Mr Chainat Kumprisri 1-15 cm	May 98
	-11	FPR fert. trial #2 Mr. Thareep Sutyaka 1-15 cm	May 98
	-12	FPR fert. trial #3 Mr. Sankaya Boonvasna 1-15 cm	May 98
	-13	FPR fert. trial #4 Mrs. Tim Duan Kunt 1-15 cm	May 98
	-14	FPR fert. trial #5 Mr. Tonglai Bhutatngan 1-15 cm	May 98
	-15	FPR fert. trial #6 Mr. Ngao Boonvasna 1-15 cm	May 98
	-16	FPR fert. trial #8 Mr. Watchala Boonvasna 1-15 cm	May 98
	-17	FPR fert. trial #9 Ms. Yanong Mudsingh 1-15 cm	May 98

-18 FPR fert. trial #10 Mr. Somkuan Moonklai 1-15 cm May 98

Table 6. Soil samples taken in Thailand, 1996-2000. (continued)

Sample no.		Sample location and description	Date
Kalasin	-19	Variety trial #1 Mr. Sumniang Soommart 1-15 cm	May 98
	-20	Variety trial #2 Mrs Sonjai Bhutakom 1-15 cm	May 98
	-21	Variety trial #3 Mr. Tongmuan Bhtakom 1-15 cm	May 98
	-22	Variety trial #4 Mrs. Rabiat Prasertsung 1-15 cm	May 98
	-23	Variety trial #5 Mr. Somsark Bhungamdao 1-15 cm	May 98
	-24	Variety trial #6 Mr. Jarun Booncharoen 1-15 cm	May 98
	-25	Variety trial #7 Mrs. Tongyoon Bhutongsri 1-15 cm	May 98
	-26	Variety trial #8 Mrs. Nuanlaat Chaikummi 1-15 cm	May 98
	-27	FPR erosion trial #1 Mr. Tar Poommak 15-30 cm	May 98
	-28	FPR erosion trial #1 Mr. Chainat Kumprisri 15-30 cm	May 98
	-29	FPR erosion trial #1 Mr. Sumniang Soommart 15-30 cm	May 98
	-30	Sahatsakham, Noonsawan village 3; white-red sandy soil next to gulley	Aug 00
	-31	Sahatsakham, Noonsawan village 3; white-red soil of Mr. Phong Bai	Aug 00
	-32	Sahatsakham, Noonsawaat village; white-red soil of Mrs. Tanam	Aug 00
	-33	Noonkhungsri, Khamsri village 3; sandy soil, cassava very poor	Aug 00
	-34	Noonkhungsri, Khamsri village 3; cassava with P-def symptoms, serious erosion	Aug 00
Prachinburi	-1	Kabinburi district; farmers field in Baannaa village	Apr 97
	-2	Kabinburi district, Naadii subdistrict; farmers field in Khaeng Dinso	Apr 97
	-3	Naadii, Kaengdinso, Aang Thong; Mr. Buunsong, sandy soil, poor cassava	Nov 00
	-4	Naadii, Kaengdinso, Aang Thong; Mr. Buunsong, very poor cassava with gulleys	Nov 00
	-5	Naadii, Kaengdinso, Aang Thong; Mr. Nuun Chaikhai, sandy soil, good cassava	Nov 00
	-6	Naadii, Kaengdinso, Khaw Khaat; white sandy soil with serious gulleys	Nov 00
	-7	Naadii, Kaengdinso, Khaw Khaat; very poor cassava in check plot, K def	Nov 00
	-8	Naadii, Kaengdinso, Khaw Khaat; field with severe K deficiency	Nov 00
Sra-Kaew	-1	Wang Nam Yen district, Wang Sombuun, 1 rai plot of Mrs. Daruni	Feb 98
	-2	Wang Nam Yen district, Wang Sombuun, 1 rai plot of Mr. Sawing	Feb 98

Table 7. Chemical and physical characteristics of cassava soils in Thailand, 1995-2000.

	Chemical characteristics													Physical characteristics			
		%	ppm	me/100 g				%	ppm					%			
Sample no.	pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1]
N. Ratchasima -1	7.0	0.9	14.1	0	4.84	0.96	0.30	0	0.65	0.69	42.2	0.27	8.6	57.3	15.2	27.5	s.c.l.
-2	7.7	1.3	11.9	0	10.76	1.30	0.40	0	0.58	0.73	63.0	0.39	11.3	56.0	13.9	30.0	s.c.l.
-3	7.5	0.8	12.0	0	12.85	1.73	0.33	0	0.55	0.69	71.2	0.35	10.3	54.7	16.5	28.8	s.c.l.
-4	7.1	0.8	7.0	0	4.98	0.90	0.28	0	0.70	0.40	32.5	0.35	11.4	58.6	15.2	26.2	s.c.l.
-5	7.1	0.6	8.6	0	6.32	0.93	0.24	0	0.46	0.37	31.3	0.37	13.8	59.9	15.7	24.4	s.c.l.
-6	7.1	1.0	9.5	0	5.78	1.08	0.28	0	0.57	0.63	41.4	0.34	7.2	58.6	14.5	26.9	s.c.l.
-7	7.5	1.0	24.6	0	14.22	1.08	0.42	0	0.50	0.90	52.3	0.38	13.9	49.5	20.9	29.6	s.c.l.
-8	6.9	0.6	7.9	0	4.20	0.98	0.23	0	0.63	0.37	25.6	0.28	26.0	60.2	18.1	21.7	s.c.l.
-9	7.5	0.9	11.2	0	12.97	1.18	0.36	0	0.80	0.59	44.6	0.38	14.5	52.4	18.2	29.4	s.c.l.
-10	7.6	0.9	16.6	0	13.39	1.08	0.35	0	0.55	0.58	56.0	0.38	9.7	55.7	15.3	29.0	s.c.l.
-11	7.6	1.0	13.4	0	9.66	1.17	0.38	0	0.61	0.57	49.6	0.33	12.6	57.1	16.5	26.4	s.c.l.
-12	7.6	0.8	12.3	0	11.34	1.17	0.31	0	0.66	0.51	44.2	0.34	10.0	55.6	15.3	29.1	s.c.l.
-Av	**7.35**	**0.88**	**12.4**	**0**	**9.28**	**1.86**	**0.32**	**0**	**0.60**	**0.59**	**46.2**	**0.35**	**12.4**	**56.3**	**16.3**	**27.4**	**s.c.l.**
-13	6.2	1.1	9.2	0	3.75	0.88	0.26	0	0.45	0.51	39.7	0.34	7.2	59.6	15.1	25.3	s.c.l.
-14	7.0	1.1	11.9	0	9.80	1.25	0.45	0	0.49	0.53	57.1	0.46	9.4	56.7	14.0	29.3	s.c.l.
-15	7.0	1.0	7.3	0	4.84	1.05	0.30	0	0.35	0.42	37.3	0.31	7.2	61.0	13.5	25.5	s.c.l.
-16	6.1	0.9	5.7	0	2.50	0.71	0.34	0	0.94	0.29	21.9	0.18	6.5	61.2	16.0	22.8	s.c.l.
-17	7.0	1.1	8.9	0	6.09	0.97	0.40	0	0.54	0.49	38.1	0.32	8.7	58.5	16.1	25.4	s.c.l.
-18	6.9	1.2	9.6	0	4.12	0.96	0.36	0	0.36	0.65	36.9	0.27	6.4	61.2	13.5	25.3	s.c.l.
-19	7.6	1.2	16.2	0	13.76	1.06	0.39	0	0.43	0.83	59.4	0.31	7.3	53.2	17.4	29.4	s.c.l.
-20	7.3	0.8	16.2	0	3.62	0.67	0.29	0	0.35	0.26	22.4	0.23	32.2	60.9	18.8	20.3	s.c.l.
-21	7.6	1.1	14.0	0	11.50	1.09	0.40	0	0.47	0.71	67.9	0.34	11.6	51.6	17.8	30.6	s.c.l.
-22	7.5	1.0	9.6	0	7.14	0.88	0.31	0	0.43	0.47	40.7	0.31	7.6	54.1	17.8	28.1	s.c.l.
-23	7.4	1.1	9.8	0	6.03	0.90	0.35	0	0.36	1.17	40.1	0.32	11.0	55.7	18.9	25.4	s.c.l.
-24	7.5	1.2	10.3	0	10.16	1.12	0.38	0	0.34	0.65	54.2	0.32	12.5	53.1	17.7	29.2	s.c.l.
Av.	**7.09**	**1.07**	**10.7**	**0**	**6.94**	**0.96**	**0.35**	**0**	**0.46**	**0.58**	**43.0**	**0.31**	**10.6**	**57.2**	**16.4**	**26.4**	**s.c.l.**
-25	7.6	4.7	7.5	0	58.2	4.51	0.98	0	0.64	0.07	0.3	0.12	0.4	11.9	25.9	62.2	clay
-26	7.4	4.5	13.2	0	43.72	2.17	0.50	0	0.80	0.02	0.9	0.15	0.3	17.9	22.3	52.8	clay
-27	7.6	4.8	15.6	0	50.98	2.65	0.69	0	0.76	0.03	1.1	0.05	0.3	17.0	26.9	56.1	clay

[1] s.c.l. = sandy clay loam

Table 7. Chemical and physical characteristics of cassava soil in Thailand, 1995-2000. (continued)

Sample no.		pH	% OM	ppm P	me/100 g Al	Ca	Mg	K	% Al	ppm B	Zn	Mn	Cu	Fe	% Sand	Silt	Clay	Texture[1)]
N. Ratchasima	-28	7.1	1.5	41.4	0	5.40	0.80	0.32	0	0.23	2.15	34.9	0.59	6.0	52.4	20.7	26.9	s.c.l.
	-29	6.3	1.4	36.7	0	4.65	0.76	0.25	0	0.22	2.05	30.3	0.63	5.9	52.2	23.4	24.4	s.c.l.
	-30	6.2	1.3	56.0	0	4.41	0.69	0.25	0	0.26	2.93	37.4	0.79	8.6	52.6	23.2	24.2	s.c.l.
	-31	6.5	1.3	25.1	0	4.25	0.68	0.33	0	0.23	0.60	35.4	0.34	5.7	51.7	25.8	22.5	s.c.l.
	-32	6.0	1.6	54.0	0	4.05	0.74	0.33	0	0.30	0.70	36.6	0.39	7.8	51.6	24.5	23.8	s.c.l.
	-33	7.4	2.2	176.0	0	6.12	0.67	0.35	0	0.46	22.10	49.0	4.41	16.9	51.9	23.0	25.1	s.c.l.
	-34	7.1	1.9	46.6	0	6.30	0.96	0.37	0	0.37	1.47	37.1	0.56	6.3	50.1	23.4	26.5	s.c.l.
	-35	7.0	1.6	49.3	0	4.52	0.79	0.35	0	0.32	2.21	33.0	0.57	6.9	56.5	19.6	23.9	s.c.l.
	-36	7.5	0.99	15.6	0	5.44	0.69	0.21	0	0.53	0.54	40.9	0.31	15.9	62.0	13.8	24.2	s.c.l.
	-37	7.5	0.71	35.3	0	13.13	0.99	0.34	0	0.57	0.61	63.8	0.24	8.0	65.8	8.7	25.5	s.c.l.
	-38	7.7	1.80	15.5	0	16.48	1.20	0.64	0	0.82	0.98	72.9	0.22	4.1	39.0	24.0	37.0	c.l.
	-39	7.5	0.94	77.8	0	8.86	0.58	0.60	0	0.57	0.81	63.1	0.30	11.2	58.3	16.3	25.4	s.c.l.
	-40	7.5	0.45	6.4	0	5.07	0.71	0.25	0	0.47	0.46	48.2	0.31	12.4	60.8	11.2	28.0	s.c.l.
	-41	7.5	0.65	33.7	0	6.15	0.54	0.41	0	0.53	0.55	51.9	0.31	11.8	60.8	15.0	24.2	s.c.l.
	-42	5.5	0.58	30.0	0	1.17	0.23	0.09	0	0.36	1.44	31.3	0.18	2.6	77.7	10.9	11.4	s.l.
	-43	5.5	0.95	20.0	0	1.15	0.45	0.11	0	0.36	1.02	20.3	0.22	5.1	75.1	12.2	12.7	s.l.
Khon Kaen	-1	4.8	0.5	8.4	0.52	0.60	0.24	0.04	37	0.82	0.08	17.8	0.16	4.2	65.5	12.3	22.2	s.c.l.
	-2	4.2	0.6	6.8	0.83	0.30	0.17	0.04	62	-	-	-	-	-	-	-	-	-
	-3	4.3	0.5	54.8	0.73	0.40	0.18	0.03	54	-	-	-	-	-	-	-	-	-
	-4	4.5	0.6	5.5	0.62	0.30	0.17	0.06	54	-	-	-	-	-	-	-	-	-
	-5	4.4	0.6	46.0	0.62	0.30	0.16	0.06	54	0.41	0.14	6.7	0.19	6.1	-	-	-	-
	-6	6.7	1.3	241.0	0	3.27	0.47	0.16	0	0.69	16.88	37.7	4.76	24.3	-	-	-	-
	-7	5.3	0.8	46.0	0.25	0.80	0.32	0.09	17	0.46	0.65	22.8	0.37	6.6	-	-	-	-
	-8	5.5	0.5	13.3	0.10	0.90	0.31	0.04	7	0.39	1.21	18.2	0.61	7.4	-	-	-	-

[1)]s.c.l. = sandy clay loam; s.l. = sandy loam

Table 7. Chemical and physical characteristics of cassava soil in Thailand, 1995-2000. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Kalasin	-1	5.4	0.48	3.2	0.10	0.64	0.32	0.06	9	0.39	0.36	26.9	0.36	5.5	-	-	-	-
	-2	6.9	0.48	12.8	0	0.86	0.21	0.10	0	0.44	0.64	23.4	0.25	3.5	71.9	13.5	14.6	s.l.
	-3	5.4	0.17	3.2	0.10	0.83	0.27	0.10	8	0.63	0.45	5.7	0.24	8.3	66.0	17.5	16.5	s.l.
	-4	5.5	0.18	2.7	0.05	1.19	0.27	0.10	3	1.30	0.82	15.9	0.22	6.9	70.9	12.5	16.6	s.l.
	-5	5.5	0	5.3	0.05	0.46	0.15	0.07	7	0.38	0.58	4.3	0.29	15.5	68.8	14.7	16.5	s.l.
	-6	5.7	0.04	4.7	0.05	0.79	0.25	0.12	4	0.45	0.57	51.0	0.26	8.9	63.5	20.0	16.5	s.l.
	-7	5.7	0.37	3.6	0.05	1.64	0.40	0.19	2	0.92	0.60	24.4	0.44	17.4	67.1	16.4	16.5	s.l.
	-8	5.7	0	4.4	0.05	0.57	0.22	0.09	5	0.35	0.93	42.6	0.26	7.3	71.0	13.7	15.3	s.l.
	-9	6.0	0.03	6.0	0	0.32	0.11	0.09	0	0.58	0.38	20.8	0.28	10.3	55.9	26.3	17.8	s.l.
	-10	5.7	0.11	8.9	0.05	0.50	0.12	0.08	7	0.47	0.75	7.8	0.25	41.6	63.4	16.3	20.3	s.l.
	-11	5.7	0.24	4.0	0.05	1.00	0.21	0.08	4	0.62	0.70	18.7	0.24	14.6	61.0	22.5	16.5	s.l.
	-12	5.6	0.34	3.6	0.05	1.18	0.36	0.08	3	0.48	0.63	35.8	0.53	7.3	67.1	14.8	18.1	s.l.
	-13	5.6	0.14	13.7	0.05	0.83	021	0.12	4	0.57	0.81	35.9	0.34	14.1	71.0	13.4	15.6	s.l.
	-14	5.8	0.21	3.6	0.05	0.93	0.50	0.15	3	0.83	0.37	22.6	0.27	14.1	55.7	26.1	18.2	s.l.
	-15	5.5	0.54	3.3	0.05	1.77	0.68	0.22	2	0.64	0.76	28.7	0.27	14.9	63.3	16.0	20.7	s.c.l.
	-16	5.5	0	5.0	0.16	0.41	0.16	0.10	19	0.75	0.58	19.7	0.26	11.3	61.0	24.7	14.3	s.l.
	-17	5.7	0.09	15.7	0.10	0.64	0.19	0.05	10	0.38	0.31	25.4	0.32	19.1	69.5	14.0	16.5	s.l.
	-18	5.8	0.35	7.4	0.10	1.09	0.28	0.06	7	0.59	0.72	50.6	0.28	7.6	69.3	14.1	16.6	s.l.
	-19	5.8	0.10	2.7	0.09	1.09	0.22	0.07	6	0.56	0.43	12.0	0.23	4.2	69.3	14.1	16.6	s.l.
	-20	5.6	0.35	3.6	0.19	1.44	0.57	0.15	8	0.65	0.68	11.6	0.56	22.3	51.7	29.2	19.1	s.l.
	-21	5.7	0.19	11.4	0.16	0.96	0.31	0.09	10	0.19	0.58	31.6	0.33	31.4	-	-	-	s.l.
	-22	5.6	0.12	4.4	0.16	1.38	0.51	0.13	7	0.61	0.32	6.1	0.27	9.2	67.0	20.4	16.6	s.l.
	-23	5.5	0	7.0	0.10	0.50	0.19	0.12	11	0.28	0.97	24.3	0.26	112.4	70.9	15.0	14.1	s.l.
	-24	5.4	0.36	12.7	0.10	0.98	0.29	0.08	7	0.23	0.70	41.5	0.32	10.5	70.8	12.6	16.6	s.l.
	-25	5.4	0.48	21.8	0.08	1.37	0.34	0.08	4	0.25	1.30	65.7	0.25	7.5	68.4	13.8	17.8	s.l.
	-26	5.7	0.14	8.5	0.05	0.92	0.21	0.06	4	0.23	0.78	35.4	0.41	6.6	69.7	13.8	16.5	s.l.
	-27	5.8	0	2.0	0.05	0.63	0.15	0.06	6	0.32	0.51	5.3	0.25	7.5	69.6	13.8	16.6	s.l.
	-28	5.6	0	4.7	0.10	0.47	0.13	0.05	13	0.18	0.71	4.4	0.27	46.1	69.7	13.8	16.5	s.l.
	-29	5.8	0	1.4	0.10	1.90	0.35	0.06	4	0.20	0.27	4.9	0.27	10.0	63.4	15.0	21.6	s.l.
	-30	5.7	0.32	8.4	0	0.35	0.09	0.05	0	0.27	0.45	23.2	0.18	6.6	71.4	15.9	12.7	s.l.
	-31	5.5	0.50	8.7	0	0.68	0.29	0.07	0	0.50	0.46	46.5	0.21	7.6	65.2	21.7	13.1	s.l.

[1)]s.c.l. = sandy clay loam; s.l. = sandy loam

Table 7. Chemical and physical characteristics of cassava soil in Thailand, 1995-2000. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Kalasin	-32	5.6	0.70	8.5	0	0.91	0.34	0.06	0	0.36	0.37	19.1	0.12	4.3	72.6	15.5	11.9	s.l.
	-33	5.8	0.55	6.7	0	0.74	0.20	0.07	0	0.28	0.81	27.4	0.15	6.3	70.0	18.1	11.9	s.l.
	-34	5.9	0.50	7.2	0	0.96	0.25	0.08	0	0.23	0.61	21.5	0.11	2.4	73.9	14.2	11.9	s.l.
Prachin buri	-1	5.3	1.60	4.3	0.10	2.98	0.69	0.12	3	0.41	1.55	103.9	0.35	25.7	58.7	18.5	22.8	s.c.l.
	-2	4.8	0.94	18.4	0.52	0.55	0.23	0.11	37	0.45	0.42	5.9	0.10	23.5	68.7	9.7	21.6	s.c.l.
	-3	5.1	0.64	7.0	0.42	0.37	0.09	0.03	46	0.50	0.73	4.4	0.25	38.8	73.9	14.3	11.9	s.l.
	-4	6.2	0.42	5.6	0	0.26	0.06	0.03	0	0.33	0.22	2.7	0.13	23.1	81.4	5.0	13.6	s.l.
	-5	4.3	0.99	7.4	2.29	0.28	0.11	0.12	82	0.37	0.24	1.1	0.07	49.7	68.7	14.3	17.0	s.l.
	-6	4.6	1.02	4.3	1.25	0.33	0.09	0.05	73	0.33	0.18	2.3	0.15	52.1	67.7	19.2	13.1	s.l.
	-7	4.4	0.95	31.0	1.87	0.21	0.05	0.10	84	0.31	0.25	1.1	0.11	64.4	67.5	16.3	16.1	s.l.
	-8	4.5	1.10	8.0	1.56	0.29	0.10	0.06	78	0.32	0.27	3.1	0.08	79.2	67.7	16.3	16.1	s.l.
Sra Kaew	-1	6.6	4.50	8.4	0	22.60	8.57	0.23	0	0.56	1.01	79.8	0.43	5.9	33.3	20.3	46.4	clay
	-2	6.5	3.50	5.3	0	21.41	8.27	0.30	0	0.40	1.58	92.4	0.86	6.0	39.9	15.0	45.1	clay

[1)]s.c.l. = sandy clay loam; s.l. = sandy loam

Table 8. Soil samples taken in Vietnam, 1997-2000.

Sample no.		Sample location and description	Date
Thai Nguyen	-1	Pho Yen district, Dac Son village; FPR trial with B def. symptoms	Mar 98
	-2	Pho Yen district, Dac Son village; FPR fert. trial Mr. Toan, T_1 KM95-3+KM60	June 98
	-3	Pho Yen district, Dac Son village; FPR erosion trial Mrs. Doan T_1	June 98
	-4	Pho Yen district, Minh Duc village; FPR erosion trial of Mr.Hung	Apr 99
	-5	Pho Yen district, Minh Duc village; FPR fert. trial Mr. Nguyen Van Hai, check	May 00
Tuyen Quang	-1	Son Duong, Thuong Am; good soil on hill with eroded sediments, SC205	Sept 99
	-2	Son Duong, Thuong Am; poor soil on same hill with SC205	Sept 99
	-3	Son Duong, Thuong Am; FPR fert. trial check plot on slope with Vinh Phu	May 00
	-4	First FSP site, SC205 with *Flemingia* hedgerows, poor cassava	Aug 00
Phu Tho	-1	Thanh Ba, Kieu Tung; FPR erosion trial, Mr. Quet, T_2 mono cassava, no fert.	June 98
	-2	Thanh Ba, Kieu Tung; FPR erosion trial, Mr. Quet, T_3 C+P, with fert.	June 98
	-3	Thanh Ba, Kieu Tung; FPR erosion trial, Mrs. Ngan, T_6 C+P just above vetiver	June 98
	-4	Thanh Ba, Kieu Tung; FPR erosion trial, Mr. Ngan, T_6 C+P in plot below vetiver	June 98
	-5	Thanh Ba, Kieu Tung; FPR fertilizer trial, Mr. Fu, check plot	June 98
	-6	Thanh Ba, Kieu Tung; FPR fert. trial, Mr. Bui Xuan Nghiem, check plot	May 00
	-7	Phu Ninh, Thong Nhat; yellow-red soil on 20% slope, future FPR trials	Sept 99
	-8	Phu Ninh, Thong Nhat; farmer's field with *Tephrosia* hedgerows	May 00
Ha Tay	-1	Thach That district, Thach Hoa; field of Mrs. Sau	Sept 99
	-2	Thach That district, Thach Hoa; check plot in fertilizer trial Mrs. Sau	May 00
	-3	Thach That district, Thach Hoa; yellow soil on steep slope, future erosion trial	Sept 99
	-4	Chiong Mi district, Tran Phu; yellow-red soil in cassava fields	Sept 99
	-5	Chiong Mi district, Tran Phu; FPR variety trial Mr. Nguyen Van Xiem	May 00
Hoa Binh	-1	Luong Son district, Dong Rang village; FPR trial with B. def. symptoms	Mar 98
	-2	Luong Son, Dong Rang; FPR erosion trial Mr. NguyenVan Tho, T_1	June 98
	-3	Luong Son, Dong Rang; FPR erosion trial Mrs. Bui Thi Ban, T_1, poor cassava	June 98
	-4	Luong Son, Dong Rang; FPR erosion trial Mrs. Bui Thi Ban, T_1, with vetiver	June 98
	-5	Luong Son, Dong Rang; Mrs. Bui Thi Ban-T_2 with vetiver+fert.	June 98
Hue	-1	Hue University; cassava varietal evaluation	June 98
	-2	Hue, Univ. Research Station near Hue city; intercropping trial, Av. 3 Reps	Apr 99
	-3	A-Luoi district, Hong Van commune; field with *Tephrosia*+pineapple hedgerows	Apr 99
	-4	A-Luoi district, Hong Bac 1 commune; red soil with *Tephrosia*+pineapple hedgerows	Apr 99
	-5	A-Luoi district, Hong Ha village; cassava field, sandy loam soil	Mar 98
	-6	A-Luoi district, Hong Ha village; hill side reforested with *Cassia mangium*	Nov 98
	-7	A-Luoi district, Hong Ha village; cassava garden with yellow sandy loam soil	Nov 98
	-8	A-Luoi district, Hong Ha village; variety trial, red-yellow clay	Apr 99
	-9	A-Luoi district, Hong Ha; FPR fert. trial Mrs. Ram, Av. 3 check plots	May 00
	-10	A-Luoi, Hong Ha; cassava field on 40% slope with hedgerows of Mr. Thao	May 00
	-11	A-Luoi, Hong Ha; erosion trial Mr. Dow; yellow sandy soil with K deficiency	May 00
	-12	A-Luoi, Hong Ha; field of 50% slope next to Mr. Thao	Aug 00
	-13	Nam Dong district, Xuan Loc village; slash/burn field of cassava	Mar 98
	-14	Nam Dong, Huang Hiu; cassava field with N+K deficiencies in Nep variety	May 00
Khanh Hoa	-1	Suai Cat, Khanh Hoa Extension station; Regional trial	June 98
	-2	Suai Cat, Khanh Hoa Extension station; mulliplication field	June 98

Table 8. Soil samples taken in Vietnam, 1997-2000. (continued)

Sample no.		Sample location and description	Date
Lam Dong	-1	Dalat; mottled clay loam from steep embankment	June 98
	-2	Dalat; yellow clay loam from vegetable nursery	June 98
	-3	Duc Trong, between Phu Hai and Di Linh; grey soil, maize field	June 98
	-4	Di Linh; south of Di Linh; red soil in new coffee field	June 98
Dong Nai	1-12	Hung Loc Center; NPK trial, 8th year, T_1-T_{12}	Apr 97
	13-20	Hung Loc Center; soil improvement trial, 6th year, T_1-T_9	Apr 97
	-21	Hung Loc Center; soil erosion trial, 1st year	May 97
	-22	Thong Nhat district, An Vien village; on-farm NPK trial, T_1 Av.3 Reps	July 99
Baria-Vungtau	-1	Suoi Rao, Chau Duc district; FPR fert. trial Mr. Hugnh, sandy soil+ laterite	Aug 00
	-2	Chau Duc district, sample taken by Mrs. Sam	Aug 00
Ho Chi Minh	-1	Thu Duc, Univ.; experim field, Av. 4 Reps $N_0P_0K_0$ of fertilizer trial	July 99
	-2	Thu Duc Univ.; experim. field, Av. 3 Reps $N_0P_0K_0$ of fertilizer trial	Aug 00
	-3	Thu Duc Univ.; sample 1 taken by Mrs Sam	Aug 00
Binh Phuoc	-1	Dong Xoai, Vedan factory; red-clay soil, variety trial	Sept 99
Tay Ninh	-1	Tay Ninh; grey sandy soil in T_1 of on-farm fertilizer trial	Sept 99

Table 9. Chemical and physical characteristics of cassava soils in Vietnam, 1997-2000.

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture
Thai Nguyen	-1	4.1	1.8	19.2	1.04	0.80	0.31	0.44	40	0.27	0.75	6.1	0.22	55.2	51.5	27.5	21.0	s.c.l.
	-2	4.8	1.4	228.0	0.43	3.24	0.30	0.11	11	1.80	1.35	14.4	0.40	78.6	66.2	16.9	16.9	s.l.
	-3	4.7	2.3	60.6	0.87	2.50	0.40	0.38	21	1.74	1.93	20.2	0.42	62.8	45.7	35.2	19.1	loam
	-4	4.1	1.7	19.6	2.29	0.61	0.12	0.10	73	0.47	0.47	4.3	0.38	116.7	57.4	16.4	26.2	s.c.l.
	-5	5.1	0.9	11.2	0.73	0.64	0.16	0.15	43	0.50	0.71	6.2	0.29	47.3	71.4	15.5	13.1	s.l.
Tuyen Quang	-1	5.5	3.4	1.6	0.31	7.57	3.35	0.18	3	0.85	1.97	355.5	0.43	16.8	38.6	26.1	35.2	c.l.
	-2	5.7	2.4	1.3	0	6.18	1.75	0.10	0	0.85	2.91	225.5	0.72	15.1	40.5	29.7	29.8	c.l.
	-3	5.4	3.9	1.9	0.21	9.33	4.84	0.17	1	0.65	1.89	283.0	0.40	16.8	31.9	28.8	39.2	c.l.
	-4	4.9	2.4	1.7	1.98	0.83	0.48	0.11	58	0.21	1.23	25.6	1.06	21.4	-	-	-	-
Phu Tho	-1	4.2	2.1	15.0	5.41	1.11	0.19	0.09	80	1.34	1.16	13.0	0.68	70.7	21.2	17.9	60.9	clay
	-2	4.2	1.9	6.1	5.30	0.88	0.13	0.10	83	1.22	0.70	8.3	0.57	47.5	17.0	20.0	63.0	clay
	-3	4.2	2.4	12.0	5.10	1.33	0.18	0.09	76	1.16	0.97	10.8	0.46	58.2	22.3	17.9	57.8	clay
	-4	4.2	1.7	4.9	5.20	1.07	0.18	0.09	80	1.27	0.95	10.0	0.51	54.5	21.8	17.9	60.3	clay
	-5	4.1	2.3	6.7	5.00	1.11	0.18	0.08	78	0.94	0.98	10.9	0.37	83.3	29.6	27.7	42.7	clay
	-6	4.3	2.3	2.3	7.24	0.73	0.20	0.10	87	0.45	1.18	8.9	0.55	59.7	24.8	20.9	54.3	clay
	-7	4.3	1.4	11.5	2.60	0.44	0.07	0.06	82	0.87	0.59	6.0	0.96	21.8	35.7	11.8	52.4	clay
	-8	4.5	1.6	7.8	2.08	1.14	0.15	0.14	59	0.50	0.74	9.5	0.78	23.2	37.0	8.8	54.2	clay
Ha Tay	-1	4.4	4.9	38.2	2.91	1.85	0.33	1.89	42	0.99	1.86	22.1	0.94	23.0	15.7	23.5	60.8	clay
	-2	4.6	1.8	36.7	2.08	0.53	0.14	0.13	72	0.57	1.59	52.6	2.48	33.7	44.7	17.7	37.6	c.l.
	-3	3.4	4.5	3.1	8.20	0.18	0.06	1.82	80	0.75	0.79	2.0	2.37	55.6	21.1	27.2	51.6	clay
	-4	4.5	2.9	9.1	2.60	1.81	0.58	0.29	49	0.86	1.67	22.5	0.96	43.6	22.3	23.5	54.3	clay
	-5	4.2	1.8	6.9	2.08	0.59	0.26	0.41	62	0.52	1.02	41.0	0.96	31.9	35.2	14.0	50.8	clay

s.c.l. = sandy clay loam; c.l. = clay loam.

Table 9. Chemical and physical characteristics of cassava soils in Vietnam, 1997-2000. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Hoa Binh	-1	5.0	5.0	46.2	0.31	2.20	1.80	0.18	7	0.41	1.52	222.1	6.11	19.6	20.2	23.1	56.7	clay
	-2	4.7	4.7	2.6	1.35	1.29	0.60	0.18	39	1.90	1.94	442.3	7.65	19.5	11.3	35.6	54.1	clay
	-3	4.7	4.3	2.2	0.99	0.96	0.49	0.08	39	1.68	2.14	586.8	8.02	22.2	22.4	22.1	55.5	clay
	-4	4.8	4.3	4.5	0.54	1.62	0.95	0.16	16	1.63	2.25	549.4	7.38	17.4	21.2	22.2	56.6	clay
	-5	4.9	4.6	5.7	0.42	2.00	1.15	0.20	11	1.13	2.72	457.0	7.39	14.7	-	-	-	-
Hue	-1	6.3	1.9	195.0	0	14.03	0.52	0.41	0	0.52	17.66	37.1	1.94	17.1	46.2	27.5	26.3	s.c.l.
	-2	5.0	0.2	38.6	0.10	0.55	0.09	0.06	12	0.53	0.61	5.0	0.48	86.4	65.0	17.2	17.8	s.l.
	-3	4.4	3.2	7.6	1.98	0.47	0.29	0.16	68	0.74	0.92	4.9	0.50	131.8	47.0	28.7	24.3	s.c.l.
	-4	4.0	4.9	4.0	4.16	0.30	0.15	0.16	87	0.94	0.75	4.1	0.46	116.7	12.4	26.8	60.8	clay
	-5	4.6	2.0	2.6	1.25	0.21	0.23	0.08	71	0.35	0.62	21.8	1.22	73.3	44.0	28.1	27.9	c.l.
	-6	4.7	1.9	2.4	1.46	0.57	0.25	0.08	62	0.69	2.60	10.0	0.68	172.0	34.2	34.0	31.8	c.l.
	-7	4.6	2.1	2.9	1.72	0.41	0.18	0.09	72	1.20	0.91	31.0	1.41	105.5	31.7	34.0	34.3	c.l.
	-8	4.5	2.6	1.7	2.70	0.35	0.20	0.08	81	0.68	2.02	64.4	1.76	69.6	47.8	15.0	37.2	s.c.
	-9	4.8	1.9	3.2	2.18	0.42	0.29	0.12	72	0.52	1.14	25.0	1.08	89.6	43.1	28.8	28.1	c.l.
	-10	4.3	4.8	2.6	5.91	0.19	0.22	0.16	91	0.71	1.62	4.4	1.93	200.7	30.6	26.6	42.8	clay
	-11	4.6	2.6	1.6	2.61	0.72	0.73	0.17	62	0.65	6.10	55.7	1.46	53.3	48.0	21.7	30.3	s.c.l.
	-12	4.4	3.2	2.6	3.80	0.25	0.18	0.21	86	0.35	1.54	7.8	1.11	143.4	-	-	-	-
	-13	4.4	1.6	2.8	1.35	0.12	0.14	0.06	81	0.25	0.50	1.6	0.55	105.2	65.4	11.8	22.8	s.c.l.
	-14	4.4	2.4	4.1	3.02	0.14	0.10	0.09	90	0.52	0.71	6.4	0.54	90.5	30.0	36.6	33.4	c.l.
Khanh Hoa	-1	5.3	1.4	68.0	0.22	4.68	0.91	0.26	4	0.27	3.00	118.9	1.73	102.8	29.1	36.7	34.2	c.l.
	-2	4.8	1.0	73.3	0.73	1.60	0.41	0.15	25	0.22	1.45	14.5	0.61	139.4	57.6	21.2	21.2	s.c.l.
Lam Dong	-1	5.3	0.0	2.4	3.12	0.10	0.05	0.12	92	0.16	0.17	0.1	0.76	5.9	16.6	40.7	42.7	c.l.
	-2	4.9	0.0	1.9	2.50	0.34	0.09	0.05	84	0.20	0.08	0.4	1.18	13.9	17.7	43.3	39.0	si.c.l.
	-3	4.9	3.6	210.0	0.98	11.51	7.02	0.54	5	0.50	2.19	48.7	0.38	32.3	17.2	46.8	36.0	si.c.l.
	-4	5.0	1.9	4.4	0.16	0.50	0.30	0.10	15	0.40	0.53	4.9	0.57	15.8	31.2	20.5	48.3	clay

s.l. = sandy loam; c.l. = clay loam; s.c.l. = sandy clay loam; si.c.l. = silty clay loam

Table 9. Chemical and physical characteristics of cassava soils in Vietnam, 1997-2000. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1]
Dong Nai	-1	4.7	3.0	14.7	1.66	1.00	0.61	0.21	48	-	-	-	-	-	-	-	-	-
	-2	4.3	2.9	38.4	2.18	0.90	0.32	0.20	60	-	-	-	-	-	-	-	-	-
	-3	4.3	3.1	33.7	1.98	0.90	0.31	0.17	59	-	-	-	-	-	-	-	-	-
	-4	4.4	2.5	28.0	1.77	1.10	0.35	0.16	52	-	-	-	-	-	-	-	-	-
	-5	4.3	2.9	38.4	1.98	1.20	0.37	0.19	53	-	-	-	-	-	-	-	-	-
	-6	4.4	3.0	15.2	1.35	1.50	0.64	0.25	36	-	-	-	-	-	-	-	-	-
	-7	4.3	2.7	21.5	2.18	0.84	0.35	0.22	61	-	-	-	-	-	-	-	-	-
	-8	4.4	2.9	39.6	1.66	1.60	0.45	0.19	43	-	-	-	-	-	-	-	-	-
	-9	4.3	2.7	26.5	2.18	0.95	0.39	0.12	60	-	-	-	-	-	-	-	-	-
	-10	4.4	2.6	25.7	1.77	1.30	0.35	0.18	49	-	-	-	-	-	-	-	-	-
	-11	4.4	2.6	23.4	1.98	1.10	0.37	0.25	53	-	-	-	-	-	-	-	-	-
	-12	4.3	3.0	37.1	1.66	1.50	0.47	0.24	43	0.30	1.18	105.9	0.80	16.7	11.1	11.2	77.6	clay
	-13	4.6	2.5	9.5	1.04	1.70	0.58	0.24	29	0.24	1.60	125.1	0.90	16.0	-	-	-	-
	-14	4.6	2.7	14.4	1.98	1.80	0.62	0.34	42	-	-	-	-	-	-	-	-	-
	-15	4.6	2.9	12.0	1.04	1.70	0.60	0.26	29	-	-	-	-	-	-	-	-	-
	-16	4.4	2.9	10.2	1.35	1.50	0.51	0.27	37	-	-	-	-	-	-	-	-	-
	-17	5.1	3.0	11.3	0.31	2.80	0.69	0.32	7	-	-	-	-	-	-	-	-	-
	-18	4.7	2.7	9.7	0.83	1.80	0.65	0.27	23	-	-	-	-	-	-	-	-	-
	-19	4.7	3.0	19.2	0.62	2.10	0.75	0.38	16	-	-	-	-	-	-	-	-	-
	-20	4.6	2.9	11.3	0.73	1.90	0.72	0.37	20	-	-	-	-	-	-	-	-	-
	-21	4.8	3.5	8.0	0.62	2.70	1.20	0.14	13	0.34	1.30	159.7	0.74	17.8	24.3	12.7	63.0	clay
	-22	4.6	1.0	8.1	0.98	0.19	0.08	0.04	76	0.52	0.50	1.4	0.45	113.5	64.1	12.4	23.3	s.c.l.
Baria-Vungtau	-1	5.3	1.8	4.0	0.62	1.46	0.78	0.10	21	0.25	0.73	65.7	0.36	22.0	59.7	25.8	14.5	s.l.
	-2	5.1	2.5	6.5	0.31	1.45	0.33	0.16	14	0.36	0.97	50.4	0.49	18.5	-	-	-	-

s.c.l. = sandy clay loam; s.l. = sandy loam; c.l. = clay loam

Table 9. Chemical and physical characteristics of cassava soils in Vietnam, 1997-2000. (continued)

		Chemical characteristics													Physical characteristics			
			%	ppm	me/100 g				%	ppm					%			
Sample no.		pH	OM	P	Al	Ca	Mg	K	Al	B	Zn	Mn	Cu	Fe	Sand	Silt	Clay	Texture[1)]
Ho Chi Minh	-1	4.7	1.1	54.9	0.42	0.57	0.14	0.09	34	0.54	2.68	2.2	2.16	215.4	64.4	16.3	19.4	s.c.l.
	-2	5.2	0.6	164.0	0.10	0.72	0.07	0.06	11	0.24	2.75	5.5	2.03	81.8	74.4	13.8	11.8	s.l.
	-3	5.5	0.6	148.0	-	1.54	0.08	0.15	-	1.35	3.22	7.2	2.39	91.3	73.1	10.8	16.1	s.l.
Binh Phuoc	-1	4.7	4.2	53.0	3.33	0.51	0.10	0.10	82	0.93	0.67	38.4	0.37	19.4	17.0	17.1	65.9	clay
Tay Ninh	-1	4.9	0.9	57.3	0.83	0.64	0.15	0.11	48	0.92	0.47	12.9	0.27	60.6	61.2	23.1	15.7	s.l.

s.c.l. = sandy clay loam; s.l. = sandy loam; c.l. = clay loam

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