PN-ABE-090

Cassava Breeding and Agronomy Research in Asia

Proceedings of a Regional Workshop Held in Rayong, Thailand, Oct. 26-28, 1987.

Organized by Centro Internacional de Agricultura Tropical (CIAT) with financial support from the United Nations Development Programme (UNDP) and the cooperation of the Department of Agriculture of Thailand

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Information and conclusions reported herein do not necessarily reflect the position of any of the aforementioned entities.

PN-ABE-090
64336

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Technical Editors : R. H. Howeler and K. Kawano

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Cover photo : Kazuo Kawano
Cassava harvest at Umas Jaya Farm in South Sumatra.

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Bangkhen, Bangkok, Thailand

October 1988
Print order : 400 copies

CIAT (Centro Internacional de Agricultura Tropical) 1988. Cassava breeding and agronomy research in Asia. Proceedings of a workshop held in Thailand, Oct 26 – 28, 1987. Howeler, R.H. and K. Kawano (Eds), Bangkok, Thailand. 350 p.

I Cassava Asia – Breeding – Agronomy – Congresses, Conferences, etc.
II Howeler, R.H. and K. Kawano. III Centro Internacional de Agricultura Tropical IV United Nations Development Programme V Thailand, Department of Agriculture

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WELCOMING ADDRESS

Dr. Vichitr Benjasil
Director
Field Crops Research Institute,
Department of Agriculture,
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In the name of the Department of Agriculture of the Thai Government I wish to welcome to Thailand all the participants of this Workshop on Cassava Breeding and Agronomy Research in Asia. In collaboration with the Regional Cassava Program of the Centro Internacional de Agricultura Tropical (CIAT), the Department of Agriculture has helped to organize this workshop in order to establish closer links and collaborative research with breeders and agronomists of the various cassava producing countries in southern Asia.

During this week we hope to share with each other the experience we have gained in cassava research, both in the development of new and higher yielding varieties, as well as better cultural practices, in order to improve the efficiency of our research effort. While we all know that cassava is one of the most efficient producers of carbohydrates and is an extremely important crop for many farmers, especially in the more marginal areas, it is also well known that most governments in Asia have given priority to research on rice, and that funding for cassava research is generally very limited. Thus, under these circumstances, it is not only desirable but absolutely necessary to pool our combined knowledge and experience of this crop in order to speed up its development, not only as a subsistence staple but as a highly productive and highly versatile crop that has a multitude of end uses, both for human and animal nutrition as well as for industrial purposes.

There remains a challenge for both breeders and agronomists, to develop better varieties and management practices for cassava cultivation in order to increase the productivity and the standard of living of the poorest sector of the population-our cassava farmers. This task will be more efficiently done and more easily accomplished through the collaboration with other national cassava programs as well as with international institutes like CIAT. I therefore hope that the deliberations during this week will be fruitful and will lead to the establishment of a cassava research network in order to increase cassava productivity in the region and improve the lives of our peoples.

CIAT CASSAVA PROGRAM AND ITS ROLE IN ASIA

Kazuo Kawano[1]

CGIAR Centers

The 1950s and 1960s were a period of widespread public and scientific concern that the rapidly growing population in less developed countries would soon outstrip the world's capacity to provide food. With the initiative of the Rockefeller and Ford Foundations, which had ample experience in cooperating with national agricultural research programs of less developed countries, the International Rice Research Institute (IRRI) was established with the cooperation of the Philippine government in the early 1960s. The Rockefeller Foundation's cooperative program in Mexico evolved about the same time into the establishment of CIMMYT, the International Maize and Wheat Improvement Center. The common objective of the research efforts of these two institutes was to improve the quantity and quality of food production in developing countries. The basic strategy was to apply scientific research that had been successful in temperate zone food production to the tropical zone. Concentration on key crop commodities and an interdisciplinary crop improvement approach were the style of this new research endeavor. The advantage of international centers in collecting, evaluating and distributing world germplasm resources and offering communication and training opportunities to national programs soon became obvious.

The spectacular success of new high-yielding strains of rice and wheat adapted to high input cultural conditions not only increased the production of major food commodities in many tropical countries, but also convinced administrators of both developed and developing countries of the benefit of investing in tropical agriculture research. This led to the establishment of the International Institute of Tropical Agriculture (IITA) in Nigeria and the Centro Internacional de Agricultura Tropical (CIAT) in Colombia in the late 1960s. The Consultative Group on International Agricultural Research (CGIAR) was established in 1971 to coordinate the management of these international agriculture research centers around the world. CGIAR is an association of countries, international and regional organizations, and private foundations. The international agriculture research centers under the auspices of CGIAR, which have now grown into 13 centers, are commonly called CGIAR centers (Figure 1).

While much of the original research strategy is still valid, the CGIAR centers have increasingly identified problems which could not be solved simply by applying production technology developed in temperate countries to the tropics. The basic difficulty of tropical agriculture stems from the tremendous variability in crop germplasm, in pests, and in the production systems, as well as the highly complex edapho-climatic and socio-economic situations

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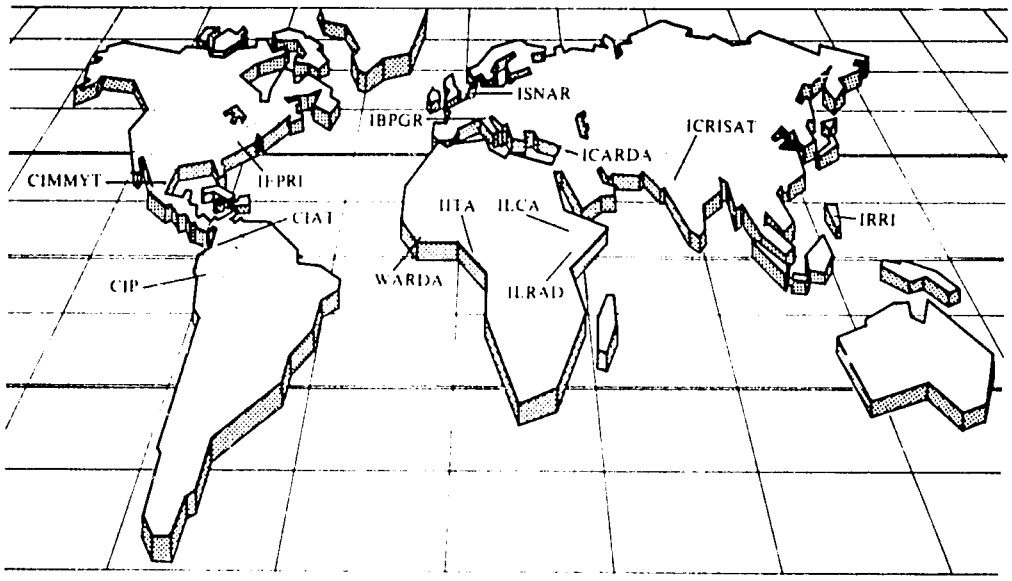

Figure 1. CGIAR Centers in 1986.

in which each farmer conducts his production. "Low-input technology", "Sustainability" "Social equity" or "Decentralization of crop improvement" are the key words in these days, especially among the CGIAR centers whose research commodities are small farmers' crops, such as beans and cassava of CIAT. The final objectives of the endeavor rest on the strengthening of national programs by offering technology and information which can better be handled by international centers through international cooperation.

Cassava Program at CIAT

Cassava is one of the most efficient producers of carbohydrates in the tropics (de Vries *et al.*, 1967; Martin, 1970; Nojima and Hirose, 1977; Kawano *et al.*, 1978; Cock, 1982) and under marginal soil and rainfall conditions it is unsurpassed by other crops (Cock and Howeler, 1978). It is grown throughout the tropics by small farmers, using traditional methods of cultivation in areas with poor soils. Cassava is the fourth most important crop in terms of dietary energy produced and consumed within the tropics (Table 1). More recently, it has been used increasingly for animal feed and industrial starch. The importance and potential of cassava, however, has been largely neglected when compared with other crops, as can be seen from the distinctly small amount of resources allocated to research on this crop (Table 2).

Cassava originated in Latin America and most of its evolution took place there. It was widely distributed throughout the lowland tropics of Latin America, and before the arrival of the Europeans in the 15th century it did not exist outside this continent. However, in the post-Colombian era, the crop spread rapidly, first to Africa and later to Asia.

Germplasm variation of a crop species is richest at the center of origin and diversification of the species. Evolution of disease and pest species that thrive on a crop parallels the evolution of the crop species; thus, the number of biological yield constraints is highest in the center of crop origin and diversification (Jennings and Cock, 1977).

Table 1. Calories produced and utilized for direct human consumption within the tropics from major staples.

Crop	Calorie consumption Billions of calories per day Tropics	World	Tropics % World
Rice	924	2043	45
Sugar	311	926	33
Maize	307	600	51
Cassava	172	178	97
Sorghum	147	208	71
Millet	128	204	63
Wheat less than	100*	1877	5
Potato	54	434	12
Banana	32	44	73
Plantain	30	30	100
Sweet Potato	30	208	14

*Wheat figures are distorted by the fact that major production zones in Brazil, Mexico and India are outside the tropics and have been adjusted to account for this.

Source : FAO Food Balance Sheets 1975 – 1977.

Table 2. Research expenditure as a percentage of commodity value for various crops in Asia (excluding China and Japan) in 1959 and 1974.

Crop	Percentage of product value Expended on research 1959	1974
Cotton	0.43	0.58
Rubber	0.40	0.57
Sugarcane	0.10	0.24
Wheat	0.08	0.23
Maize	0.06	0.12
Rice	0.05	0.12
Sorghum and Millets	0.04	0.11
Pulses	0.02	0.06
Roots and Tubers	0.01	0.03

Source : R.E. Evenson (1978).

True to the theory, nearly the entire germplasm variation of cassava exists in Latin America; the African and Asian germplasm consists of a part of the Latin American germplasm and its local recombinants. A broad spectrum of diseases and pests is found in Latin America, while the number of diseases and insects is less in Africa and especially in Asia. African mosaic disease seems to be the only major disease of cassava that does not exist in Latin America.

This background makes Colombia, South America, a logical location for an international center of cassava research. Thus, a cassava program was established in the early 1970s at the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia. The importance of African mosaic disease, and the overwhelming importance of cassava to the African diet, led to the establishment in the late 1960s of the Cassava Program of the International Institute

for Tropical Agriculture (IITA) at Ibadan, Nigeria with the regional responsibility for cassava research in Africa.

The CIAT Cassava Program seeks to develop improved technologies in support of increased production efficiency and utilization of cassava. One of the cores of the new production technology will be improved germplasm having increased yield potential and tolerance to diseases, insect pests, and adverse soil and environmental conditions. Additional constraints will be minimized through the development of low-input, but sustainable management practices. Training and communication, to make the developed technology more readily available, are also important parts of the program.

Cassava in Asia

Of the new world food crops introduced into tropical Asia, cassava has become the most important on the basis of production. Nearly 40% of the world cassava is now produced in Asia (Table 3). The crop's peculiar adaptability to upland conditions, particularly where there are either soil or moisture constraints, and its multiple end-market uses, give cassava a certain malleability in adapting to different production and demand conditions. Cassava is an important food source in India, Indonesia and the Philippines, an important export crop in Thailand, and an important source of starch in all these countries. One of the dominant trends in the Asian food economy is the rising demand for livestock products and the derived demand for carbohydrate and protein sources for concentrate feeds. A large and growing domestic food market remains unexploited in most countries (Table 4).

Cassava's role in each country's agricultural economy is different, but in each case cassava can be a basis for meeting multiple policy objectives (Table 5). Cassava, because of its multiple-market potential, can play a major role as a source of income generation for small farmers in upland areas. A further advantage in satisfying growing domestic markets by increasing domestic

Table 3. Cassava production in the world and Asia.

Country	Area (million ha)	Yield (fresh, t/ha)	Production (fresh, million tons)
Thailand	1.23	16.3	20.0
Indonesia	1.50	9.7	14.5
India	0.31	18.1	5.6
China	0.25	15.7	3.9
Vietnam	0.50	6.0	3.0
Philippines	0.26	8.1	2.1
Sri Lanka	0.06	13.4	0.8
Malaysia	0.04	10.6	0.4
Total Asia	4.16	12.1	50.5
Total Africa	7.49	7.5	56.5
Total Latin-America	2.36	12.0	28.4
Total World	14.20	9.6	136.5

Source : FAO, 1986.

Table 4. Principle factors determining expansion of cassava production and utilization.

Country	Major market	Dominant constraint	Constraint factor
Thailand	Export pellets	Demand	EC export quota and price competitiveness in international markets
Indonesia	Fresh food	Demand	Relative price and availability of rice
	Starch	Supply	Infrastructure, Farm land (Java)
India	Fresh food	Demand	Relative price and availability of rice
	Starch	Supply	Infrastructure and price competitiveness, Farm land
China	Starch	Supply	Farm land, Price policy
	Export pellets	Supply	Farm land, Price policy
Philippines	Fresh food	Demand	Relative price and availability of rice
	Starch	Supply	Infrastructure and price competitiveness
Malaysia	Starch	Supply/Demand	Price competitiveness and import policy

Table 5. Potential role of cassava in agricultural policies of Asian countries.

Agricultural policy objectives	Contribution according to country					
	Thailand	Indonesia	India	China	Philippines	Malaysia
Food and nutrition policies						
a. Flexibility in rice policies		×	×			
b. Nutrition of the poor		×	×		×	
Farm income and land use						
a. Higher small-farm income in upland areas	×	×	×	×	×	×
b. Exploitation of frontier areas		×		×	×	×
Balance of payments						
a. Increased export earnings	×	×		×		
b. Import substitution		×			×	×

production is the positive impact on the balance of payments. Cassava is a major, if not the major, crop in a position to foster income growth in the upland areas of tropical Asia.

Cassava Regional Program for Asia

Compared with Africa or Latin America, cassava yields in Asia are high. Part of this is due to the significantly lower disease and insect pressure, since Asia is outside cassava's center of origin. The other factor is the more intensive cassava cropping systems found in Asia. Yet, the average yields, in general, remain far below the known potential of the crop. What still remains largely undefined is the means of achieving this high yield capacity in varying situations. National cassava research programs in Asia that have emerged over the last two decades are comparatively strong, and continued cooperation with CIAT will broaden the research basis of the national programs.

The functions of the CIAT Cassava Asian Regional Program are :

1. Distribution and utilization of CIAT's Latin-American germplasm in Asian national programs through direct cooperation.

2. Development of better cultural and soil management practices for increased cassava production and sustainable production systems in cooperation with Asian national programs.

3. Coordination between national programs and CIAT with special emphasis on training and communication.

The Green Revolution that swept the Asian continent in the late-sixties and seventies was limited to relatively well-off farmers in the irrigated areas. The next major challenge is to raise the productivity and incomes of small farmers in the upland areas. Dealing with a small farmers' crop, grown mostly under low-input conditions, progress may be slower, yet this is one inevitable research commitment towards greater social equity.

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CASSAVA BREEDING IN THAILAND

Sophon Sinthuprama[1/]
Charn Tiraporn[1/]
Watana Watananonta[1/]

Introduction

Cassava is considered as one of the most drought resistant crops in the tropics. In Thailand cassava is one of the most important economic crops eventhough it is not a staple food of the Thai people. It is a cash crop produced by a large number of small farmers and nearly all the production is processed into animal feed components or starch. Next only to rice, cassava is Thailand's second major export crop, making Thailand the principal cassava exporting country in the world. In 1986 Thailand exported 6.6 million tons of cassava products, earning US$ 723 million. About 95% of the total production is exported, mainly as pellets (90%), followed by chips (6%) and starch (4%). The most important market is the European Economic Community, amounting to 5.3 million tons in 1986. Domestic use is only about 5% of the total production, and is utilized as starch for industrial use, and as pellets for the production of animal feed.

In Thailand cassava occupies the third largest area, next to rice and corn (Table 1). The area under cassava increased from about 328,000 ha in 1972/73 to over 1.3 million ha in 1982/83. The major cassava area is in the Northeast region amounting to 61% of the total area, followed by the Central Plain region with 33%, and the North region, with 6%. The

Table 1. Planted area and production of major field crops in Thailand, 1985/1986.

Crop	Planted area (000 ha)	Production (000 ton)	Farm value (mil. $)
Rice	9,510	17,930	1,599
Corn	1,980	4,934	339
Cassava	1,240	15,255*	457
Sugar cane	551	24,093*	220
Mungbean	548	323	82
Sorghum	310	404	28
Soybean	244	309	76
Peanut	125	171	47

* Fresh weight.

Source: Office of Agricultural Economics, 1986.

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area under cassava quadripled during the ten years with an annual growth rate of 16%. Total cassava production also increased about four times in the same period, from 4 million tons of fresh root in 1973 to about 19.3 million tons in 1983, corresponding to an annual growth rate as high as of 19.3% (Table 2). The increase was almost entirely due to an increase in planted area. The minor fluctuations from year to year are mainly caused by price variations which in turn are due to the foreign market situation. During this period, there was no consistent increase in yield, which ranged from 11 to 15 t/ha, with an overall national average yield of 13.5 t/ha (Table 2).

Table 2. Cassava planted area, production and average yield in Thailand.

Year	Planted area (000 ha)	Production (000 t)	Yield (t/ha)
1972/73	328	3,974	12.12
1973/74	432	5,668	13.12
1974/75	473	6,240	13.19
1975/76	593	8,100	13.65
1976/77	679	10,138	14.93
1977/78	960	12,372	12.89
1978/79	1,010	15,048	14.90
1979/80	1,041	11,136	10.69
1980/81	1,270	17,744	13.97
1981/82	1,236	17,788	14.39
1982/83	1,385	19,316	13.95
1983/84	1,405	19,985	14.22
1984/85	1,477	19,263	13.04
1985/86	1,240	15,255	12.30

Source : Office of Agricultural Economics, 1986.

Cassava Production and Principal Constraints

Edafo-climatic conditions:

In both major cassava growing regions, the Northeast and Central Plain, the normal onset of rain (over 100 mm/month) is in May and the termination in October. Both regions are predominantly dry for six consecutive months (November to April) receiving less than 50 mm rainfall per month.

Following the Great Soil Group classification the major cassava soils in Thailand are classified as Gray Podzolic soils. The soils are highly leached with low base saturation (35-50%) and low levels of N, available P, and K. They are light in texture and are moderately to excessively drained. Available moisture storage ranges from 60 to 80 mm per meter of soil. The soil pH is between 5.0 and 6.0 in the surface soil and decreases with depth. The pH of the subsoil ranges from 4.5 to 5.0 in the subsurface, and 3.8 to 4.0 at the lowest depth.

Cultivars used:

"Table type" cassava cultivars are grown in a very small acreage for fresh human consumption and processing into desserts. The principal cultivar of this type is called "Hanatee".

"Industrial type" cassava is grown on a much larger scale for chip and pellet making and for starch extraction.

The great majority of the cassava area is planted with a single genotype, Rayong 1. All evidence shows that it is a typical farmers' cultivar. Yet, Rayong 1 is basically a high yielding cultivar and its ability to tolerate sub-optimal conditions is striking. This cultivar is suitable for harvest in 12 months or more after planting. It is not an ideal cultivar for early harvest, hence, not suitable for relay or sequencial cropping systems. The selection and recommendation of Rayong 1 was one of the most important factors responsable for successful cassava production in Thailand.

Biological yield constraints:

Cassava bacterial blight (CBB), caused by *Xanthomonas campestris* pv. *manithotis*, is the only major disease of cassava that is widely spread in the country. Rayong 1 is moderately susceptible to CBB; however, it is not well known how much effect CBB has on cassava yields. Brown leaf spot, caused by *Cercosporidium henningsii* and mites *(Tetranychus truncatus)* are commonly observed, but their effects on yield are not well known.

At present, cassava in Thailand is affected by a comparatively small number of diseases and pests. However, this is no guarantee for the future because of the dynamic nature of biological yield constraints. The present situation of more than one million hectares planted with virtually one single genotype is extremely vulnerable to any future change in the disease and pest situation. Diversification of cassava genotypes is therefore very important, and extra care should be taken to avoid accidental introduction of diseases and insects.

Cassava Breeding to Overcome Productivity Constraints

The national average yield of 13.5 t/ha is rather low compared with experimental yields of more than 50 t/ha obtained in Thailand or at CIAT. There are clones with much higher root dry matter content than Rayong 1. Hence, there is still much room for yield improvement through additional germplasm collection/introduction and breeding.

Germplasm collection and introduction:

Cassava breeding research began with the collection of local cultivars throughout the country and their systematic evaluation in 1956 at Rayong Field Crop Research Center in Rayong province. There were not many cultivers and several, collected from various locations and having different names, were identified to be the same genotype. This was called "Local Rayong", to be used in comparison with introduced cultivars. It appeared that Local Rayong yielded higher than all introduced clones from Java, the Virgin Islands and CIAT. This cultivar was named Rayong 1 by the Department of Agriculture in 1975. Before 1960, some twenty cultivars had been introduced, probably from Malaysia, Java and Mauritius. From this stock, the venerable Rayong 1 probably emerged. During the 1960's, more clones were introduced, from Java in 1963, and from the Virgin Islands in 1965. The first introduction of planting material from CIAT took place in 1970.

The introduction of CIAT germplasm in the form of hybrid seeds started in 1975. Ten hybrid clones were first introduced in the form of meristem culture from CIAT in 1979.

Table 3. Introduction of cassava germplasm to Thailand through the Department of Agricuture.

Year	Number of genotypes introduced	Origin
Before 1960	about 20	Malaya, Java, Mauritius, etc.
1963	7 cultivars	Java
1965	44 clones	Virgin Island
1970	5 accessions	CIAT
1975	900 seeds	CIAT
1977	10 hybrid clones	CIAT
	6170 seeds	CIAT
1978	7720 seeds	CIAT
1979	10 hybrid clones	CIAT
1980	3050 seeds	CIAT
1981	1400 seeds	CIAT
1982	7450 seeds	CIAT
1984	7900 seeds	CIAT
1985	6650 seeds	CIAT
1986	6600 seeds	CIAT
1987	8600 seeds	CIAT
1988	9200 seeds	CIAT

Source : Field Crops Research Institute, Dept. Agric.

Introduction of CIAT seed populations from more specifically defined cross parents, adapted to the Thai conditions, started in 1982 (Table 3). All these introductions have passed and are passing through several evaluation steps of the breeding program, and selected clones are utilized in hybridizations.

Germplasm introduced from CIAT contributed to increase the genetic variation. Many crosses were made every year between Thai and CIAT clones, supplemented by a smaller number of crosses between Thai clones. From the CIAT hybrid seeds introduced in 1975, two cultivars were developed, Rayong 2 and Rayong 3.

Breeding program:

The breeding program, based on open-pollinated seeds from Rayong 1 and introduced cultivars, started in 1971. Not much was gained from the selections of open-pollinated seeds. Controlled hybridization started in 1975 by utilizing limited germplasm from Java, the Virgin Islands and CIAT. With the return of researchers, trained at CIAT since 1977, the breeding program at Rayong Research Center began to function as the core of the national program.

Breeding objectives:

The major objectives of the cassava breeding program are:

1. high yield, in terms of dry matter and starch,
2. good adaptation to local production environments with drought tolerance etc.,
3. early harvestability,

4. diversification of germplasm, including resistance to diseases and pests, etc.

5. good plant type for intercropping, easy harvest, etc.

Breeding a high yielding cultivar is based on high yield, high harvest index, and high root dry matter content. High yielding cultivars will contribute to higher productivity, hence decreasing the cost of production and increasing their competitiveness with feed grains. Higher root dry matter content will lead to lower cost through higher value of the roots and lower cost of processing. Breeding for early harvest is done by high yield selection at an early age. Early cultivars will increase the opportunities for more efficient land usage, better cropping systems and crop rotation to minimize soil erosion. Resistance breeding focuses on resistance to CBB and mites. Breeding for drought tolerance also aims at finding cultivars that can be used for late rainy season plantings. Finding clones suitable for intercropping is another important selection target.

Structure of varietal testing :

The development of new cassava cultivars involves the following steps:

1. Hybridization: Some 12,000 to 20,000 hybrid seeds from 200 to 250 crosses are obtained every year at Rayong Research Center. The majority of these come from controlled pollinations between Thai and CIAT clones. Several thousands open-pollinated seeds are collected. Some 6,000 to 8,000 hybrid seeds introduced from CIAT are added to these every year.

2. Seedling selection : From 15,000 to 20,000 F_1 seeds are planted at 1 × 1.5 m spacing. Selection is based on plant vigor, disease/insect incidence, harvest index and yield. About 10% of the plants are selected for the single-row trial.

3. Single-row trial : Stakes from selected plants from the seedling trial are planted in a single row of 10 plants. The rows are one meter apart. Every 10 rows Rayong 1 is planted as the control. About 10-20% selection is practised based on designated objectives.

4. Preliminary yield trial: Selected clones from the single-row trial are planted in 5 × 10 m plots with two replications in Rayong Center.

5. Standard yield trial : About 20 clones are evaluated in 5 × 10 m plots with 4 replications in two to three stations located in major cassava growing areas.

6. Regional yield trials : About eight to ten clones, including local cultivars, are evaluated in 5 × 10 m plots with 4 replications in six to ten stations located throughout the major cassava growing areas.

7. Farmers' field trials : Promising clones from regional yield trials, usually three to five clones, are tested on farmers' fields in 5 × 10 m plots with 4 replications. The trials are conducted by using farmers' land and labor, but the management input is the responsibility of the researchers. The number of trials depends on the resources available.

8. Farmers' field test : The best clones are compared with the farmers' crop in farmers' fields using the farmers' technics. Large plots (1600 sq.m.) are required. Extension workers of the Department of Agricultural Extension from the area and farmers participate in the evaluation.

When the best material is approved, it is named as a new cultivar and released by the Department of Agriculture.

9. Production of planting material : Promising clones are multipled on a small scale in research stations. Once the cultivar is named and released, only a limited area of multiplication plots is kept in the research stations. The planting material produced is turned over to the extension workers from the Department of Agricultural Extension, who in turn use it for demonstration and multiplication in selected farmers' fields.

10. Distribution of planting material : Distribution of a released cultivar to farmers is done mainly by extension workers. Materials are obtained from research stations and selected farmers who had planted the new cultivar in the previous season. Research stations also distribute materials to nearby farmers.

Achievements

Recommended cultivars :

Rayong 1 is basically a farmers' cultivar. However, it was collected, purified, evaluated, named and recommended by the Department of Agriculture. It is a high yielding cultivar with moderately high harvest index. The cultivar provides a good quantity of high quality planting stakes, and sprouts well even under water deficient conditions, which makes this cultivar highly versatile. Data from CIAT suggest that Rayong 1 is supperior to most Latin American cultivars under conditions similar to those found in the Thai cassava area.

Rayong 2 was selected from hybrid seeds of CM 305 cross, which was introduced from CIAT in 1975. Its fresh root yield, dry matter content and starch content (calculated from Reihmann scale) are similar to those of Rayong 1. This cultivar is a table type, good for making fried chips and other convenient foods, and has a higher yielding capacity than its counterpart Hanatee, the traditional table type cultivar. Its yellow root flesh contains high carotene. Some agronomic characters of Rayong 2 are shown in Table 4. Rayong 2 was released in 1984.

Table 4. Characteristics of Rayong 2 compared with Rayong 1.

Character	Rayong 2	Rayong 1
Height (cm)	285	282
Outer root skin color	light brown	cream
Flesh color	light yellow	white
Fresh root yield (t/ha)	21.5	23.5
Dry matter content (%)	29.8	30.8
Starch content (%)	19.0	20.0
HCN (peeled) (ppm)	24	43
Carotene (ug/100g)	502	80
Vitamin A (IU/100g)	837	130
CBB resistance	MS	MS

Source : Field Crops Research Institute, Dept. Agric.

Rayong 3 was selected from hybrid seeds of CM 407 cross, which was introduced from CIAT in 1975. The results of experiments conducted from 1979 to 1984 show that the root dry matter and starch contents of Rayong 3 are higher than those of Rayong 1, while fresh root yield of Rayong 3 is similar to that of Rayong 1. Some characteristics of Rayong 3 are compared with those of Rayong 1 in Table 5. Higher starch content results in a higher price being paid for roots of Rayong 3. The differential is $ 0.74/ton per 1% starch. The higher dry matter content of Rayong 3 is welcomed by the chippers because it results in a shorter time required for drying. Rayong 3 was released in 1983.

Table 5. Characteristics of Rayong 3 compared with Rayong 1.

Character	Rayong 3	Rayong 1
Height (cm)	174.0	282.0
Fresh root yield (t/ha)	19.7	22.5
Dry matter content (%)	37.0	30.0
Dry yield (t/ha)	7.3	6.7
Starch content (%)	25.3	19.2
Starch yield (t/ha)	5.0	4.3
H.I.	0.57	0.45
HCN	medium	high
CBB	MS	MS

Source : Field Crops Research Institute, Dept. Agric.

Rayong 60 was selected from a cross between CIAT and Thai clones (M Col 1684 × Rayong 1). It has outyielded Rayong 1 by 24% in fresh and 31% in dry root yield at 6-8 month harvest in a series of regional and on-farm trials (Table 6). At 12 month harvest, Rayong 60 has outyielded Rayong 1 by 40% in fresh and 45% in dry yield (Table 7). This clone was approved, named and released by the Department of Agriculture on September 30, 1987. It can be used both for early and for 12 month harvests. Characteristics of Rayong 60 and Rayong 1 are compared in Table 8.

Table 6. Yield parameters of Rayong 60 and Rayong 1 at 6-8 month harvest in various trials from 1984 to 1987.

Year	Trial	No. of trials	Fresh yield (t/ha)		Dry yield (t/ha)		Dry matter content (%)		Starch content (%)	
			R60	R1	R60	R1	R60	R1	R60	R1
84	Preliminary	1	23.3	15.2	6.7	3.7	39.9	33.9	28.3	24.1
85	Standard	3	15.3	13.9	3.6	3.2	35.6	36.6	24.0	25.3
85	Standard	1	27.5	28.9	6.1	4.3	33.0	31.8	22.0	22.8
86	Regional	3	15.1	14.3	4.1	4.1	38.4	37.8	27.8	27.3
86	Regional	4	19.6	16.5	4.6	3.7	34.3	33.8	22.0	21.4
87	Standard	1	26.2	17.1	7.1	4.6	37.9	37.8	27.1	26.8
87	Regional	1	22.3	17.6	6.0	4.4	37.7	36.2	26.8	18.9
87	Farm trial	2	23.0	16.6	5.6	3.1	34.9	32.2	24.5	18.9
Average			19.7	15.8	4.9	3.7	36.2	34.9	24.9	23.5
Relative to R1 (%)			125	100	131	100	104	100	105	100

Source : Field Crops Research Institute, Dept. Agric.

Table 7. Yield parameters of Rayong 60 and Rayong 1 at 12 month harvest in various trials from 1984 to 1987.

Year	Trial	No. of trials	Fresh yield (t/ha)		Dry yield (t/ha)		Dry matter content (%)		Starch content (%)	
			R60	R1	R60	R1	R60	R1	R60	R1
84	Preliminary	1	29.5	17.3	9.7	5.3	32.8	31.0	19.8	17.5
85	Standard	1	34.3	26.6	14.0	10.2	39.5	38.3	24.7	27.8
86	Regional	1	36.8	30.8	12.3	10.8	33.3	35.0	20.7	23.0
86	Farm trial	10	23.5	15.1	7.1	4.6	32.9	30.7	19.8	18.0
87	Farm trial	2	31.2	29.1	9.5	9.1	30.7	31.3	17.1	17.7
87	Farm test	1	23.6	18.2	8.3	5.6	35.0	30.8	23.0	17.0
Average			26.4	18.9	8.8	6.0	33.2	31.5	20.0	18.8
Relative to R1 (%)			140	100	145	100	105	100	106	100

Source : Field Crops Research Institute, Dept. Agric.

Table 8. Characteristics of Rayong 60 compared with Rayong 1.

Character	Rayong 60	Rayong 1
Height (cm)	275	220
Fresh root yield (t/ha) :		
8 month	19.0	15.8
12 month	26.4	18.9
Dry matter content (%) :		
8 month	36.2	34.9
12 month	33.2	31.5
Dry yield (t/ha) :		
8 month	7.6	5.4
12 month	8.8	6.0
Starch content (%) :		
8 month	24.9	23.5
12 month	20.0	18.8
Starch yield (t/ha) :		
8 month	4.9	3.7
12 month	5.3	3.6
Fresh yield per day (kg/ha) :		
8 month	81.9	65.6
12 month	72.5	51.9
H.I. : 8 month	0.67	0.55
HCN : 8 month	M. high	M. high
CBB resistance	MS	MS

Source : Field Crops Research Institute, Dept. Agric.

Promising new clones :

There is a very promising clone, (CMC 76 × V43) 21-1 in the final stages of evaluation in farmers' fields. It was selected from hybrid seeds of a cross between CMC 76, from CIAT, and V 43 from the Virgin Islands. (CMC 76 × V 43) 21-1 outyielded Rayong 1 by 8% in fresh and 25% in dry yield at 12 month harvest. Dry matter and starch contents of (CMC 76 × V 43) 21-1 are higher than those of Rayong 1 (Table 9).

Table 9. Yields parameters of (CMC 76 × V 43) 21-1 and Rayong 1 at 12 month harvest in various trials from 1980 to 1986.

Year	Trial	No. of trials	Fresh yield (t/ha)		Dry yield (t/ha)		Dry matter content (%)		Starch content (%)	
			R1	21-1	R1	21-1	R1	21-1	R1	21-1
1980	Preliminary	1	42.6	42.2	13.7	15.4	32.1	36.4	19.5	25.0
1981	Standard	3	36.9	36.7	10.5	14.0	32.8	38.2	19.8	27.3
1982	Standard	3	19.4	23.5	5.9	8.2	30.6	34.9	16.3	22.9
1983	Regional	4	29.2	33.4	9.5	12.1	32.6	36.3	19.7	24.9
1984	Farm trial	10	22.3	22.8	7.2	8.7	31.6	34.5	18.4	22.3
1985	Farm trial	8	14.2	16.2	4.5	5.9	31.2	35.4	17.7	23.6
1985	Farm Test	18	16.8	18.1	5.1	6.5	30.9	35.8	17.2	24.1
1986	Regional	3	26.6	27.1	8.2	9.4	30.1	33.3	16.4	20.4
1986	Farm trial	2	21.0	22.8	6.6	8.3	31.6	36.5	18.2	25.2
1986	Farm Test	18	19.9	21.6	6.4	8.0	32.2	37.0	19.2	25.8
Average			20.5	22.2	6.5	8.1	31.5	35.9	18.2	24.2
Relative to R1 (%)			100	108	100	125	100	114	100	133

Source : Field Crops Research Institute, Dept. Agric.

Another promising clone, CM 3299-15, was selected from hybrid seeds of CM 849-1 × M Col 22 cross, introduced from CIAT in 1982. CM 3299-15 outyielded Rayong 1 by 12% in fresh yield and 16% in dry yield. Its starch content is higher than that of Rayong 1 (Table 10). Its plant type and root shape are very favorable.

Table 10. Yield parameters of a promising clone, CM 3299-15, and Rayong 1 in various trials from 1985 to 1987.

Year	Trial	No. of Trials	Fresh yield (t/ha)		Dry yield (t/ha)		Dry matter content (%)		Starch content (%)		H.I.	
			R1	CM	R1	CM	R1	CM	R1	CM	R1	CM
85	Preliminary	1	30.0	31.9	9.8	10.3	32.8	32.4	19.9	19.4	0.50	0.64
86	Standard	3	23.7	29.4	7.4	9.3	31.4	31.8	18.0	18.4	0.49	0.54
87	Regional	6	32.1	35.1	10.1	11.6	31.0	32.8	17.4	20.0	0.53	0.57
Average			29.4	33.1	9.3	10.8	31.3	32.5	17.8	19.5	0.51	0.57
Relative to R1 (%)			100	122	100	116	100	104	100	109	100	111

Source : Field Crops Research Institute, Dept. Agric.

Performance of Rayong 3 in farmers' fields.

Rayong 3 was released in 1983. Planting materials had been multipled in research station and farmers' fields simultaneously with the final evaluation. In 1987 planting material was distributed to farmers to be grown in about 1,000 ha.

The results of 153 tests in farmers' fields from 1983 to 1986 showed that Rayong 3 had an average fresh root yield of 19.4 t/ha, dry matter content of 36.1%, dry yield of 7.0 t/ha, and starch content of 24.2%, whilst those of Rayong 1 were 21.9 t/ha, 32.0%, 7.0 t/ha and 19.8%, respectively.

Constraints and Prospects

Thai farmers prefer to adopt a new cultivar in the hope that a higher yield and a higher price can be attained without large additional costs. The major constraint in releasing new cultivars is the slow rate of propagation of cassava, which makes availability of large quantities of planting material for distribution to farmers difficult. There are no cassava multiplication farms of the government or private sector. Starting with about 100 ha of Rayong 3 in 1985 and a multiplication rate of 1 to 10, it requires at least 5-6 years to plant this cultivar in 0.6 million ha, about half of the total cassava planting area.

Rapid propagation or single two-node propagation may help hasten planting material production and distribution of newly released cultivars. But these methods are costly.

Major yield increases on a large scale through the release of new cultivars will not be realized in a short period of time. Although Rayong 3 has a higher starch content, it may not replace Rayong 1 on a large scale because the total dry matter yield of Rayong 3 does not greatly exceed that of Rayong 1. There are a number of promising hybrid clones for high yield and earliness in the pipeline, yet it will take some time before any one of these passes to the production fields.

Whether we can obtain new clones with a yielding capacity sufficiently high to significantly reduce the production costs depends on future work. It is expected that high yielding cultivars will provide the opportunity for higher competitiveness in the international market. Also, higher yielding cultivars may induce farmers to grow cassava only in areas that are not susceptible to erosion. Additionally, early cultivars, will increase the possibility for better land use through better cropping systems and crop rotation to avoid soil degradation.

Summary

Cassava is one of the most important economic crops in Thailand. It is produced by small farmers and its products are exported mainly to the EEC. The production has increased rapidly and steadily during the last two decades through the expansion of planted area. The national average yield has been stagnant at about 13.5 t/ha, which is higher than the world average yet low compared with the potential of the crop.

Major production problems include declining soil fertility, soil erosion and the limited genetic diversity of the crop. The research effort of the Department of Agriculture has resulted in the identification of a high yielding, versatile cultivar, Rayong 1. Latinamerican germplasm, provided by CIAT, is now well incorporated into the breeding system. High yield capacity and early maturity are important selection targets.

The Thai cassava breeding program includes every step of varietal improvement activity. Selected clones are evaluated in research stations located in the major cassava growing areas. Extension workers and farmers are involved in testing the promising clones before the release of new cultivars.

Three cultivars, Rayong 2, Rayong 3 and Rayong 60 have been released. Rayong 2 and Rayong 3 were developed from CIAT hybrid seeds. Rayong 3 has high root starch and dry matter content, while Rayong 2 is good for human consumption. These two cultivars

performed well in research stations and farmers' fields. Recently, Rayong 60 was released. It is high yielding and suitable for early harvest. There are many promising clones along the various steps of evaluation.

Superior cassava cultivars will provide the opportunity for reducing the cost of production, increasing farmers' income as well as the competitiveness of the product in the international market.

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CASSAVA VARIETAL IMPROVEMENT AT KASETSART UNIVERSITY, THAILAND

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Kasetsart University is the Thai name for agricultural university. In 1985 there were 70 departments, 1,412 lecturers, 5,189 staff members, and 11,083 students. Several cassava research projects have actively been conducted in various departments such as Agronomy, Soil Science, Animal Science, Microbiology, Products Development, and Agricultural Economics. Research projects are coordinated by the Kasetsart University Research and Development Institute (KURDI). There are ten research stations, of which four involve field crops.

Accomplishments and Present Status of Cassava Breeding Program

A cassava breeding project was launched by the introduction of hybrid seeds from CIAT in 1975. Subsequently, seedling selection began in 1976 with 2,574 seeds; their pedigrees are shown in Table 1. The majority of the seeds were obtained from open-pollinations of 230 selected CIAT germplasm accessions at CIAT, in Cali Colombia. Clones selected from this seed population have been tested from 1981 to 1986 in a total of 23 trials, of which 11 trials were conducted by the Field Crops Research Institute of the Department of Agriculture. The best selected clone was MKU 2-151 from the cross MCol 113 × MCol 22. MKU 2-151 had a yield, averaged over all the trials similar to that of Rayong 1 (Table 2). This clone was not released as a commercial cultivar, but was registered as a parent in the hybridization program.

Table 1. Code, pedigree and number of seeds introduced from CIAT in 1975 for selection.

Code	Pedigree	Number of seeds
MKU 1	Open-pollinated	1,006
MKU 2	MCol 113 × MCol 22	342
MKU 3	MCol 113 × MCol 638	224
MKU 4	MCol 113 × MCol 647	295
MKU 5	MCol 647 × MCol 638	129
MKU 6	CM 2-6 × CM 309-206	80
MKU 7	CM 180-4 × MCol 638	58
MKU 8	Open-from MVen 285	122
MKU 9	CM 152-14 × MCol 638	99
MKU 10	MCol 113 × MMex 55	219
	Total	2,574

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Table 2. Dry root yield (t/ha) of MKU 2-151 from 23 trials during 1981-1986.

Clones	Sriracha Res. Stn.		Field Crops Res. Inst.			Farmers' fields	Average
	81-84	84/85	84/85	85/86	86/87	85/86	
	No. of trials		No. of locations				
	3	3	1	3	7	6	
MKU 2-151	10.5	8.8	14.6	9.1	9.2	7.3	9.0
Rayong 3	—	8.3	10.6	6.9	8.4	8.2	8.2
Rayong 1	9.8	9.9	9.3	7.4	10.2	8.0	9.1

The progress of the breeding project was delayed from 1981 until 1984 because the principle breeder was on study leave. The germplasm flow in the breeding project is summarized in Table 3. The project operates in close cooperation with the Field Crops Research Institute (FCRI). As a part of the activities, selected clones have been sent to FCRI for field trials and *vice-versa*. Some of the selected clones from the preliminary yield trial in 1986/87 have shown very promising results (Table 4). Since Rayong 1 is exceptionally well adapted to the Thai environment it is too early, with this preliminary yield trial, to conclude that Rayong 1 can be replaced by those clones. Most of the promising clones are F_1 hybrids with Rayong 1. New promising clones are added into the hybridization and evaluation programs every year. It is hoped that in the near future Rayong 1 may be replaced by superior clones.

Table 3. Stage and number of cassava clones in breeding program from 1984 to 1987.

Stage	Year	Number of clones			
		1984/85	1985/86	1986/87	1987/88
F_1 seedling trial		4,114	7,884	3,433	5,000
Single row trial		—	375	435	202
Preliminary trial		—	—	93	97
Regional trial		—	—	—	10

Table 4. Performance of selected clones from a preliminary yield trial at Sriracha in 1986/87.

Clone	Fresh root yield (t/ha)	Starch (%)	H.I.
Group I			
(MKU 1-506 × Rayong 1) # 34	30.1	17.6	.59
(Rayong 1 × Rayong 3) # 2	38.0	18.4	.65
(MKU 2-162 × Rayong 1) # 23	31.8	20.4	.62
(MKU 1-316 × Rayong 1) # 91	43.3	14.8	.67
Rayong 1 (check)	30.5	15.0	.58
Group II			
OP. 27-77-10 # 60	29.4	18.6	.50
Rayong 1 (check)	21.6	13.7	.48

Utilization of Local, Introduced and CIAT Developed Germplasm

Before the release of Rayong 3 by the Department of Agriculture in 1983, there were only 3 commercial cassava cultivars, namely Rayong 1, Hanatee, and Munsuan. Rayong 1 is a very important cultivar with more than one million hectares under cultivation for industrial purposes. Hanatee and Munsuan are economically less important since the roots are used only for human food. Yields of these two cultivars are inferior to that of Rayong 1 but the HCN content of roots is lower (Table 5).

Table 5. Yield of three local cassava cultivars from 3 trials during 1984/85.

Cultivar	Fresh root yield (t/ha)	Root starch content (%)	Root HCN
Rayong 1	36.6	21.4	high
Hanatee	27.1	20.7	low
Munsuan	21.0	21.1	low

Rayong 1 possesses excellent agronomic characteristics such as high yield, good germination, good plant type, wide adaptation, ease of harvest and moderately high root starch content. Kawano *et al.* (1986) stated that the superior agronomic characteristics of Rayong 1 were the main factor for successful cassava production in Thailand.

Introduced cassava germplasm is necessary since local germplasm is very limited. Seeds and meristem cultures were introduced from CIAT, Malaysia and Indonesia through the CIAT *in vitro* culture laboratory (Table 6). Additional breeding materials have been obtained from the Field Crop Research Institute also.

Table 6. Kasetsart cassava germplasm introduction from CIAT and other countries with CIAT coordination.

Year	Type of germplasm
1975	8,000 F_1 seeds from CIAT
1984	9 clones of meristem culture from CIAT, (MBra 12, CM 681-2, MCub 74, CM 981-8, CM 523-7, CM 507-37, CM 342-170, CM 982-20, and MVen 156)
1985	3,150 F_1 seeds from CIAT
1986	Meristem culture : 64 clones from Indonesia, 68 clones from Malaysia

Without irrigation most of the CIAT-clones tended to germinate poorly under Thai conditions (Kawano *et al.*, 1986). Our F_1 seedling introduction from CIAT in 1975 when planted at Sriracha in single row trials in 1977 gave the same result (Figure 1). Unlike the low germination characteristic, these materials showed more promising variation in root starch content when compared with Rayong 1 (Figure 2). However, clones recently introduced from CIAT through meristem culture showed satisfactory germination, compared with Rayong 1 and Rayong 3, when planted in the dry season at Sriracha (Table 7).

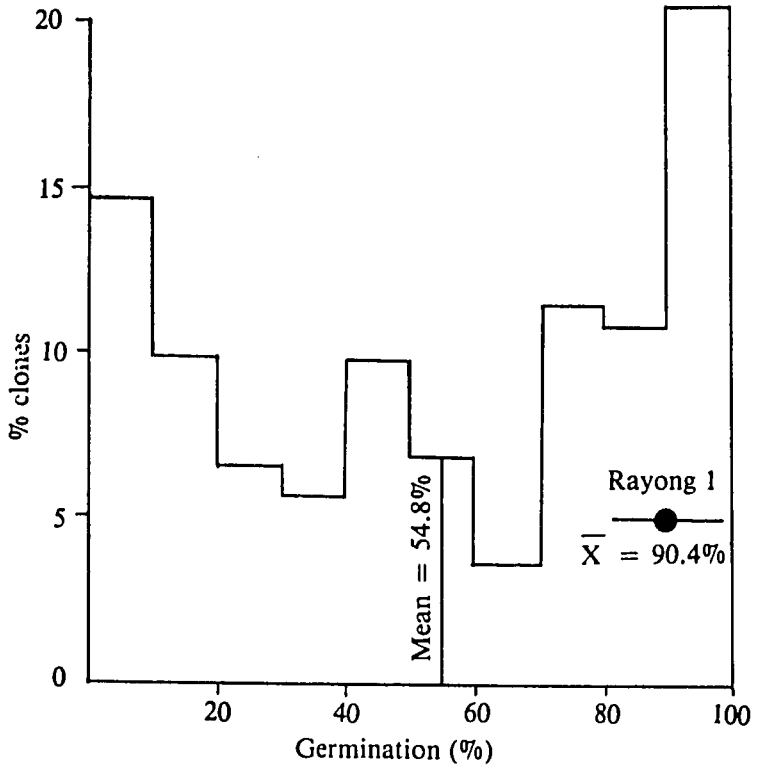

Figure 1. Germination of 1,046 cassava clones introduced from CIAT as Sriracha in 1977-78.

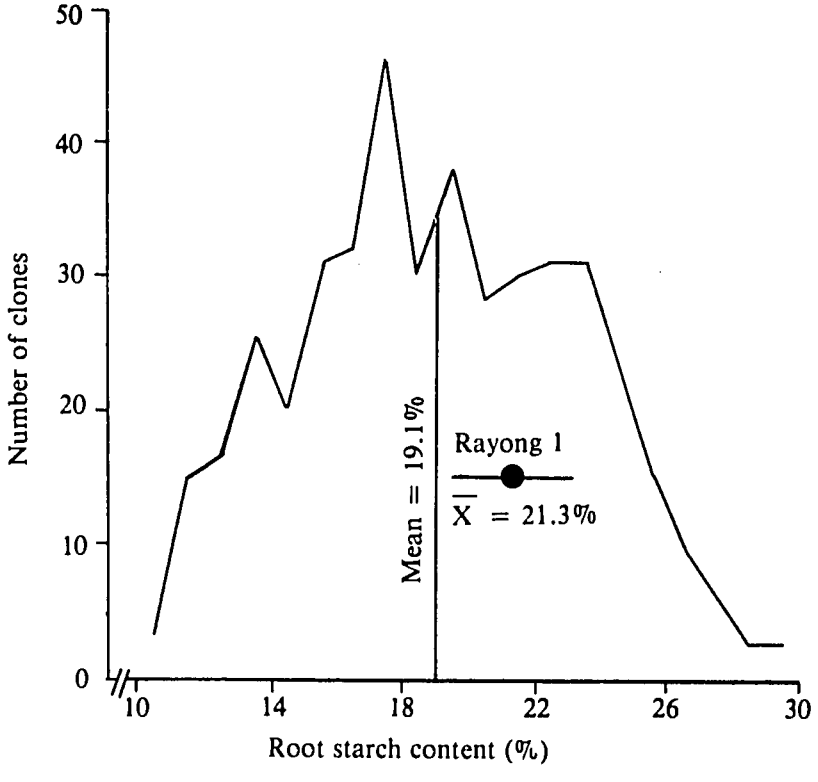

Figure 2. Root starch content of 729 cassava clones introduced from CIAT at Sriracha in 1977-78.

Table 7. Germination of CIAT cassava clones planted in November, 1986 at Sriracha Research Station.

Clones	Germination (%)
CM 981-8	77.5
MCub 74	93.8
CM 523-7	95.4
CM 681-2	99.6
Rayong 1 (local check)	87.9
Rayong 3 (local check)	98.8
LSD (0.05)	9.46

Introduced materials have been evaluated through the steps of evaluation trials and selected clones have been incorporated into the hybridization scheme. Our breeding objective is to develop cassava cultivars for industrial purposes; thus, from the local germplasm only Rayong 1 is used in the hybridizations with selected introduced clones.

Future Directions and Priorities

Cassava industry personnel mentioned earliness, high root yield, and high root starch content as the most desirable characteristics expected in new cultivars. Earliness is one of the objectives of several cassava breeding programs. Up to date there is no cassava cultivar that is clearly suited to early harvesting. We tested 10 cassava clones with harvesting time at 8, 10 and 12 months. Interaction between clone and harvesting time was not detected in the analysis of variance for fresh and dry root yield. The result indicate that cassava clones in this experiment responded similarly to harvesting time. Hence, selection for earliness is not included in our objectives.

Our short term goals in breeding are:

1. higher root starch content than Rayong 1 with similar root yield; or higher root yield than Rayong 1 with similar root starch content,
2. similar agronomic triats to Rayong 1,
3. not susceptible to diseases and insect pests.

For the long term objectives, new clones should be higher in both fresh root yield and starch content than Rayong 1, but with similar agronomic triats as Rayong 1.

Needs of Network Research and Cooperative Projects

Continuous flow of cassava germplasm into the project is necessary for the future success. Hence, we set the first priority for germplasm introduction and exchange. International varietal trials are also important to obtain further information on cultivar performance and disease and insect pests reactions. These tasks can be accomplished by coordination and support from an international institute such as CIAT.

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CASSAVA BREEDING IN INDONESIA

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Introduction

Cassava *(Manihot esculenta* Crantz*)* in Indonesia has a great potential, both for domestic consumption as well as for export purposes. Its harvested area is presently about 1.4 million hectares with an annual production of about 15 million tons (Table 1).

Table 1. Cassava harvested area and production in Indonesia, 1981-1985.

Year	Harvested area (000 ha)	Production (000 t)
1981	1,412	13,673
1982	1,440	12,636
1983	1,452	13,798
1984	1,485	14,205
1985	1,492	15,403

Source : Achmad Affandi, 1986; Central Bureau of Statistics, 1985.

The crop is grown in monoculture as well as intercropped with other crops. It is grown mainly by small farmers, but large scale plantations of over a thousand hectares also exist in the country. The roots are processed into a multitude of end products ranging from simple boiled roots for direct human consumption to starch and liquid sugar produced in large factories (Soenarjo, 1986c).

Status of the Breeding Program

Cassava breeding is a part of the Root and Tuber Crops Program of the Central Research Institute for Food Crops (CRIFC) in Bogor. Malang Research Institute for Food Crops (MARIF) under the auspices of CRIFC has the mandate to do research and development work on all palawija (non-rice) crops, including cassava. The Root and Tuber Crops Program of CRIFC has its headquarters at MARIF, which is expected to be the palawija center of Indonesia in the future. The very low level of government financial support for cassava research obliged the cassava varietal improvement program of CRIFC to depend heavily on the resources of

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P.T. Umas Jaya Farm in southern Sumatra, one of the largest private plantations in the country, to carry out the major part of the actual breeding and selection work. This arrangement proved highly successful, and research conducted at Umas Jaya is now the most important genetic evaluation/selection scheme for cassava production under high rainfall conditions.

Cassava varietal evaluation/selection has recently started also at the University of Brawijaya (UNIBRAW) in Malang, in cooperation with CIAT and the International Development Research Centre (IDRC) from Canada. The cassava evaluation at UNIBRAW appears to offer a good selection scheme for cassava production under low rainfal conditions. An integrated root crop research program is being formed, encompassing MARIF and UNIBRAW so as to make better use of limited resources and avoiding duplications.

Objectives and Priorities

The main objectives in the breeding program are to develop superior cassava clones that are suitable for industrial use as well as for fresh human consumption (Soenarjo, 1986b).

For industrial use cassava clones should have the following characteristics:

- High HCN content of roots (> 100 ppm) to prevent wild pig damage as well as theft
- Non-branching growth habit
- Easy to harvest
- Suitable for mechanization.

For fresh human consumption cassava clones should be characterized by:
- Low HCN content of roots (< 30 ppm)
- Good eating quality

In addition, those clones have to possess the following common attributes:

- High yield and high harvest index
- Early harvestability
- Tolerance to major pests and diseases
- High root starch content
- Good root shape
- Broad adaptation to various soil and climatic conditions

Recently the demand for cassava clones with high starch content has been increasing. Meanwhile the incidence of cassava bacterial blight (CBB) in the wet region, and mites *(Tetranychus* sp.*)* in the dry region are becoming more serious. Additional research priority should be given to these problems in the future.

Strategy

In general, Indonesia can be divided climatically into two major regions: wet and dry. The wet region has an annual rainfall of over 1500 mm with less than four dry months. This region is located mainly in the western part of West Java and in Sumatra. The dry region extends from the eastern part of West Java toward the east of Indonesia up to Nusa Tenggara and East Timor. This region is characterized by annual rainfall of less than 1500 mm and over four dry months.

The major constraints in the wet region are acid soils with low fertility and high incidence of CBB, while those in the dry region are drought stress and red mite infestations.

For these reasons the breeding activities are now centered at Lampung in South Sumatra and in Malang in East Java, representing the wet and dry regions, respectively. Selected clones obtained from each evaluation site are distributed to other important cassava growing regions for further evaluation.

Utilization of Local and Introduced Materials

To increase genetic variability the program has been maximizing the use of both local and introduced materials. Most local clones from both wet and dry regions, considered as potential cross parents, are now being used in the breeding program.

Many local clones have poor yield potential, low harvest index and other undesirable characteristics. However, these clones have been adapted to the region for many years. Past evaluation indicate that local clones such as Muara, Bogor, Gading, Faroka, Manalagi and Genjah Kretek or Balerante have several good characteristics.

A cross of a local clone, Ambon resulted in a new improved cultivar, Adira 1, which is suitable for fresh human consumption. Another cross with Muara has given an outstanding new cultivar, Adira 4, which is suitable for industrial use.

Introduction of cassava germplasm from other countries has been limited and CIAT has been the major source of cassava germplasm. In the recent five years, the breeding programs of both CRIFC and UNIBRAW have received more than 10,000 F_1 hybrid seeds through this channel. Now that an integrated root crop improvement program, including both CRIFC/MARIF and UNIBRAW, has been organized and cooperative breeding activities with private plantations in Sumatra are well coordinated, our integrated program can take the sole responsibility for receiving germplasm materials from CIAT and appraising the breeding potential of these materials in the breeding/selection program.

The clones selected from these seed introductions are being evaluated in various steps of our evaluation/selection scheme. The most advanced among these are now entering the advanced yield trial stage in Lampung, Sumatra, and in Malang.

Because of limitations of land and resources it was decided to prevent the possible loss of the most valuable local genetic material by sending 50 local cultivars and 14 breeding lines to CIAT through meristem culture to be included in CIAT's world cassava germplasm bank (See section "Cassava breeding - CIAT headquarters").

Accomplishment in Cassava Breeding

During the past decade the program released three improved cassava clones, namely Adira 1, Adira 2 (released in 1978) and Adira 4 (1986). Among these, Adira 1 has proven to be a successful cultivar for fresh consumption and Adira 4 appears to be highly promising for industrial (large plantation) use.

Adira 1 is a sweet cultivar with only 30 ppm of HCN content in the root and is suitable for fresh human consumption and fermented cassava (home industry). This cultivar is suitable

for small scale farmers who usually grow cassava intercropped with other food crops. It can be harvested at 7 to 8 months, having fresh root yields of 25-30 t/ha with 38-40% root dry matter content when grown on reasonably good soils with good cultural practices and with nearly continuous rainfall.

Adira 4 on the other hand, is more suitable for production on large plantations for industrial use (Soenarjo, 1986a) since it is a bitter cultivar with approximately 90 ppm HCN content in the root. It has a good root shape and compact root system as well as good plant type. Its harvest index is usually over 0.60 and its non-branching habit enables the crop to be handled mechanically. This cultivar is well adapted to wet regions, but can show reasonably good performance in the dry region as well. It can be harvested at 9-10 months after planting with fresh root yields of 35-45 t/ha, with 36-37% root dry matter content when grown under good conditions. This cultivar is also well adapted to marginal soils with a soil pH of 4.5-5.5. Adira 4 can produce 30-40% higher yields than Adira 1 and 50-70% higher yields than local cultivars (Soenarjo and Hardono, 1984). This clone was planted in considerable acreage even before its formal release in 1986. It is spreading rapidly among cassava plantations in Lampung as well as in other areas. It is now estimated to be planted in approximately 10,000 hectares.

Intensive cooperation with CIAT and the Umas Jaya Farm started with the introduction of 4600 F_1 hybrid cassava seeds from CIAT in 1983. This seed population has been evaluated through the established evaluation steps of conventional cassava varietal improvement, including single plant selection, single-row trial, non-replicated preliminary trial, replicated trial and advanced yield trial (Chart 1). From the original 4600 genotypes, 31 cleared all these steps to be included in the advanced yield trial. Additional seed introductions have been made thereafter and the derived clonal materials are being evaluated similarly.

All the 31 clones, which were selected from the 1983 seed introduction, outyielded significantly the local traditional cultivar, Kretek, and several gave higher dry root yields than Adira 4 (Table 2). The general characteristics of CIAT derived clones in comparison with traditional cultivars is their high harvest index, similar to that of Adira 1 or Adira 4. Evaluation of the same 31 clones for reaction to major diseases and pests revealed that the CIAT population contained much wider genetic variability in reaction to CBB, brown leaf spot and mites than the local cultivars, which were shown to be mostly susceptible (Table 3). This clearly indicates that the introduction of CIAT germplasm, when properly managed, adds useful genetic variation required by the national cassava breeding program (Soenarjo *et al.*, 1986).

Date	No. of clones/seeds	Activity
Jul 1983	4600	Introduction
Aug 1983	4600	Germination
Sep 1983	2906	Transplanting (F_1 trial)
Jun 1984	1906	Harvest
		Single plant selection
	574	Planting (Single-row trial)
Mar 1985	574	Harvest
		Single-row selection
	95	Planting (Preliminary trial)
Mar 1986	95	Harvest
		Selection
	31	Planting (Replicated trial)
Dec 1986	31	Harvest
		Selection
	13	Planting (Advanced trial-I)
Dec 1987	13	Harvest
		Selection
	6	Planting (Advanced trial-II)

Chart 1. Schemetic presentation of evaluation/selection of the 1983 CIAT seed introduction.

Table 2. Result of advanced yield trial at Umas Jaya Farm, Lampung, Sumatra, Indonesia, harvested at 8.5 months.

Clone	Parents	Root dry yield (t/ha)	Root fresh yield (t/ha)	Root dry matter content (%)	H.I.
CM 4013-3 UJF	CM 728-2 × CM 922-2	17.2	47	36	.63
CM 4014-5 UJF	CM 728-3 × CM 681-2	16.1	46	35	.63
CM 3433-6 UJF	CM 681-2 × CM 91-3	13.7	38	36	.69
CM 4049-2 UJF	CM 1015-19 × CM 849-1	13.7	37	37	.62
CM 4049-7 UJF	CM 1015-19 × CM 849-1	13.7	38	36	.64
CM 3435-5 UJF	CM 681-2 × CM 91-3	13.3	39	34	.68
CM 4051-4 UJF	CM 1015-34 × M Pan 51	13.3	39	34	.61
CM 3970-4 UJF	CM 342-170 × M Col 1684	13.1	36	36	.61
CM 3997-26 UJF	CM 681-2 × CM 849-1	13.0	37	35	.66
CM 3341-13 UJF	CM 342-170 × CM 523-7	12.9	33	39	.62
CM 4013-8 UJF	CM 728-2 × CM 922-2	12.9	39	33	.66
CM 3997-5 UJF	CM 681-2 × CM 849-1	12.6	36	35	.65
CM 3997-7 UJF	CM 681-2 × CM 849-1	12.6	37	34	.63
CM 3959-5 UJF	M Col 22 × CM 180-5	12.6	36	35	.62
CM 4031-10 UJF	CM 922-2 × CM 507-37	12.6	34	37	.60
CM 4045-6 UJF	CM 1015-13 × CM 922-2	12.6	35	36	.61
CM 3504-9 UJF	CM 728-2 × CM 523-7	12.2	34	36	.63
CM 3998-13 UJF	CM 681-2 × CM 922-2	12.2	33	37	.60
CM 3997-14 MJF	CM 681-2 × CM 849-1	12.2	36	34	.55
CM 4045-1 UJF	CM 1015-13 × CM 922-2	12.2	34	36	.67
CM 3997-19 UJF	CM 681-2 × CM 849-1	11.9	33	36	.66
CM 4040-2 UJF	CM 1015-19 × CM 922-2	11.9	33	36	.62
CM 3380-10 UJF	CM 586-1 × CM 523-7	11.6	34	34	.63
CM 3341-9 UJF	CM 342-170 × CM 523-7	11.5	32	36	.60
CM 4058-9 UJF	CM 1015-42 × CM 180-5	11.5	32	36	.66
CM 4063-12 UJF	CM 1015-42 × CM 849-1	11.5	32	32	.69
CM 4031-11 UJF	CM 922-2 × CM 507-37	11.2	35	32	.66
CM 3993-28 UJF	CM 681-2 × M Col 1684	10.8	30	36	.63
CM 3970-1 UJF	CM 342-170 × M Col 1684	10.1	28	36	.57
CM 3341-2 UJF	CM 342-170 × CM 523-7	9.5	25	38	.51
CM 3967-2 UJF	M Bra 12 × CM 922-2	10.2	29	35	.57
M-30 (Selection from local breeding program)		14.1	42	35	.68
Adira 4 (Selection from local breeding program)		12.2	33	37	.62
Rayong 1 (Introduction from Thailand)		9.2	27	34	.52
Adira 1 (Selection from local breeding program)		9.1	24	38	.60
Kretek (Leading local cultivar)		7.7	25	31	.48

Table 3. Resistance characteristics of selected clones compared with those of local clones at Umas Jaya, Lampung, Indonesia, 1985/86.

Clone	Root dry yield (t/ha)	CBB[2]	Brown leave spot[3]	Mite[4]
Selected clone				
CM 4013-3 UJF	17	MR	R	MS
CM 4014-5 UJF	16	R	R	MR
CM 3433-6 UJF	14	R	MS	R
CM 4049-2 UJF	14	MR	R	MR
CM 4049-7 UJF	14	MS	R	MR
CM 3970-4 UJF	13	MR	R	R
CM 3341-13 UJF	13	R	S	MR
CM 4031-10 UJF	13	R	R	R
CM 4045-6 UJF	13	R	MS	MR
CM 3998-13 UJF	12	MR	MS	S
CM 3997-19 UJF	12	MR	R	S
CM 4031-11 UJF	11	R	R	R
CM 3970-1 UJF	10	R	R	MR
Local clones				
M-30	14	MR	S	S
Adira 4	12	MR	MS	S
Rayong 1	9	MS	MR	MS
Adira-1	9	MR	MS	MS
Kretek	8	MS	MS	MS

1) R: Resistant, MR: Moderately resistant, MS: Moderately susceptible, S: Susceptible. Evaluated by R. Soenarjo, CRIFC, Indonesia.

2) Cassava Bacterial Blight (caused by *Xanthomonas manihotis*)

3) Caused by *Cercosporidium henningsi*

4) *Tetranychus* spp.

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CASSAVA VARIETAL IMPROVEMENT IN INDIA

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Introduction

Among the root and tuber crops grown in India, cassava *(Manihot esculenta* Crantz*)* takes the second position to potato with regard to area and production. While potato is predominantly grown in the temperate northern region, cassava is mainly cultivated in the southern states of India having a tropical climate. The tuberous roots of cassava are a rich source of starch. They are used as a staple human food, as animal feed and as an industrial raw material.

According to MacMillan, cassava (tapioca) was introduced into Ceylon (Sri Lanka) and India by the Portuguese during the 17th Century, while Burkhill states that it was directly introduced from South America into India in 1840 (Abraham, 1956). The planting material was brought to the Malabar coast. Though the original material was limited in number, at present a large number of cultivars are available, which have resulted from bud mutations or open pollinations. Over the years they have been selected for desirable attributes and adaptation to local conditions and requirements. Thus the majority of cultivars possessed native or local names which generally indicated the features of the plant such as "Kayyalachedi" (like elephants) "Ethekka kappa" (like banana fruit) etc.

Though cassava has been cultivated in India for a long time, improvement work in this crop did not receive due attention. Earlier attempts in cassava breeding in India have been reviewed by Abraham (1957), Magoon (1968, 1970), etc. For a long time after its introduction, the crop was restricted to the erstwhile Travancore State, from where it slowly spread to the other neighboring states and to the northeastern region of India.

Though cassava is presently cultivated in many different states in India, the major share is contributed by Kerala state with about 70 per cent of the area and 75% of the total production. Data on total area, production and yield of cassava in India since 1950, shows that there was a progressive increase in area and production up to 1975, after which there was a decrease in area and total production (Table 1). However, cassava yields showed a steady increase from 5.8 t/ha in 1950 to 18.9 t/ha in 1985, which is a three and a half fold increase and is quite significant.

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Table 1. Area, production and productivity of cassava in India.

Year	Area (000 ha)	Production (000 ton)	Yield (t/ha)
1950	218.2	1265.6	5.8
1955	222.1	1594.1	7.1
1960	236.7	1644.6	6.9
1965	229.7	3095.7	13.5
1970	345.2	5129.6	14.9
1975	392.0	6638.3	16.9
1980	320.8	5668.1	18.3
1985	307.9	5573.5	18.9

Source : Agricultural Situation in India.

Research on the varietal improvement of cassava was initiated by the then existing Travancore University. Realizing the significance of the varietal improvement to achieve high yield, breeding was carried out through introduction, varietal hybridization and through production of chromosomal lines. The scheme of the work was further enlarged under a cassava improvement program, jointly financed by the Indian Council of Agricultural Research and the Government of Travancore-Cochin (present Kerala). Realizing the importance of root and tuber crops in the Indian economy, the Central tuber Crops Research Institute (CTCRI) was established by the Indian Council of Agricultural Research in 1963 as a National Centre for the overall improvement of tropical root and tuber crops (other than potato) in India. In the program cassava received the first priority among the various crops under purview. This paper presents a comprehensive overview of research conducted by the cassava varietal improvement program of CTCRI in India.

Germplasm Collection and Evaluation

For any meaningful breeding program to succeed, availability of diverse genetic material in the crop is of great significance. In cassava, which had a meagre 75 types reported during the 1950's, the collection has been steadily increased to a total of 1354 genetic materials in 1986. These include 605 indigenous, 689 exotic, 60 hybrids and four wild species. The exotic collection includes materials received from CIAT, Brazil, IITA, Madagascar, Malaya, Sri Lanka etc. Among the exotics, a major share has been received from CIAT, in Cali, Colombia. These clones were extensively used in the hybridization program and a few promising lines could be identified. However, most of these clones were highly branching in nature. In 1984, several thousands hybrid seeds from 158 crosses were received and their progenies are now under observation.

Based on the detailed studies of the morphological and root characteristics, the genetic stock in cassava could be grouped into various classes in relation to various traits. The studies also helped to identify duplicates in the collection. It has also been noted during the collection that the same cultivar is known by different names at different places.

The evaluation of the introduced clones in the early period has resulted in the identification of two promising cultivars, M-4 and M-6 from Malaya. Originally, when cassava was

introduced into India, the roots were primarily used as a food item and emphasis was given to the cultivars having good culinary qualities. The clone M-4, which was introduced in the 1940's, showed good culinary qualities and even today it is the best cultivar accepted for table purposes in Kerala, where cassava is used mainly for human consumption. M-4 is characterised by a predominantly non-branching growth habit, relatively light green leaves, late flowering, roots with pink rind, white flesh and the cooked roots are mealy and soft. The HCN content in the cooked root is negligible and the taste is good. M-4 was found to be highly field tolerant to cassava mosaic disease, although it is susceptible to *Cercospora* leaf spot. The roots should be harvested at about 10 months after planting. Due to the selection pressure many cultivars that were popular at one time have disappeared from cultivation during the course of time. More recently Magoon *et al.*, (1970) have reported that Acc. No. 2371 and 1310 are high yielding selections from materials received from Madagascar.

Cassava Breeding

Intervarietal hybridization :

In the comprehensive scheme of research, jointly financed by Indian Council of Agricultural Research and the Govt. of Travancore-Cochin, a varietal improvement program was initiated. This included selection from existing clones, intervarietal hybridization, inter-specific hybridization and artifical production of chromosomal races (Abraham, 1957). As a result of inter-varietal hybridization, H-96 and H-105 were identified as high yielding clones.

In the initial period, the Central Tuber Crops Research Institute placed emphasis in the breeding program to develop high yielding clones. Large scale intervarietal hybridizations by selected parents from the germplasm accessions, have been carried out to achieve this goal. As a result of continuous efforts, six hybrid clones have been reported by Magoon *et al.* (1970) as high yielding. Among them, H-97, H-165 and H-226 were released for cultivation in 1971 based on their consistently high yielding performance in multi-location trials. At central Mysore, the clone H-97 recorded a yield as high as 84.7 t/ha, whereas the yield of the control, *viz.* M-4, was only 31.0 t/ha. One of the hybrids, H-3641, developed at CTCRI has been identified as high yielding in Tamil Nadu and was released there as cultivar "Mulluvadi-1".

The Tamil Nadu Agriculture University has also released Co-1 and Co-2 as high yielding cultivars (Shanmugavelu *et al.*, 1987). Co-1 is a selection from a local collection, while Co-2 is a clonal selection from the seedling progeny of a local type. The yield of Co-1 is about 30-38 t/ha and the recorded HCN content is 10 mg/kg in the flesh.

Later attempts in the varietal hybridization at CTCRI have resulted in the isolation of two still higher yielding hybrids, *viz.* H-1687 and H-2304 developed from a single cross and multiple crosses, respectively (Jos *et al.*, 1980). The mean yields reported for H-1687 and H-2304 are 44 and 45 t/ha, respectively, based on a number of trials conducted at different locations.

Kawano *et al.* (1978) reported extensive studies on the factors affecting the efficiency of hybridization and selection in cassava and considered controlled pollination as highly recommendable. The pedigree of the hybrids developed at CTCRI are shown in Chart 1. It can be seen from the chart that both indigenous and exotic accessions have been selected as

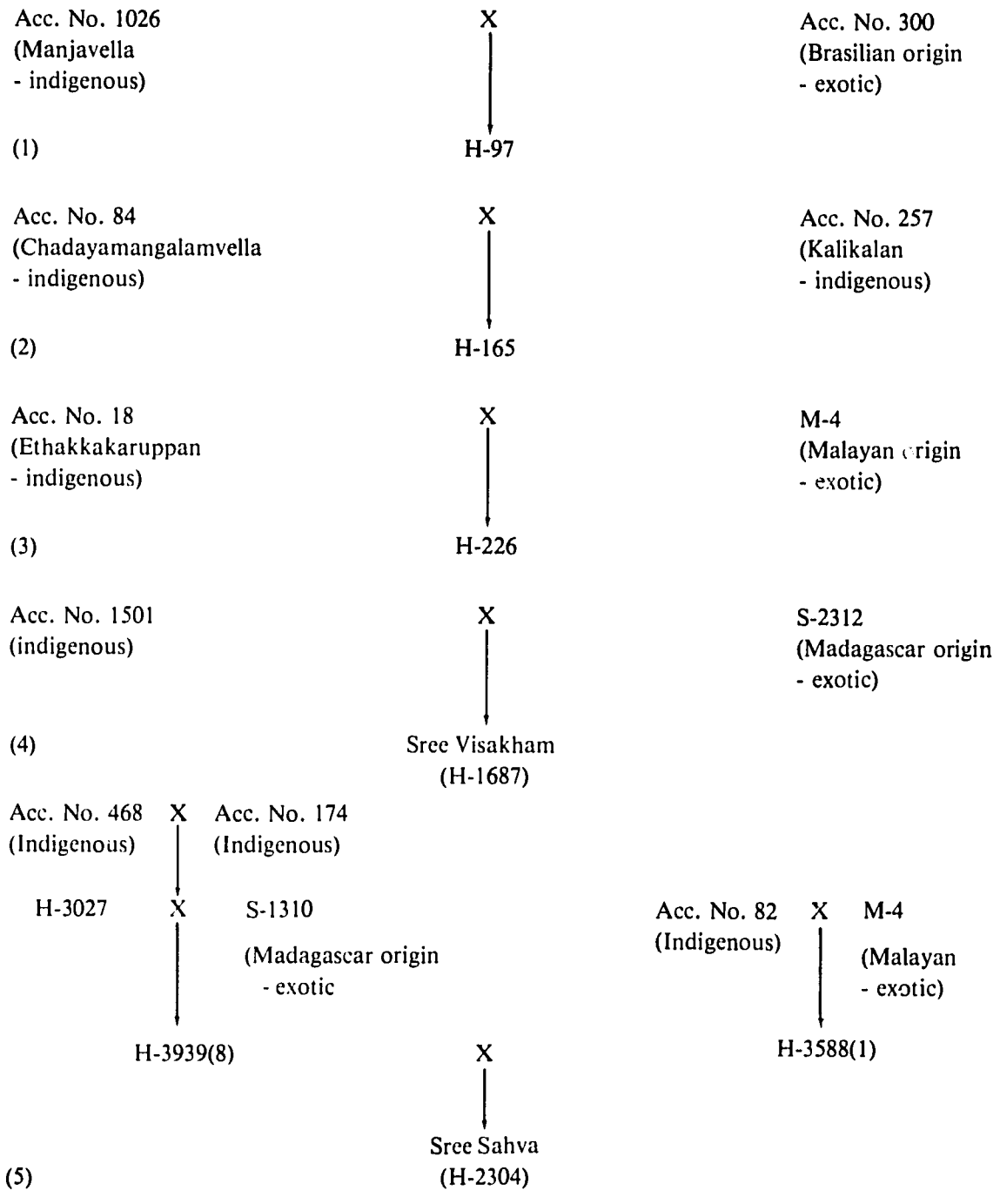

Chart 1. Pedigrees of the five released cultivars.

parents in the crossing program. Though hybrid clones were developed by using exotic accessions received from other countries as parents, they did not prove to be superior in yield. The hybrids H-1687 and H-2304 have been released for general cultivation in Kerala state in 1977 with the names "Sree Visakham" and "Sree Sahya", respectively. These two clones were further released at the national level in 1983, after conducting multi-location trials in other parts of the country. The salient features of the five hybrids are given in Table 2. The

Table 2. Salient features of released hybrid cultivars.

Cultivar	Growth duration (months)	Yield t/ha (range)	Starch content (%)	Cooking quality	Response to CMD
H-97	10	25-30	30	Fair	Tolerant
H-165	8	33-38	24	Poor	Tolerant
H-226	10	30-35	29	Fair	Susceptible
Sree Visakham (H-1687)	10	33-38	26	Fair	Tolerant
Sree Sahya (H-2304)	11	35-40	30	Fair	Tolerant

yields given are the mean of various trials conducted over the years at various locations. The root flesh of Sree Visakham is light yellow because of a high carotene content of about 466 IU, and this cultivar is thus more nutritious.

Among the five released cultivars (Table 2), H-97, H-226, Sree Visakham and Sree Sahya should be harvested at about 10-11 months. Though H-165 can be harvested at 8 months with a satisfactory yield, the root quality, especially the cooking quality and starch content, are poor. "Sree Prakash" is a selection from the germplasm accession S-856 and has been found to be good for early harvest (Nair *et al.*, 1987). During several years of testing the average yield was 35-40 t/ha at 7 months (Table 3 and 4). The plant type is good with high leaf retention, occasionally branching at the top, and the roots are shallow bulking and radial in arrangement. The cultivar "Sree Prakash" is highly tolerant to the major diseases and pests and probably suited to cultivation in the non-traditional areas in India, where short duration cultivars are preferred and rainfall is relatively low.

Table 3. Fresh root yield (t/ha) of trials conducted with cassava selections for earliness at CTCRI Farm. Crop period is 7 months.

Clone	Years		Mean
	1983	1984	
S-856	43.6*	26.5*	35.0
H-119	33.6	18.6	26.1
H-5/78	33.6	17.3	25.4
H-1687	30.4	16.9	23.6
M-4	16.8	10.9	13.8
H-165	32.8	18.0	25.4
CD at 5%	8.1	2.3	

Source : Nair *et al.*, 1987.

In recent years, interest in cassava has spread to other parts of India. Today, its cultivation has reached non-traditional areas, especially as a source of industrial raw material and as an ingredient in animal feed. The crop was unknown to these areas and its potential is yet to be assessed. Thus, the breeding strategy now focusses on the development of cultivars having the following characteristics :

Table 4. Fresh root yield (t/ha) of 6 early maturing cassava selections under multilocation trials in Kerala state.

Entries	Trivandrum		Mavelikkara		Chokkad		Kozha		Pooled mean
	1985	1986	1985	1986	1985	1986	1985	1986	
S-856	26.2	41.9	37.6	39.1	55.0	40.5	—	36.3	39.5
H-5/78	17.1	35.0	24.6	24.4	24.4	26.0	—	35.0	26.6
H-119	18.5	30.1	27.5	19.5	29.9	27.0	—	22.1	25.0
Ci-590	17.5	30.6	20.8	23.4	28.1	24.4	—	30.3	25.0
H-1687	14.9	26.0	20.8	20.8	22.2	31.1	—	22.6	22.2
H-165 (check)	14.8	33.7	24.2	30.9	24.8	27.3	—	33.4	27.0
CD at 5%	3.2	7.3	11.1	5.6	11.5	7.8	—	8.5	

Source : Nair *et al.*, 1987.

1. Early harvestability (6-7 months),
2. High content and good quality of starch (>30 percent),
3. Drought tolerance,
4. Low fertilizer requirement,
5. Ideal plant type for intercropping,
6. Shade tolerance,
7. Disease and pest tolerance.

Recent studies of seedling and the following clonal population from different cross combinations, have shown that the occurence of cassava mosaic disease (CMD) was high in those crosses in which at least one of the parents was susceptible to the disease.

Due to the hardy nature of the crop, cassava in Kerala is generally cultivated in marginal land and to a great extent under partial shade of coconut. Some attempts have been made in screening promising germplasm accessions under partial shade conditions. However, the results show that the best selections under partial shade could produce only about 12 t/ha. Among the clones tried under shade, triploids, which possessed broader and thicker leaves, yielded better than the diploids. It is felt that the screening of true seedlings as well as their clonal generations may help to identify certain genotypes with tolerance to partial shade.

Polyploids and mutation breeding :

Based on the information available for many other crop plants, induction of polyploidy and development of other chromosomal lines were tried as early as 1957 (Abraham *et al.*, 1964). Though tetraploids did not show superior yield performance, the triploids, developed by crossing tetraploids with diploids, have shown superiority over tetraploids. Jos *et al.* (1972) and Nayar (1975) also reported on tetraploids in cassava. Though the tetraploids were noted to be almost similar in yield to their respective parents, the former showed a marginal increase in protein content. Jos *et al.* (1985, 1987) have reported on triploids in cassava resulting from crossing diploids with colchicine-induced tetraploids. Though a few of the selected triploids showed higher dry matter and extractable starch content, they did not prove to be superior in yield to their parental lines. Incidentally, the roots of triploids have been reported to be bitter and poor in culinary qualities.

To correct specific genetic defects in popular cultivars, mutation breedings was initiated and the results have been reported by Abraham (1957), Vasudevan *et al.* (1967), Nayar (1975) and Nayar and Rajendran (1975). The studies were of a preliminary nature and a few special morphological and chlorophyl materials have been reported. A mutant with short petioles, isolated by Nayar and Rajendran (1985) from H-165 is reported to have practical application. Incidentally, the chlorophyl-mutant reported by Nayar and Rajendran (1985), showed conspicuously high HCN content, both in the leaves and roots, and it appears that HCN content in cassava is controlled by recessive genes.

Inter-specific hybridization :

Though cassava roots are rich in starch, the protein content is negligible. Induction of tetraploids enhanced the protein content by about one percent, but this increase is not considered to be substantial. To enhance the protein content and to incorporate disease resistance into cultivated cassava, hybridization between ceara rubber *(Manihot glaziovii)* and selected clones of cassava was attempted. Repeated back crossing of inter-specific hybrids to cassava was carried out, but acceptable root quality did not recover (Abraham, 1972).

Tissue culture techniques :

Tissue culture techniques have also been standardized recently to develop disease-free materials by meristem culture and for germplasm preservation.

Summary

Cassava varietal improvement in India is chiefly carried out through selection of promising clones from both indigenous and exotic germplasm; intervarietal and interspecific hybridization; artifical production of chromosomal races; induction of mutation; tissue culture techniques, etc. One of the popular cultivars, presently in cultivation in areas where cassava is mainly used for fresh human consumption, is M-4, a cultivar introduced from Malaya. Similarly, "Sree Prakash", was identified as an early cultivar and is a selection from the indigenous collection. Sree Prakash recorded a yield of 35-40 t/ha in 7 months. Five high yielding hybrid clones have been developed following single or multiple hybridization involving both indigenous and exotic germplasm. These hybrids have recorded yields of 33-40 t/ha as compared to 23-28 t/ha of the local cultivars. The production of tetraploids, having higher protein content, and triploids with higher dry matter content, are the other achievements by the cassava breeding program. Research to develop clones with shade and drought tolerance, better plant type for close spacing, early harvestability, lower fertilizer requirement, high yield with good culinary quality, high starch content, etc, is also in progress.

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CASSAVA VARIETAL IMPROVEMENT AT PRCRTC, PHILIPPINES

Algerico M. Mariscal[1/]

Historical Background

Cassava *(Manihot esculenta* Crantz*)* has been providing subsistence Filipino farmers with an inexpensive source of carbohydrate since it was introduced to the Philippines in the early eighteenth century. It has been used as food, animal feed and industrial raw material. In 1951 the Philippine Congress passed Republic Act 657, known as the Cassava Flour Law (Acena, 1953) to encourage and promote the production, processing and consumption of cassava flour as a measure to conserve foreign exchange and regulate the importation of wheat. However, very little was achieved, possibly because of the lack of improved cassava cultivars as well as of strong policy support from the government.

Early research on cassava was focused on production and utilization problems (Molinyawe, 1967). Breeding activities consisted mainly of varietal trials of a few local and introduced cultivars. Major production constraints were identified. Yet no substantial improvement of yield was recorded.

Responding to this, the Philippine Council for Agriculture and Resources Research and Development (PCARRD) conceived a national research program on root crops in 1973. An assessment of the root crop industry was made and research needs were identified. The Visayas State College of Agriculture (ViSCA) in Baybay, Leyte, Philippines was chosen as the site of the National Root Crop Research Center, which later developed into the Philippine Root Crop Research and Training Center (PRCRTC). The center is mandated to spearhead root crop research in the country.

Varietal collection within the country started in 1975. In mid-1976 the International Development Research Center (IDRC) of Canada granted funds for a research project on cassava germplasm collection, hybridization and selection. It was only in 1977, though, that actual hybridization work started at PRCRTC.

To enable regional testing of developed and introduced cassava clones, the center established several cooperating stations in strategic locations throughout the country.

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Past Accomplishments

From 1975 to 1978 PRCRTC collected several cassava cultivars from different areas of the Philippines and abroad. Introduced accessions were obtained from Mayaquez Institute of Tropical Agriculture (MITA) of Puerto Rico and from Hawaii. In 1979, the cassava germplasm collection totalled 939 accessions, 254 of which were introduced hybrids or cultivars. Systematic evaluation and characterization eliminated duplicates. Hybrids not yet properly evaluated were not included in the germplasm collection. After characterization, PRCRTC maintained a total of 384 cassava accessions (Table 1).

After evaluating this germplasm material over the years and in different locations, PRCRTC recommended 3 cultivars for the farmers in 1980 (Table 2). These were edible types and were consistently giving good yields under the conditions of cooperating stations.

Table 1. PRCRTC cassava germplasm collection, 1987.

Source	No. of accessions
Local cultivars	134
Introduced accessions from	
CIAT, Colombia	30
Puerto Rico	6
Hawaii	6
Clones/hybrids from Puerto Rico and local crosses	208
Total	384

Table 2. Cassava cultivars released by PRCRTC, March 29, 1980.

Cultivar	Months to mature	Yield (t/ha)*	
		Fresh	Dry
PR-C 13 (Kadabao)	10-12	42	14.4
PR-C 24 (Golden Yellow)	8-10	43	16.9
PR-C 62 (Colombia)	10-12	46	15.2

* Average yield computed from the results of a series of tests from different testing locations.

Source : PRCRTC, 1980.

The germplasm accessions were evaluated for starch and HCN content, the main criteria used for selection of cultivars for fresh consumption. Using a quantitative analytical method (modified Lambert method), HCN levels lower than 50 mg/kg tissue were classified as low, 51-100 as intermediate, and higher than 100 as high (i.e. toxic) (Coursey, 1973). The germplasm collection had a wide variation in root starch and HCN contents, but no correlation was found between these (Table 3).

The quantitative analysis of HCN is costly and time consuming. To be able to analyze many samples in less time, the sodium picrate method, using 1 to 9 grades, was introduced and a highly significant correlation of this simplified method with the modified Lambert

Table 3. Evaluation of cyanide (sodium picrate method) and starch content among cassava germplasm.

Category	HCN 1/	Starch (% wet basis)	No. of accessions
Low (Sweet)	1-4	6-31	150
Medium	5-7	9-33	85
High (bitter)	8-9	5-34	125
		Total	360
Controls			
Golden Yellow	3	24.2	
Kadabao	4	24.3	
Hawaiian 5	9	18.3	
M Col 1684	9	24.7	

1/ Rating scale 1 to 9 based on color chart reaction of cyanide.
1-4: table type (< 50 ppm HCN)
5-7: moderately toxic (51-100 ppm HCN)
8-9: highly toxic (> 100 ppm HCN)

Source : PRCRTC, 1984.

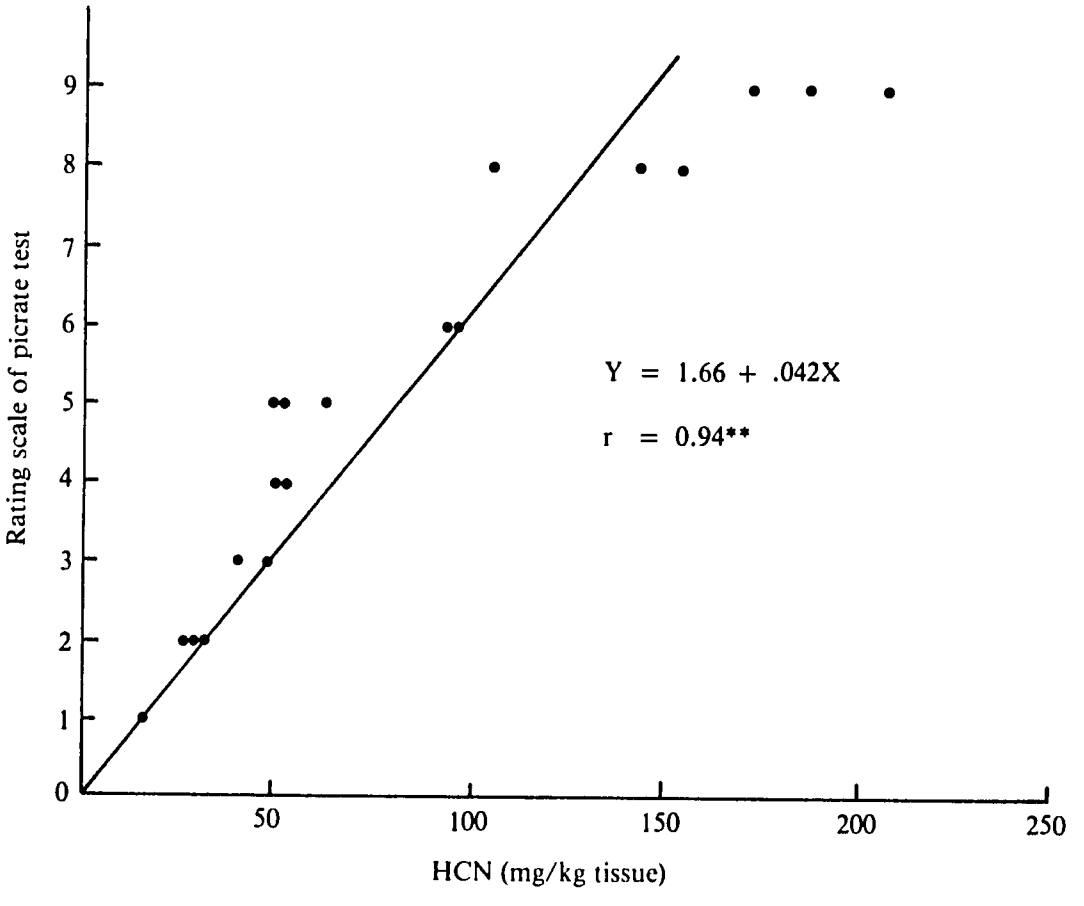

Figure 1. Relationship between the picrate test evaluation and the HCN content of various cassava clones as determined by the modified Lambert method.

method was obtained (Figure 1). The sodium picrate method is now routinely used at different levels of selections.

Promising parents were identified from both introduced and local germplasm for use in controlled pollination. Characteristics considered were high dry matter yield, low HCN level and resistance to pests and diseases.

In many areas along the Pacific coast and in the Visayas and Mindanao provinces, cassava is planted under coconut shade. Hence, a specific evaluation for cassava under this condition seemed appropriate. Results of the first evaluation using local germplasm from 1983 to 1984, revealed that a yield level of 8-19 t/ha under coconut trees was possible (Table 4).

Table 4. Performance of 8 cassava clones under coconut, 1983-1984.

Entries	Yield 1/ (t/ha)	Dry matter (% wet basis)	Starch (% wet basis)	HCN (ppm)
Lakan	16.0	45.0	38.7	27.2
Sip 242	19.7	35.7	26.3	59.0
PR-C108	13.7	39.6	29.3	9.2
C-CS 319 × 135	12.6	38.0	26.4	9.1
C-CS 135	8.2	34.8	25.0	11.5
Kadabao	14.4	44.0	34.3	45.1
PR-C 105	12.3	41.9	33.6	9.2
Golden Yellow	14.3	43.4	36.6	12.8
Level of significance	NS			
CV (%)	37%			

1/ Average of 4 replications.

Source : PRCRTC, 1984.

Table 5. Evaluation of introduced CIAT clones of PRCRTC and in farmers' fields, 1981-1982.

Entry	General yield trial, 1981 1/ (t/ha)	Farmer's field trial (1982) 2/	
		Fertile soil (t/ha)	Poor soil (t/ha)
CM 323-52	32.2	41.6	22.8
CM 305-38	20.9	35.5	12.8
MPTR 26	23.1	32.9	—
CM 308-197	21.9	46.5	—
CMC 84	14.3	32.7	—
HMC 4	17.6	32.7	—
CMC 40	21.2	36.5	16.9
M Col 1684	20.7	39.2	13.5
Golden Yellow (Check)	24.1	28.0	17.4
Kadabao (Check)	—	23.6	11.7

1/ Average yield from two different locations at PRCRTC

2/ Conducted in farmer's fields with their direct involvement.

Source : PRCRTC, 1982.

Lankan 1, Golden Yellow and Kadabao, recommended cultivars in the open field, were found to perform well also under partial shade.

The evaluation of ten clones introduced from CIAT in the early years, through the SEARCA and IDRC projects, resulted in the identification of CM 323-52, a clone selected from the M Col 22 × M Mex 59 cross, as the best, and well adapted to Philippine conditions (Table 5). It is characterized by high harvest index, good plant type and good root shape. It has shown stable performance in a predominantly rainforest climate. It can be used for starch and feed production or for fresh human consumption. In 1986, after clearing several years of regional trials, the Root Crop Technical Working Group of the Philippines Seedboard decided to officially release CM 323-52 as cultivar VC-1.

Table 6 shows that under the partial shade of coconut palms, CM 323-52 (VC-1) also showed high yield, compared to other entries of regional yield trials. Under coconut shade a yield of 16.0 t/ha is considered a great accomplishment.

Table 6. Resulf of regional trial (fresh root yield, t/ha) for 12 cassava entries under partial shade of coconut, 1984-1987.

Entry	Seasons				% of Check
	1984-1985	1985-1986	1986-1987	Mean	
Bogor 397	18.5	19.5	11.8	16.6	102
CMC 40	13.8	19.1	13.4	15.4	95
CM 308-197	15.1	—	11.2	13.2	92
Datu 1 (Check)	16.9	19.8	11.9	16.2	100
Golden Yellow	9.9	11.1	3.0	8.0	49
G 50-3	15.9	—	15.6	15.8	97
Lakan 1	—	13.0	7.4	10.0	63
M Col 1684	14.6	19.4	14.8	16.3	101
M Ven 218	—	13.1	5.3	9.2	58
PR-ch 1	—	18.2	8.3	13.2	84
Vassourinha	14.5	18.0	7.9	13.5	83
CM 323-52 (VC-1)	—	19.0	14.2	16.6	105
CV (%)	29.7	19.9	31.1		

Source : BPI-Tiaong Experiment Station, Tiaong Quezon, 1987.

Recent Developments

Cassava breeding of local and introduced cultivars started in 1977. Controlled hybridization utilized only limited germplasm from the Philippines, Puerto Rico and CIAT, Colombia. Progress in selection during this period was slow.

A systematic evaluation of locally developed and introduced hybrid materials started in 1982. This was made possible through the cooperative efforts between the PRCRTC and CIAT breeders and the establishment of the CIAT Regional Cassava Program in Asia in 1983.

When the PRCRTC researchers trained at CIAT returned in 1984, the Center's systematic breeding program was further accelerated.

The program was designed to produce cultivars that are best suited to the farmers' resources and conditions (Mariscal, 1985). The specific objectives are :

1. High-yielding capacity,
2. High root dry matter content,
3. Tolerance to pests and diseases as well as environmental stresses,
4. Early harvestability,
5. Low cyanide content of the root.

Breeding for high yielding cultivars is based on high harvest index and high root dry matter content under minimum input. High yielding cultivars will contribute to cassava's competitiveness with other feed sources by lowering the cost of production. Breeding for pest and disease resistance emphasizes on scale insects, mites and cassava bacterial blight (CBB), while breeding for tolerance to environmental stress focuses on drought, prolonged rainy days, partial shade and acid soils. Breeding for low cyanide content is important because of the need of subsistence farmers for sweet cultivars. Cultivars used for starch extraction need not consider the level of cyanide in the root. However, large starch factory farms generally prefer high cyanide cultivars to reduce losses from stealing.

To enable efficient selection and evaluation of developed and introduced hybrids, a systematic scheme was adopted, patterned after that used by CIAT.

Varietal Testing Scheme for Cassava

F_1 field selection :

Hybrid seedlings, including those from CIAT, are subjected to individual plant selection at this stage. Number of entries are normally in the thousands and these are planted at 2 × 1 m spacing. Selection is based on general stand of the crop, harvest index and disease and insect incidence. About 5-10% selection intensity is applied.

Observational trial :

About 5-7 stakes from plants selected in the F_1-trial are planted in a single row, at 1 × 1 m spacing without replication. A check clone is planted every 10 rows. Selection criteria at this stage of evaluation are yield per plant, harvest index, dry matter content and reaction to pests. About 10-20% selection intensity is practiced.

Preliminary yield trial :

Selected clones from single rows are planted in 5 × 5 m plots without replication. Selection becomes stricter, considering yield per plot, dry matter content, harvest index, root cyanide content and general stand of the crop.

General yield trial :

Selections from the preliminary yield trial are planted in 5 × 5 m plots with 2-4 replications. Important economic characteristics are closely monitored at this stage and yield, on a per hectare basis, is computed.

Advanced yield trial :

Selected clones from the previous trial are planted in 5 × 6 m plots replicated 3-4 times. At least 2-3 testing sites are required for each selected clone. Harvesting is done 10 months after planting. Parameters considered are yield per hectare, root dry matter and cyanide contents and general reaction to pests and diseases.

Regional yield trial (Philippine Seedboard trial) :

About 10-20 entries, selected by the Root Crop Technical Working Group, are planted in 4 × 9 m plots with 4 replications in each of 6-8 cooperating stations scattered throughout the country. Planting distance is 1 × 0.75 m. This trial is normally conducted in two cropping seasons per location.

Varietal recommendation :

Results of the regional trials for two normal growing seasons over a minimum of six locations are discussed in the annual meeting of the Root Crop Technical Working Group. A promising entry is then recommended to the Seedboard on the basis of superior yield, better agronomic and quality characteristics and a higher level of pest resistance over existing cultivars. It is at this meeting that entries may be dropped or retained and new entries for testing are determined.

Production of planting materials :

When the varietal release is approved by the Seedboard it is the responsibility of the agency developing the cultivar to maintain a supply of planting material for distribution. A multiplication plot is maintained in the center. Moreover, the cooperating station involved in testing are requested to establish multiplication plots for the approved cultivar(s) so that farmers and planters in their immediate vicinity can readily avail of the materials.

Distribution of planting materials :

This is usually done by extension workers and researchers during farmers' trainings on root crop production, usually held in VISCA or in other government centers upon request.

Utilization of Local and CIAT Introduced Germplasm Materials

It cannot be denied that local germplasms can be an excellent source of adaptation to local environments and traditional cultural requirements (Kawano *et al.*, 1986). However, a quantum leap in either yield or resistance factors cannot be expected as long as the breeding program uses only local germplasm, which by nature, possesses limited genetic variability. Thus, it seems that incorporating CIAT germplasm into PRCRTC breeding populations is desirable. The CIAT germplasm offers much wider genetic variation, considering that Latin American is the center of genetic diversity for cassava.

The PRCRTC germplasm collection has provided initial breeding material, though only to a very limited extent. Controlled breeding has yielded minimal and unsatisfactory results due to the narrow genetic variation of the available germplasm. It was only in 1983 that the local breeding program gained momentum when CIAT-introduced materials were used as cross parents to the local cultivars. Some of these cross parents were CMC 40, CM 323-52,

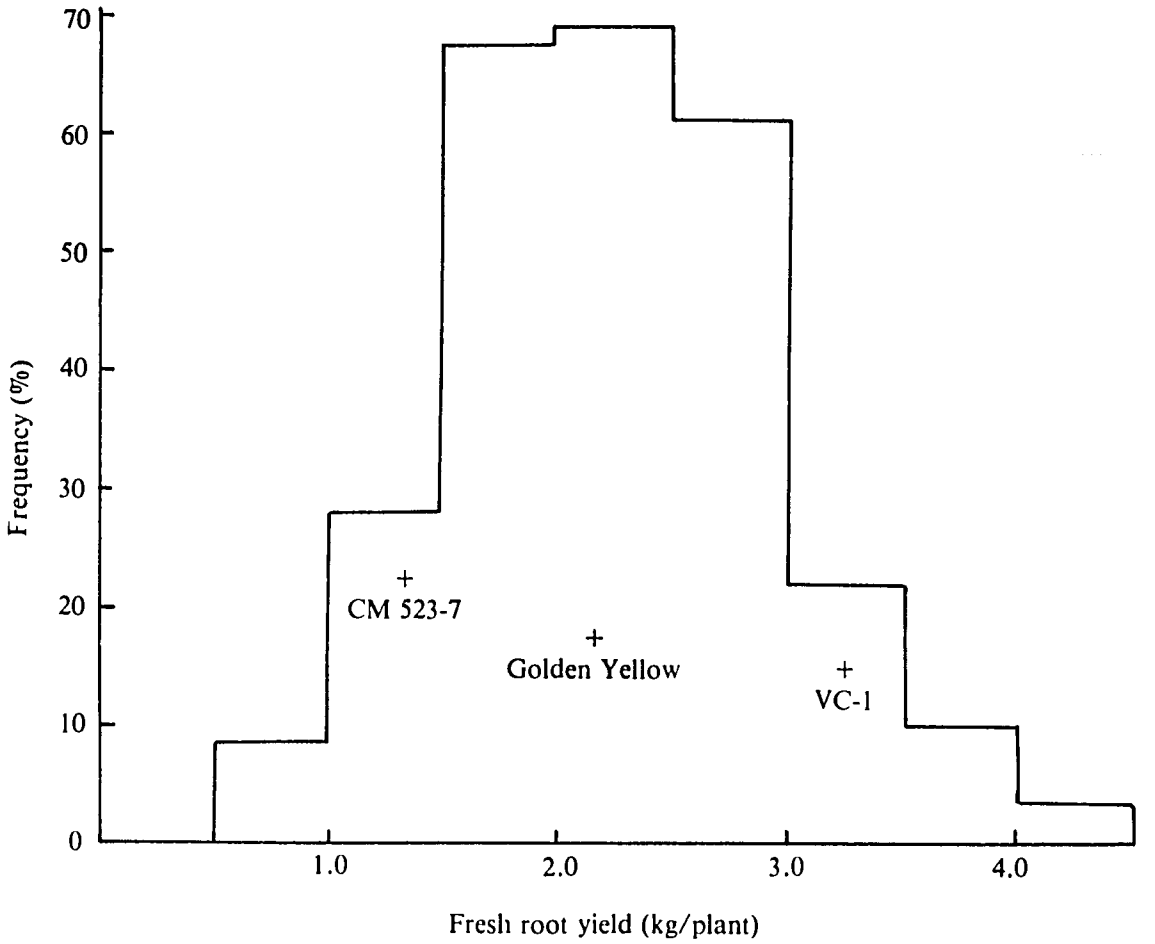

Figure 2. Frequency distribution of fresh root yield of local × CIAT crosses and check clones obtained in a single row trial at PRCRTC, ViSCA, Philippines in 1986.

M Col 1684, CM 308-197, CM 305-38 and MPTR 26. The locally developed hybrids had already undergone a series of screenings. The single row trial of CIAT × local crosses have shown very promising results (Figure 2). However, selection is still in the second stage of preliminary yield trial because of severe typhoon damage.

Starting in 1982, PRCRTC has been regularly supplied with improved seed populations from CIAT (Table 7). The introduced cassava hybrids were evaluated systematically based on the established selection criteria, allowing superior genotypes to be identified for inclusion to the advanced trials (Table 8).

The first batch of seed introduction in 1982 produced selected clones with superior yielding ability over the local cultivars (Table 9). From these, four hybrid clones: CM 3320-11, CM 3590-1, CM 3380-30 and CM 3504-8, were selected for inclusion in the seedboard regional yield trial. Of these, CM 3380-30 generally showed resistance to spider mites and CBB.

From the second CIAT seed introduction in 1983, twelve elite hybrids were selected (Table 10). The yielding ability was again superior to that of existing cultivars. Root dry matter content was relatively high compared to the commonly used cultivar Java Brown.

Table 7. CIAT cassava hybrid seeds supplied to PRCRTC, ViSCA, Baybay, Leyte, Philippines.

Date	No. of seeds	No. of crosses	Principal cross no.	Principal parents
Aug. 1976	250	5	CM 585	M Mex 55
			CM 690	M Col 638
Jan. 1982	2200	43	CM 2450	M Col 22
			CM 3320	CM 342-170
			CM 3504	CM 523-7
			CM 3816	CM 586-1
Nov. 1982	5550	100	CM 3341	CM 681-2
			CM 4011	CM 849-1
			CM 4049	CM 922-2
			CM 4234	CM 1015-19
Jan. 1985	2800	56	CM 4397	M Bra 12
			CM 5371	CM 942-14
			SM 306	CM 1335-4
			SM 418	CM 1523-19
Oct. 1985	3000	60	SM 457	M Bra 35
			SM 598	CM 681-2
				CM 2452-5
				M Thai 1
Jan. 1987	2100	42	SM 729	M Col 2207
			SM 838	CM 2772-3
			SM 845	SG 107-35

Table 8. Utilization of CIAT seed introduction by the cassava varietal improvement program, PRCRTC, ViSCA, Baybay, Leyte, Philippines. - Schematic presentation by number of genotypes.

Evaluation step	1976/ 1977		1980/ 1981	1981/ 1982	1982/ 1983	1983/ 1984	1984/ 1985	1985/ 1986	1986/ 1987	1987/ 1988
Seed introduction										
No. Seeds	250			2200		5500		2800	3000	2100
(No. crosses)	(5)			(43)		(100)		(56)	(60)	(42)
Seedling selection								2105	1200	
Single-row trial					483		819		294	61
Preliminary trial						176		156		68
Advanced trial							24	8	29	12
Regional trial									4	

Source : PRCRTC, 1987.

Table 9. Result of advanced yield trial at PRCRTC, ViSCA, Baybay, Leyte, Philippines, 1985-1986.

Clone	Parents	Dry root yield (t/ha)	Root dry matter contents (%)	H.I.	HCN 1/
CM 3504-8	CM 728-2 × CM 523-7	12.0	39	0.66	7
CM 3590-1	CM 859-12 × M Col 22	11.0	37	0.63	7
CM 323-52	M Col 22 × M Mex 59	10.4	34	0.63	6
CM 3320-11	M Bra 12 × CM 523-7	9.4	36	0.54	6
CM 3340-3	CM 342-170 × CM 586-1	8.9	32	0.63	4
M Col 1684		8.1	30	0.62	9
CM 3422-3	CM 630-122 × CM 728-2	6.6	33	0.64	6
CM 3341-4	CM 342-170 × CM 523-7	5.7	31	0.61	7
CMC 40		5.7	30	0.56	4
CM 3380-30	CM 586-1 × CM 523-7	5.1	35	0.54	5
Golden Yellow (Local control)		4.8	35	0.38	3
CM 3816-4	CM 1191-9 × CM 523-7	4.4	34	0.50	7

1/ Rating scale 1-9; 1 = very low; 9 = very high

Source : PRCRTC, 1986.

Table 10. Yield data of 12 selected cassava hybrids in advanced yield trial 1985-86.

Clone	Parents	Dry root yield (t/ha)	Root dry matter content (%)	H.I.	HCN 1/
CM 4066-1	CM 1016-6 × CM 922-2	8.0	34	0.67	5
CM 4050-1	CM 1015-19 × CM 922-2	7.4	31	0.69	6
CM 4054-3	CM 1015-34 × CM 849-1	7.3	32	0.70	9
CM 4064-6	CM 1015-42 × CM 849-1	7.3	34	0.60	5
CM 4011-5	CM 728-2 × CM 681-2	7.2	31	0.69	6
CM 4050-7	CM 1015-19 × CM 922-2	7.1	32	0.68	6
CM 4049-8	CM 1015-19 × CM 849-1	6.9	35	0.66	6
CM 4049-1	CM 1015-9 × CM 849-1	6.2	33	0.58	8
CM 4012-11	CM 728-2 × CM 849-1	6.0	31	0.74	5
CM 4014-3	CM 728-3 × CM 681-2	5.8	31	0.73	6
CM 3341-105	CM 342-170 × CM 523-7	5.0	29	0.70	5
CM 4039-7	CM 950-3 × CM 922-2	5.0	32	0.66	7
Java Brown	(Local control)	5.5	30	0.49	8
Golden Yellow	(Local control)	3.2	31	0.49	4

1/ Rating scale 1-9; 1 = very low; 9 = very high

Source : PRCRTC, 1986.

The remaining CIAT seed introductions are in different stages of screening and evaluation. Hopefully, new cultivars will be developed from this pool of improved CIAT materials.

Although PRCRTC has its own breeding program, using both local and introduced cultivars/hybrids, it seems that yearly introductions of improved populations from CIAT are

desirable so that new genes of potential utility can be continuously incorporated into the breeding program.

Future Direction and Priority Areas

The prospect of cassava in the Philippine economy rests greatly on domestic demand. In recent years, large cassava plantations have been set-up in the country to supply the raw material for starch factories. In addition, the government has been promoting cassava in order to partially replace the huge importation of corn (approximately 600,000 t/year) for animal feed. There is still an untapped market potential to be explored for cassava.

In line with the medium-term Phillippine Development Plan (1987-1992), the research priority should include a package of programs which will serve to greatly increase the crop's productivity. As such, PRCRTC should significantly contribute to development of the countryside by offering cassava cultivars that are more suitable and more attuned to the small farmers' needs and agroecological conditions.

Cassava breeding research, therefore, should have the following priorities :

1. Maintenance and development of a wide genetic base in the germplasm collection consisting of local and CIAT materials.
2. Development of high yielding cultivars for problem (acidic, water logged) and marginal (low fertility, hilly areas) soils. Tolerance to environmental stress conditions such as drought, and partial shade.
3. Selection of cultivars suited for starch production and animal feed.
4. Breeding for tolerance to pests and diseases, mainly scale insects, spider mites and CBB.
5. Establishment of a network for farmers' field trials in strategic cassava growing areas for effective transfer of developed technology.

Network Collaboration

Several countries in Asia have their own national cassava programs designed to meet the country's needs. In breeding, many of the major objectives are common among Asian countries (Kawano, 1986). Therefore, it seems imperative that the national programs of the region exchange and share research results with each other through a regional cassava network, in which the CIAT Regional Office should take the lead.

The areas in which collaborative research is needed are the following :

1. Germplasm exchange,
2. Joint testing of recommended cultivar(s) from each country,
3. Dissemination of information about cassava research and development,
4. Economic analysis on production and utilization,
5. Utilization and product diversification.

These collaborative areas will permit the national programs to design their research program in a manner that will avoid unnecessary duplication of efforts and yet permit necessary testing of results in local areas. The capabilities of each national program for

undertaking specific collaborative projects of common interest, should be assessed. The national program for network collaboration should also seek both human and financial assistance from external sources like FAO, IDRC, CIAT and others.

Through networking, each national program can gain experience from the other national cassava programs in the region. Directly or indirectly this will facilitate the improvement of cassava research and development.

Summary

Cassava breeding research in the Philippine Root Crop Research and Training Center (PRCRTC), VISCA, Baybay, Leyte, Philippines, started in 1977. Collection and evaluation of local and introduced cassava germplasm were the initial activities. In 1980, PRCRTC recommended three cassava cultivars (Golden Yellow, Kadabao and Colombia) for the farmers. These were the results of a series of tests of local germplasm. Promising cultivars for planting under coconut were also identified.

With the close collaboration with CIAT, starting in 1982, the cassava breeding program at PRCRTC significantly improved. CIAT regularly provided the center with advanced cassava hybrid seeds for evaluation and incorporation in the local × CIAT hybridizations. Systematic screening and evaluation of locally developed and introduced hybrids were made following the scheme of CIAT. In 1986, a CIAT-derived clone, CM 323-52, was recommended by the Philippine Seedboard for release as a new cassava cultivar, VC-1. Several promising hybrids are still in the pipeline for further screening and evaluation.

Cassava breeding research at PRCRTC is geared towards the development of cultivars that are useful to the starch and animal feed industries. Moreover, it will emphasize the development of cultivars adapted to stress environments.

Future network collaboration among Asian countries is discussed and areas of interest are identified.

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CASSAVA VARIETAL IMPROVEMENT AT THE UNIVERSITY OF THE PHILIPPINES AT LOS BANOS

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Historical Background

Records show that before the 1970's, research on cassava at the University of the Philippines at Los Banos (UPLB), and in the whole country for that matter, was scanty. This was especially true in the case of varietal improvement. The study of Alzona (1935), where 20 cassava cultivars were compared in terms of yielding ability and starch content, and that of Capinpin and Bruce (1955) on the floral biology and cytology of cassava, were about the only works during the early period related to varietal improvement of the crop.

Initial efforts to start a cassava breeding program at UPLB were made by Mamicpic of the Department of Agronomy when he evaluated in late 1969 (unpublished data) cultivars of cassava for yield and other characteristics, and collected in 1971 some cultivars during an exploration trip to Indonesia. Empig in 1971-72 (unpublished data) continued the varietal evaluation work as well as the collection of germplasms, so that by the time the author took over the cassava breeding work in the department (late 1972) there were already 56 accessions in the UPLB cassava gene bank. In early 1973, UPLB received a modest grant from the National Science Development Board (now Department of Science and Technology) for root crops research with emphasis on varietal improvement, marking the official start of the UPLB root crops breeding program. The establishment of the Institute of Plant Breeding (IPB) at the University two years later assured the UPLB root crops breeding program, which had then become a joint undertaking of IPB and the Department of Agronomy, of a more or less regular though limited financial support.

Breeding Objectives

From the very start, the author has held the view that cassava should be grown in the Philippines not as a food crop but more for its potential as a feed crop and as a source of industrial starch. Thus, in the UPLB cassava breeding program, the breeding objectives have always been the characteristics that are desired of a cassava cultivar to be used as a feed and/or starch source. Eating quality, earliness, and cyanogenic glucoside (this will be referred in the rest of the paper as HCN) content of the roots have not really been used as the major bases for selection, but have only been considered when everything else was equal in the genotypes

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compared. Thus, emphasis has been more on root yield, both on fresh and dry basis, starch contents and characters that are important regardless of how cassava will be utilized, like resistance to pests and diseases. Lately, tolerance to environmental stresses, particularly shading, is also being considered.

Breeding Materials and Procedures

The UPLB cassava breeding program has to date acquired 144 accessions, which, except for a few which were not multiplied, have all been evaluated at least for yield performance. However, only 79 of the accessions, 46 of which are foreign introductions, have been maintained. More than half (81) of the original cassava collection were obtained locally but many of these appear to be duplicates of a few cultivars. Carpena and Baldos' (1973) estimate of no more than five cultivars of cassava that can be considered native to the Philippines may look a little low considering the size of the local collection, but is still believed by the author to be close to the reality.

Because of the limited genetic variability available in local cassava cultivars (Carpena, 1983), the UPLB cassava breeding program has relied heavily on introduced germplasm accessions which, although not so many, fortunately seem to have provided the program sufficient genetic variability, at least during the early years of its existence. Recently, foreign materials acquired by the program have been largely in the form of seeds of CIAT-developed varietal crosses. Evaluation of some of these materials has been started. It is hoped that these materials will also prove as useful to the UPLB cassava breeding program as the earlier introductions.

Accomplishments and Present Status

In spite of the major difficulties, three of the UPLB selections have become Philippine Seed Board recommended cultivars; an edible or "sweet" (low HCN content in the roots) cultivar, namely, Lakan 1, and two non-edible or "bitter" ones (high HCN content), namely, Datu 1 and Sultan 1. Both Lakan 1 and Datu 1 are introduced cultivars, the former from Indonesia and the latter from unknown origin (it used to be called Hawaiian 4 because it was brought from abroad by somebody connected with one of the pineapple plantations in the Philippines). These two cultivars were recommended before the regional testing (third or final stage of evaluation) of cassava clones in the Philippines became an interagency activity. The basis for recommending these cultivars were therefore only the data obtained from tests conducted by UPLB (Table 1). However, even trials now, jointly conducted by UPLB, the Philippines Root Crops Research and Training Center (PRCRTC), and the Bureau of Plant Industry (BPI), have shown that these cultivars are outstanding in their respective categories (sweet and bitter types).

The third recommended cassava cultivar from UPLB, Sultan 1, is a varietal cross of two Indonesian cultivars (Bogor 397 × Sip 24-2). Table 2 shows the performance of this cultivar along with those of other promising entries from both UPLB and PRCRTC. Aside from giving a very high root yield, this cultivar also has short compact roots which makes harvesting easy. It should, however, be further improved for its root dry matter content, which, as can be seen in Table 2, is lower than that of Datu 1.

Table 1. Average yield and other characters of nine promising and one standard cassava accessions at 10-11 months, grown at UP Los Banos and La Granja, La Carlota City, in 1975-1978. 1/ 2/

Variety	Root yield (t/ha)	% Root dry matter	% Root starch (wet basis)	HCN content 3/	Plant height (cm)	% Bacterial blight infected plants 4/
Bogor 397	44.7	34.5	24.3	Med.	284	1.8
Gariasa	36.7	36.5	25.2	Med.	286	0.5
Hawaiian 3	33.9	36.5	27.4	Low	261	0.4
Hawaiian 4 (Datu 1)	43.6	39.2	28.9	Med.	268	0.6
Indonesian Acc. 16	31.5	42.2	32.1	Low	286	0.7
Indonesian Acc. 17	30.8	44.2	33.0	Low	257	4.1
Java Brown (check)	23.3	40.7	30.4	Med.	313	1.2
Matalin Collection	43.6	36.6	27.2	Med.	272	1.7
Sip 24-2	35.3	35.8	25.7	Low	269	1.2
W78 (Lakan 1) A	31.0	44.0	32.8	Low	259	5.3

1/ **Source :** IPB Report, 1976-78.

2/ Data are means of six seasons (3 in each location) except for those on dry matter and starch content which are means of four seasons only (2 in each location).

3/ Low = 0-100 ppm; Med = 200-400 ppm.

4/ In all cases, only tips of plants were infected.

Table 2. Root yield and dry matter and starch contents of 12 cassava varieties and hybrids in five years of trials in the open (5 stations) and three under partial shade (1 station)*.

Entry	Open			Under Shade		
	Root yield (ha)	% Root dry matter	% Starch (wet basis)	Root yield (ha)	% Root dry matter	% Starch (wet basis)
Bogor 397	32.1	38.5	33.2	16.6	43.8	35.1
CMC 40	26.4	40.1	37.2	15.4	44.4	36.7
CM 308-197	37.2	43.6	41.8	13.2	41.2	34.0
CM 323-52	36.6	41.3	37.4	16.6	42.0	33.9
Datu 1 (check)	37.5	39.9	35.0	16.2	43.1	34.6
Golden Yellow	25.2	47.2	42.9	8.0	51.6	41.7
G50-3 (Sultan 1)	50.8	35.2	30.7	15.8	36.8	29.5
Lakan 1	29.4	44.9	42.2	10.0	48.5	40.2
M Col 1684	36.5	38.8	34.6	16.3	40.9	34.3
M Ven 218	23.6	44.4	39.5	9.2	42.4	35.6
PR-CH 1	21.1	44.1	36.4	13.2	43.8	36.1
Vassourinha	29.6	42.0	37.5	13.5	39.5	33.1

* Root yield data in open were based on 4 to 13 trials and those under shade on 2 to 5 trials. Root dry matter and starch content data were based on 2 to 3 trials in open and on one trial under shade.

At present, three selections from the UPLB-developed varietal crosses are in regional trials, although they are not in all the stations involved because of the lack of planting material.

Most of the entries in this year's UPLB preliminary and general trials (respectively, first and second stages of varietal evaluation in the Philippines) are CIAT-developed crosses. This situation plus the fact that only 19 local crosses are being multiplied at present at UPLB make it very likely that in the next few years, varietal releases from UPLB will consist largely of introduced crosses.

Future Directions and Priority Areas

Breeding objectives :

In the light of what it has accomplished so far and the new problems it is now facing, the UPLB cassava breeding program has to make some changes in its breeding objectives and orientation. Now that it has come up with two outstanding non-edible cultivars the program is beginning to consider lower root HCN content as a major breeding objective. Varietal crosses with at least one low-HCN parent are now given priority over others. This emphasis on lower HCN content in roots should continue for some time.

Tolerance to shading (cassava grown under coconut shade) will continue to be the main component of our stress tolerance selection. Other stress environments, e.g., drought and acid soils will be considered only if more funding will go into the program.

Last year's high incidence of cassava bacterial blight (CBB) at the UPLB plantings has served as a warning that this disease could become a serious threat to cassava production in the country. The work on CBB at UPLB has so far been limited to evaluation of materials in their reaction to the disease under field conditions. Very soon, laboratory screening for resistance to the disease has to be started and so is the incorporation of resistance genes to susceptible but high yielding cultivars such as Datu 1.

Breeding methodoligies :

The finding of Rimando and Faustino (personal communication) on the reproductive physiology of cassava suggests that flowering may be jointly controlled by temperature and daylength. Indeed, more flowering is observed during short-day months in the new experimental area of UPLB, where night temperatures are lower than in the old field. The UPLB cassava breeding program may therefore be able to include more genotypes in hybridization if parental clones are grown in cooler (higher altitude) areas. Utilization of CIAT germplasm in future hybridization work is anticipated. However, the UPLB cassava breeding program should also start considering more non-conventional breeding approaches, e.g., the use of tissue culture techniques in generating genetic variation.

Need for Network Research and Cooperative Projects

As seen above, the UPLB cassava varietal improvement program would not have accomplished anything without the genetic materials it has obtained from other countries. To continue to exist, it has to also continue to receive such materials. This seems possible only if it could establish linkages with other institutions doing research on cassava. In exchange for breeding materials from these institutions, UPLB could test some of the genotypes developed by these research institutions. UPLB is at present enjoying this kind of arrangement with

CIAT only. It will be desirable if the University can also have cooperative projects with cassava research programs in other Asian countries.

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CASSAVA VARIETAL IMPROVEMENT IN CHINA

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Introduction

Cassava can be cultivated in the areas to the south of the Huaihe River and Qinling Mountain and in the reaches of the Changjiang River with a frost-free period of more than 8 months and mean annual temperature higher than 16°C. In view of the availability of suitable land and abundant labor resources, the potential of cassava production in China is high. In recent years, the use of cassava has gradually increased due to the crop's development and industrial utilization. Total cultivated area under cassava in China has increased to more than 400 thousand ha with an annual fresh root production of about 4 million tons. Cassava is one of the main starch and animal feed crops in South China. However, the cultivars which are extensively cultivated in China at present are traditional farmers cultivars. It is difficult to further improve the yield levels of farmers with these cultivars. Thus, cassava varietal improvement is much needed to introduce further social and economic benefits to the producers of this important crop in South China.

Breeding Objective

Most of the cassava producing areas in China are located between 18° and 32° N and have a subtropical climate with distinct dry and wet seasons. The temperature is low in winter and early spring. Cassava is usually planted in February and harvested in December with a growth period of only 8-9 months. The yield and root quality are often affected by typhoons in summer and autumn, as well as by the outbreak of diseases. Accordingly, the objectives of cassava breeding and selection are:

1. High yielding capacity
2. Early harvestability
3. Cold tolerance
4. Wind tolerance
5. Adaptability to low soil fertility
6. Disease resistance (especially to CBB)
7. Low root cyanide content (for table cultivars)
8. Stake storability in winter
9. Overall adaptation to each major production area.

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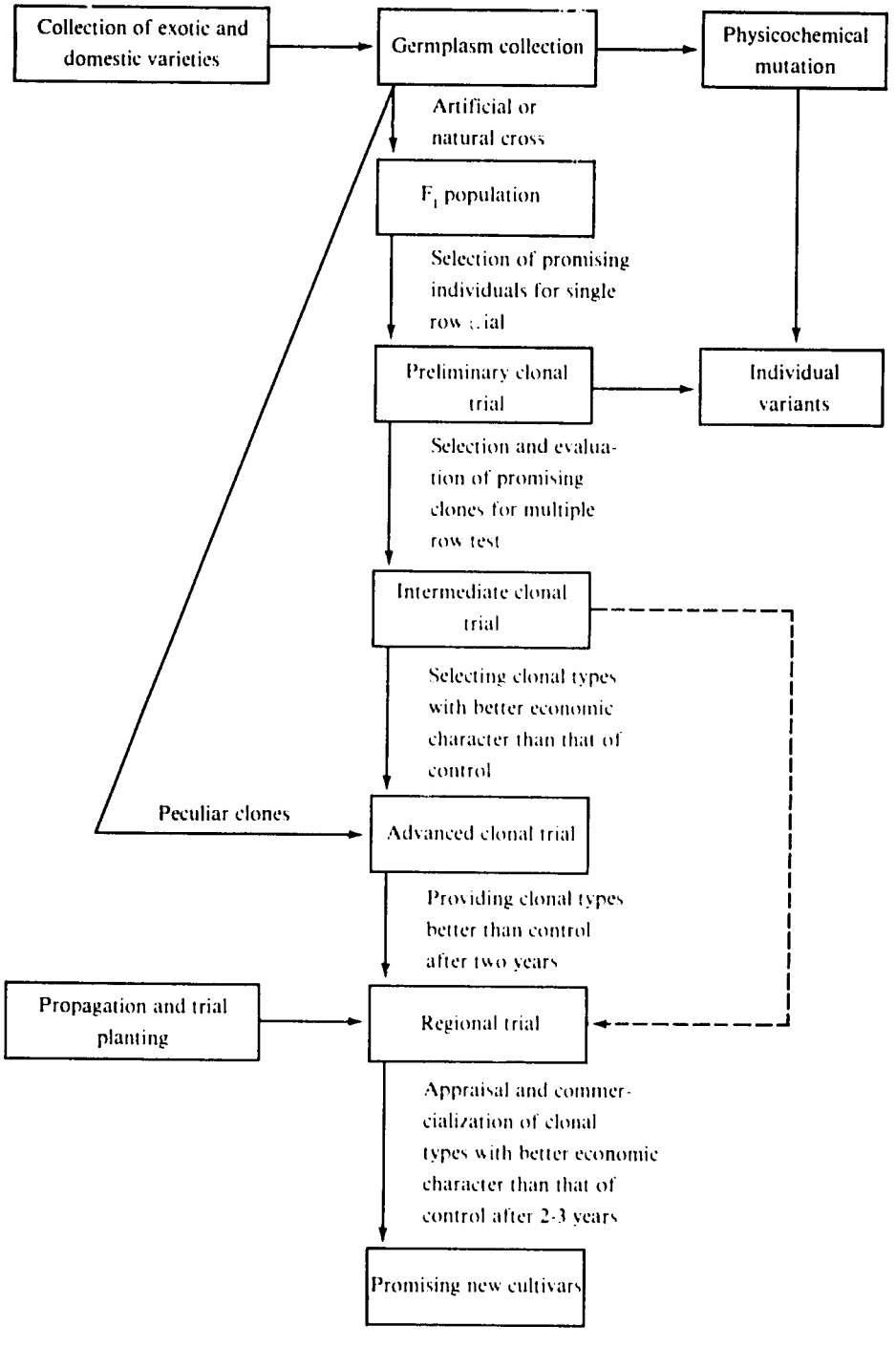

Figure 1. Methods and steps adopted for cassava varietal improvement in China.

Cultivars SC205 and SC201 are the leading cultivars for industrial purpose in Guangdong and Guangxi provinces, respectively, while SC101 and SC6068 are the most widely used cultivars for fresh human consumption. Thus, the yield levels of new cultivars must be higher than those of SC205 or SC201 in their respective areas of adaptation and the eating quality of new table cultivars must be equal to or better than SC101 or SC6068. The root starch and dry matter contents of these local cultivars are in the range of 30 and 40%, respectively; thus, the root starch and dry matter contents of new cultivars must not be below those of the traditional cultivars. Especially for the north of Guangxi province, where the winter is long, the growth duration of new cultivars should be equal to or shorter than that of SC201 and their planting stalks should be able to survive storage during the several winter months.

The main approach to cassava varietal impovement in China is to collect, conserve, evaluate and utilize the elite varietal resources both from China and abroad for intervarietal hybridization. The methods and steps usually adopted are shown in Figure 1. Generally, it takes 8-9 years to breed a new cultivar in China. But if it is started with intermediate clonal trials (F_1C_2), while regional tests are conducted at the same time, the breeding cycle can be shortened to 6-7 years.

Development of Cassava Varietal Improvement Program

Formal research on cassava varietal improvement began relatively late in China. Work has been done on the collection and utilization of foreign and domestic genetic resources, but no major breakthrough has been made and the research thus needs further effort.

Collection and utilization of domestic cassava varieties:

Cassava varietal variation in China is relatively limited. Most of the existing local cultivars were introduced from abroad. About 40-50 cultivars may exist in Guangdong, Guangxi and other provinces. However, there are less than 20 cultivars which are commercially grown in sizable areas (Table 1). These cultivars include sweet and bitter types. Most of the bitter cultivars are late or intermediately late cultivars with high yield, such as SC201, SC202, SC203 and SC205, while the sweet ones are mostly early or intermediately early cultivars with good flavor but with relatively low yield, such as SC101, SC102 and SC105. Before the 1950s the farmers paid little attention to the selection of elite cultivars, so that the productivity was low with a mixture and confusion of clones. The average yield in China at that time was less than 5 t/ha, with only 3.6 t/ha in Guangxi and about 6 t/ha, in Guangdong. Since the 1960s, the yield has increased to the present level of 9 t/ha due to the progressive commercialization of high yielding local cultivars such as SC201 and SC205.

Among the existing local cultivars, SC201 and SC205 are the best yielders. They are bitter types and are the most widely cultivated, accounting for more than 90% of cultivated area and 95% of cassava production. SC201 is comparatively tall and broad-leafed and its planting stakes can be stored for a long time and germinate well. The cultivar is tolerant of drought and low soil fertility. It produces thick and long roots, which grow shallow, making them easy to harvest. Generally, its yield can reach 30-38 t/ha under favorable conditions, but the yields of only 7-8 t/ha are also common under poor management. This cultivar is less wind-tolerant and planted mostly in the central and northern parts of Guangdong and Guangxi.

Table 1. Main local cassava cultivars in China.

Cultivar	Place of origin	Root yield (t/ha)	Dry matter content (%)	Starch content (%)	Toxicity	Maturity	Harvest index
SC201	Guangdong, Guangxi, Fujian	24.3	37.0	27.0	High	Late	0.59
SC205	Guangdong, Guangxi, Fujian	25.2	37.0	28.0	Moderate	Middle-late	0.68
SC101	Guangdong, Guangxi, Areas South to the middle and lower reaches of Changjiang River	16.2	41.0	30.8	Low	Middle-early	0.60
SC102	ditto	13-15	42.0	32.2	Low	Early	0.50
SC202	West Guangdong	23.0	35.0	24.0	Rather high	Late	0.62
SC203	West Guangdong	22.0	35.0	22.0	Rather high	Late	0.66
SC204	Guangdong, Guangxi	14.0	44.0	32.7	Moderate	Early	0.53
SC206	Hainan Island	20.3	41.6	27.2	Moderate	Middle-late	0.70
SC207	ditto	19.8	43.0	29.8	Moderate	Middle-late	0.60
SC208	Guangdong	15.0	36.0	25.5	High	Middle-late	0.63
SC209	ditto	16.6	41.0	32.4	High	Middle-late	0.56
SC210	ditto	15.0	46.6	34.8	High	Middle-early	0.61
SC211	Hainan Island	12.4	44.7	33.8	Moderate	Middle-late	0.56
SC103	ditto	14.5	43.0	31.6	Low	Middle-early	0.57
SC104	ditto	14.0	42.0	31.5	Low	Middle	0.60
SC105	Maoming in Guangdong	15.2	44.7	31.1	Low	Middle-early	0.60

SC205 is comparatively short, narrow-leafed and intermediate in growth duration. It produces well-shaped roots in large quantities and in a compact pattern, thus facilitating the harvest. Its harvest index is comparatively high and its resistance to cassava bacterial blight (CBB) is adequate. The cultivar can yield upto 45 t/ha under favorable conditions. It is widely planted in the southern parts of Guangdong and Guangxi and in Hainan island.

The root yields of all the sweet cultivars are comparatively low and their cultivated area is small. The recommended cultivars, SC101 and SC102, are characterized by precocity, high root dry matter and starch contents and low HCN content with a good taste. These two cultivars are suitable for subtropical areas, yielding upto 23 t/ha under good conditions. Presently, they are the leading cultivars in the soutnern parts of the middle and lower reaches of the Changjiang River.

Other native cultivars are planted only locally on a small scale. Recently, these materials have been collected and are being preserved as breeding materials.

Introduction and utilization of exotic germplasm resources :

Since 1982, the South China Academy of Tropical Crops (SCATC) has introduced from CIAT more than 30 clones in the form of disease-free meristem culture and 13,000 hybrid seeds from 238 cross combinations (Table 2). Some clones from the meristem culture introduction, such as M Col 22, M Thai 1 (Rayong 1), M Col 1684 and M Col 1468 have been propagated and planted for experimentation. A quantity of hybrid seeds have been obtained

Table 2. Evaluation and selection of hybrids from CIAT at SCATC in 1982-1987.

Method \ Number \ Year	1982	1983	1984	1985	1986	1987
Seeds	2300	2050	2375	1475	2500	1250
(combination)	(38)	(41)	(71)	(52)	(50)	(25)
Seedlings	830	1077	1116	1150	1323	630
Preliminary clonal trial			22	89	29	83
Intermediate clonal trial				11	26	5
Advanced clonal trial					3	14
Regional trial						1
Germplasm collection					5	2

from these clones. A great number of clones have been selected from the CIAT seed population. These new clones represent important new genetic resources for cassava breeding in China.

Promising clones selected from the earlierseed introductions are in the advanced stage of evaluation. A good example for these is CM 4031-2, which is high yielding and appears to be adapted to poor soils. Its harvest index is high and its compact root development in the shallow layer facilitates the harvest. CM 4031-2 is moderately resistant to CBB and highly tolerant to wind, but its leaves and nodes are relatively sparse and apical branching occurs rather early. The experimental results obtained between 1983 to 1986 show that the overall yield was higher than that of SC205 and that this high yielding characteristic was stable (Table 3).

Table 3. Yield parameters of CM 4031-2 and SC 205 during several years.

Clone	Root yield				Root dry matter content	Harvest index
	1983	1984	1985	1986		
	kg/plant	t/ha			%	
CM4031-2	2.4	31.5	16.5	15.5	35.5	0.66
SC205		26.0	14.5	13.0	36.7	0.68

Note: Dry matter content and harvest index are the averages of three years.

A group of new clones which have been selected from the later seed introductions are also coming out the pipeline. Among these, CM 3503-3, CM 3970-8 and CM 4146-2 are good examples, possessing good plant type and root yield (Table 4).

Observations for several years indicate that the hybrid progenies from CIAT offer a wide genetic variability, from which types with greater growth vigor, good plant type, good root shape, higher dry matter content and higher resistance to CBB can be selected.

Table 4. CIAT clones tested in an intermediate clonal trial in 1986.

Clones	Root yield (t/ha)	Root dry matter content (%)	Harvest index
CM3970-8	30	39	0.61
CM4077-1	27	39	
CM4048-8	25	37	0.56
CM3993-2	24	32	0.55
CM4230-4	29	33	0.52
CM4146-2	36	42	
CM4027-4	26	40	0.58
CM4044-1	24	41	0.51
CM3503-3	36	35	0.61
CM4063-3	26	41	
CM3993-9	32	37	
CM3993-4	36	38	
CM4046-4	45	36	0.57
SC205 (Control)	31	39	0.65

Note: The root yield of SC205 is represented by the highest yielding plot of SC205.

Present Status of Cassava Varietal Improvement in China

Open-pollinated seeds of cassava were collected and cross-breeding was tried by Prof. Liang Guangshang in the South China Agricultural University as early as 1956-1957. Extensive and systematic studies on the improvements of local cassava cultivars were conducted by Prof. Wen Jian and his team in SCATC from 1958 to 1965. Collection, conservation, evaluation, utilization and cross-breeding of these resources was done and a variety of scientific data for further cross-breeding was accumulated. In about 1975 the cassava research was reestablished, continuing the work iniciated by our predecessors. The following are the advances made in cassava varietal improvement in China in recent years:

1. Evaluation and recommendation of high yielding and precocious local cultivars, such as SC201, SC205, SC101 and SC102, which have helped increase the average yield of cassava from 5 to 9 t/ha, and have extended the cassava cultivated area to the southern part ot the middle and lower reaches of the Changjiang River.

2. Breeding and release of SC6068, which was selected from the clonal progenies of the natural hybrids of SC101. This sweet cultivar is characterized by precocity, low root cyanide content, and high root dry matter and starch contents. It is planted commercially in Guangdong, Guangxi, Fujian and other areas and has replaced the lower yielding sweet cultivars of the regions.

3. Successful breeding of a mutant of SC6068 at SCATC through chemomorphosis. This is the first cassava mutant clone in China. The clone never branches and is very wind resistant. It is more tolerant to root rot as compared with SC6068. This has provided experience for mutation breeding in China. A number of mutation lines have since been obtained and are now preserved at SCATC. But the real usefulness of these materials has yet to be determined.

4. Collection of new germplasm resources to set up a small-sized germplasm bank for their appraisal and screening to determine their agronomic and resistance characters.

5. Screening and conservation of improved clonal types, which have the characteristics of wind and disease resistance, cold tolerance, high yielding capacity, low toxicity and good flavor (Table 5). The results of regional experiments with E-24 over the years showed that it yielded between 21.7-38.8 t/ha under various soil conditions in different places, outyielding SC201 and SC205 by 24 and 28%, respectively. This clone has already started to spread to Guangdong and Guangxi provinces.

Table 5. Main improved clones selected in SCATC from 1979 to 1986.

Clones	Yield (t/ha)	Root dry matter content (%)	Starch content (%)	Harvest index	Main characteristics
E-24	27.3	37.6	28.6	0.53	High yielding, drought and cold tolerance
8342	27.4	37.6	28.6	0.65	Disease and wind tolerance and high yielding
8002	25.6	37.4	29.3	0.60	Disease and cold tolerance
8013	25.7	39.9	30.9	0.60	Disease and wind tolerance with low toxicity
8340	28.5	37.6	28.6	0.57	Disease tolerance and high yielding
8306	26.9	34.5	27.5	0.55	Good plant shape, and compact root clustering
8329	23.8	35.5	28.5	0.62	High harvest index and good anchorage
SC205	26.0	36.7	28.0	0.68	Disease resistance and high yielding

Clones 8340 and 8342, selected from 1983 to 1986, also showed a higher yielding capacity than SC205. The former has a vigorous growth habit and moderate CBB resistance and cold tolerance. The latter has a high harvest index with less and shorter branches, and is thus adapted to planting at higher density on poor soils. It is resistent to diseases and wind. Their potential productivity is being studied in regional tests.

6. Establishment of a closer relationship with CIAT from which technical information and germplasm materials have been obtained. Some improved clonal types have been selected by using these resources.

7. Accumulation of knowledge in cassava varietal improvement. Years of observations helped to establish the most desirable plant characteristics such as high harvest index and a good root setting. In general, plants that grow vigorously, with many branches at large angles and sparse leaves and nodes are mostly low yielding types. Its productivity will be unstable and more easily affected by environment. Clonal types with high harvest index are normally associated with better root setting, better tolerance to poor soils and stable produc-

tivity. Those with thick and uniform roots that grow superficially and in clusters are mostly high yielding types.

Future Research Directions

Although a foundation for cassava varietal improvement has been laid, there are still may problems to be solved due to the relatively short history of cassava research in China. The major constraint is the comparatively limited variability of germplasm resources. Also, not all clones flower under the normal conditions in China and even with flowering clones, the flowering period is usually limited to two months toward the end of the growing season. This further limits the availability of genotypes to be utilized in hybridization.

The past research attention has been largely confined to field evaluation and selection without much knowledge of genetic potential of individual germplasm accessions and genetic behavior of agronomic traits. Cassava varietal improvement work in China has proceeded more or less in a blind way.

Cassava breeding in the future will emphasize the introduction of foreign germplasm resources, identification of useful genotypes for possible varietal release as well as for hybridization, and cross breeding at home and selection in each major production site. With high yielding capacity as our main objective the second breeding target will be wind and disease resistance for the southern part of the cassava growing area and earlyness and cold tolerance for the northern part of the area.

To achieve these objectives, the following aspects should be emphasized:

1. Intensify collection, introduction, preservation and appraisal of cassava germplasm resources to further enrich the germplasm and to better define parents available for cross-breeding.

2. Develop new techniques to induce cassava flowering.

3. Investigate major agronomic traits for genetic behavior and combining abilities, in order to enhance hybridization and selection efficiency and to identify elite cross parents.

4. Establish a cassava research network to strengthen collaboration among research institutions within the country and coordinate evaluation and promotion of new promising materials, encompassing all the related research and production entities.

5. Enhance international cooperation in order to introduce new techniques and methods of cassava breeding as well as to continue germplasm exchange.

CASSAVA VARIETAL IMPROVEMENT IN MALAYSIA

Tan Swee Lian [1/]

Introduction

Cassava is the most important root crop in Malaysia, and has been traditionally a principal source of starch. In the mid-seventies, the area cultivated with cassava in Peninsular Malaysia peaked at around 20,000 ha when at least three cassava plantations were in existence (Tan, 1985b). However, as the crop has a low income-earning capacity compared with more lucrative alternatives such as oil palm, cocoa, vegetables, groundnut and maize, more and more holdings were converted to these others. With the "golden" crop, oil palm, in its heyday, one of the resultant trends has been the declining area of cassava, and the latest published statistics on production place current cultivation at around 4,000 ha in Peninsular Malaysia (Anon., 1984).

Recent world recession and depressed prices for raw agricultural commodities has caused the Government of Malaysia to review the past agricultural development pattern, which encourages the expansion of permanent tree crop areas, and to give instead more emphasis to food and feed crop production. This is a sensible move, considering the enormous food and feed import bill Malaysia incurs annually (around MR 3.2 billion [2/]), and the rather unbalanced development in favor of rubber, oil palm and cocoa that the country has experienced thus far. Except for research on rice, the staple of the people, attempts at improving the productivity of other food and feed crops have so far been meagre or perfunctory at best.

Cassava has three distinct contributory roles in offsetting part of the food and feed bill :

1. Reduction of growing amounts of starch imports ;
2. Partial substitution of grain maize as a feed component in pig and poultry rations ;
3. Partial substitution of sugar imports in the manufacture of high fructose-glucose syrups (HFGS) ;

Cassava Breeding Research

Research on cassava started before World War II when the British in the Department of Agriculture, Straits Settlements and Federated Malay States, made collections of varieties from local farmers and from nearby countries for identification and evaluation (Greenstreet

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2/ MR = Malaysian Ringgit, which has an exchange rate of about US$ 1.00 = MR 2.50.

and Lambourne, 1933). This first germplasm collection was unfortunately lost during the turmoil of the war years. Interest in cassava resumed in the sixties when the Rubber Research Institute of Malaya (Templeton, 1970) and the Department of Agriculture, West Malaysia, made new attempts at establishing and evaluating a local germplasm collection (Chan, 1969; 1970). A few varieties were also introduced from Hawaii, among which is Llanera. Evaluation of a collection of nearly 70 accessions (Table 1) resulted in the identification of two superior industrial (bitter type) cultivars, *viz.* Black Twig and Green Twig, and a popular edible (sweet type) cultivar named Medan with reasonable yield. As cassava has been more dominant as an industrial rather than a food crop, research emphasis has always been given to selection

Table 1. List of cassava accessions in the Malaysian germplasm collection maintained at MARDI.

1.	Bangkok 1	35.	Sakai
2.	Bangkok 2	36.	Sebawa Biru
3.	Bengkang Bengkok	37.	Silon
4.	Betawi	38.	Tangkai
5.	Black Twig 1/	39.	Telur
6.	Brazil 146 56/A	40.	Trinidad 146 52/A
7.	Buluh	41.	Ubi Ladang
8.	Bunga	42.	Ubi Melaka
9.	El Salvadore 8/1 326/2	43.	Variety A
10.	Fowlfat 146 42/A	44.	Variety B
11.	From Dr. Hamilton	45.	Variety C
12.	Green Twig	46.	Variety D
13.	Halban	47.	Variety E
14.	I.T.U. 15077 20/1B	48.	Yellow Twig
15.	Jantung	49.	C1
16.	Jurai	50.	C2
17.	Kemenyan	51.	C3
18.	Kerdil	52.	C4
19.	Keriding	53.	C5 3/
20.	K.G.T. 44	54.	Pantai
21.	Kucir	55.	I.T.U. 8/1 426/2
22.	Kuning 2	56.	Tiga Bulan
23.	Kunyit	57.	Bangkok 3
24.	Lemak	58.	Suting
25.	Llanera	59.	Fowlfat 146 42 20/1B
26.	Markona	60.	Lohot
27.	Medan 2/	61.	Peteh
28.	Merah Bercabang	62.	Teroh
29.	Merah Jambu	63.	Trinidad 146 52 20/B
30.	Paka	64.	Thai
31.	Perancis	65.	Batak
32.	Pulut	66.	Red Twig 4/
33.	Putih 1	67.	Ubi Java
34.	Putih 2		

1/ Recommended industrial cultivar for starch and feed production.

2/ Recommended edible cultivar.

3/ Industrial cultivar with early harvestable characteristic.

4/ Industrial cultivar with tolerance to long dry spells.

for high starch production. It soon became apparent that Black Twig was outstanding in its wide adaptability to a range of edaphic conditions.

When the Malaysian Agricultural Research & Development Institute (MARDI) was set up in 1969, it took over the research function of the Department of Agriculture, which included cassava research. Black Twig was endorsed as the best available cultivar for industrial use, while Medan was recommended as an edible cultivar (Chan *et al.*, 1983). Another cultivar, Red Twig was found to be popular with farmers in north-west Peninsular Malaysia which experiences dry spells lasting two to three months a year. This cultivar reputedly has better drought tolerance than Black Twig, and its harvest may be delayed up to 18 months with no apparent loss in root quality.

Evaluation and selection of accessions progressed to evaluation of open-pollinated seedling clones in the next phase of breeding research. Seeds were collected whenever available from the plants in the living germplasm collection, germinated and raised into plants, cloned and evaluated for root yield against Black Twig. From these initial efforts, five clones of some promise emerged: C1, C2, C3, C4, and C5 (Chan and Chia, 1974). Further testing zeroed in on C5 as the others had less stable yields. C5, though not superior in yield to Black Twig, had an advantage in earliness. It may be harvested after nine months to give a root yield equivalent to the yield of Black Twig at 12 months. C5 has been endorsed as an early variety. Subsequent work with open-pollinated seeds has proved less fruitful. Of a total of more than 1,600 open-pollinated clones tested, none has emerged to replace Black Twig.

The approval of an IDRC-Funded research project on cassava in 1975 marked the setting up of ties with CIAT, Colombia, which offered training opportunities for cassava research scientists and the introduction of germplasm materials from the center, primarily in the form of seeds. The first batch of seeds comprised largely open-pollinated materials, but subsequent batches contained seeds of various hybrid combinations. A total of 8928 seeds have been introduced to Malaysia through MARDI thus far, and evaluations of the resulting 5655 clones have succeeded in identifying several (Table 2) which are either adaptable to mineral soils or to cultivation on peat (Tan and Thiagarajan, 1986). Outstanding among these is CM 982-7,

Table 2. Promising cassava clones adapted to peat and mineral soils in Malaysia.

Clone	Parentage	Fresh root yield (t/ha)	other remarks
CM 378-17	MCol 113 × MVen 270	23-31	Adapted to mineral soil
CM 621-7	MCol 638 × MCol 1684	21-44	Adapted to peat
CM 621-22	MCol 638 × MCol 1684	17-39	Adapted to peat
CM 621-24	MCol 638 × MCol 1684	25-34	Adapted to mineral soil
CM 621-43	MCol 638 × MCol 1684	17-28	Adapted to peat
CM 845-13	MVen 270 × MCol 1684	27-28	Adapted to mineral soil
CM 982-7	CM 321-170 × MCol 1684	39-59	Adapted to peat
Black Twig	Local Clone	15-35 1/	Adapted to both soils
C5	Local early clone	18-44 1/	Adapted to both soils

1/ Range in root yields in the same trials as the above clones.

a clone which is far superior to Black Twig in root yield on peat, has a much higher harvest index, and is less susceptible to brown leaf spot disease caused by *Cercosporidium henningsii* Allescher. Its only, but serious, shortcoming is a lower starch content than Black Twig (Tan, 1987).

Attempts to carry out hybridizations locally have been thwarted by the lack of regular flowering of cassava clones (Tan, 1986). Many clones like Black Twig, Medan and C5 are generally unbranched, which means they do not flower. Some crossings have been carried out on unselected parental varieties which have qualified merely because they happened to be in flower, and, as may be expected, the performance of their progeny has not been significantly better than the mother stocks (Tan and Chan, 1981). Although it has been found that planting unbranched clones at higher altitudes (3,000 m above sea level) has been quite successful in inducing them to flower (Zainol, 1984) the general lack of manpower in the cassava breeding program has precluded this practice. The cassava research program at MARDI is currently a modest one, both in terms of budget allocation and research personnel. Research centers around breeding and agronomy, with some support in mechanization aspects of cassava cultivation. Of late, some renewed interest has been aroused in MARDI, according cassava slightly improved research priority status because of its potential as a partial substitute for feed grain and sugar. At a recent workshop on "Investment Opportunities in the Agro-based Industries", jointly organized by the Ministry of Agriculture Malaysia and the Asian Development Bank, it was revealed that one of the projects identified to have good investment prospects is the integration of cassava planting with starch and HFGS production (Anon., 1987).

Some Comments on CIAT Germplasm

While the breeding and selection program at MARDI has benefitted from the germplasm introduced periodically from CIAT, some of the hybrid combinations have not been entirely in line with the needs of the local cassava industry. One prominent example is the generally low starch content of these hybrid clones, especially among the earlier introductions, when CIAT probably gave over-emphasis to root yield only, and was guided more by the Colombian utilization pattern, *viz.* growing cassava as a partial staple food rather than as an industrial crop. This has led to disappointingly low starch contents in clones which have been selected for local adaptation and high root yield. Starch factories prefer clones with high starch content combined with a reasonable root yield rather than those having high root yield associated with low starch content, because of the sheer volume of handling the latter to get an equivalent amount of starch (Chai, pers. comm.).

Of late, CIAT has kept in mind the needs of individual clientele countries when developing germplasm for distribution. Also, the better varieties and germplasm from each country are being deposited in the CIAT collection. This will be an invaluable guarantee against irretrievable loss of germplasm, especially with changing research priorities in the developing countries. More important, such a move places CIAT in a position to provide the truly and specifically required materials to fulfill the research objectives of its clientele. Such a service will be a great boon to those national research institutes and organizations which have too modest a research budget and too few trained staff to warrant a full-scale cassava hybridization program.

A few batches of clones have been introduced from CIAT in the form of aseptic meristem cultures (Table 3). Generally, the performance of these clones show nothing to merit their difficult introduction in place of seed materials. Seeds are light, easy to transport, require no special facilities for handling at the recipient country, yet provide more opportunities for selection of clones therefrom, which are adapted to local environmental conditions. By contrast, meristem introductions need special handling during transport because they are in glass tubes, will ill-afford delays during dispatch, and require basic laboratory facilities for acclimatization and possibly subculturing, and suitable trained staff to carry out such operations (Tan, 1985a). Moreover, clones introduced as meristem cultures tend to be those which have performed well or reasonably well under testing by CIAT, which is no guarantee that they will adapt equally to local conditions. This method of germplasm dissemination may perhaps be confined to safe exchange of germplasm, and the introduction of genetic resources with very specific traits which may be introduced into local germplasm through hybridications.

Table 3. Performance of clones introduced from CIAT in the form of meristem tissue cultures.

Clone	Fresh root yield (t/ha)	Starch content (%)	Remarks
1. CM 342-55	38.7	23.5	
2. CM 458-2	33.9	24.4	
3. CM 426-6	46.6	20.8	Now in regional testing
4. CM 321-188	39.4	24.1	
5. CM 489-1	18.6	n.a.	Not selected for yield trials
6. CM 507-34	29.7	24.4	
7. CM 430-37	—	—	Did not survive subculturing
8. CM 451-1	—	—	Did not survive subculturing
9. MVen 218	—	—	Did not survive subculturing
10. MPan 19	—	—	Did not survive subculturing
11. M Col 1684	—	—	Did not survive subculturing
12. CM 517-1	15.7	26.8	
13. CM 523-7	—	—	Did not survive subculturing
14. M Col 1468	—	—	Did not survive subculturing
15. CM 323-403	—	—	Did not survive subculturing
16. CM 517-5	n.a.	n.a.	Being multiplied
17. CM 728-2	—	—	Did not survive subculturing
18. CM 342-170	—	—	Arrived in dried state
19. CM 323-375	—	—	Arrived in dried state
20. M Col 22	n.a.	n.a.	Being multiplied
21. M Col 1684	n.a.	n.a.	Being subcultured
22. MBra 12	n.a.	n.a.	Being multiplied
23. CM 681-2	—	—	Did not survived subculturing
24. CM 523-7	n.a.	n.a.	Being multiplied
25. CM 507-37	n.a.	n.a.	Being subcultured
26. Rayong 1	n.a.	n.a.	Being multiplied

Note: n.a. = not available.

Future Directions and Priority Areas

In Malaysia, the direction of cassava research will be increasingly towards its use as a component of livestock feed (particularly monogastric animals), replacing some of the grain maize which is currently imported to the value of MR380 million a year (Tan *et al.*, 1987). For this purpose, the cassava roots must have a high dry matter content to ensure good conversion rates to dried chips or root meal. However, as cassava is inferior nutritionally to grain maize (especially in protein content), the use of cassava chips in feed formulations necessitate the increased additions of protein souces such as soybean oilcake or fish meal (Tan and Welsch, 1986). Hence, in order that feedmillers be attracted to wider usage of cassava chips in feeds, the price of cassava must be much lower than the price of imported grain maize. For example, breakeven analysis by a linear program providing least-cost rations show that when grain maize ranges in prices between MR 230 and MR 320 per ton, cassava dried chips must be less than MR 230-MR 250 per ton for use in pig feeds, and less than MR 200 for use in broiler and layer feeds (Sayer, pers. comm.). To achieve a price advantage *vis-a-vis* grain maize, besides reducing the costs of production for cassava, it will be necessary to improve dry root yields significantly.

Some interest has been generated in the use of HFGS in place of sugar in the food and drink industries. Imported HFGS from corn has appeared on the local market. It makes greater sense to manufacture such syrups from a locally available starch source such as cassava. However, at present the demand for starch outstrips its supply, and any move towards local manufacture of HFGS will require increasing the production of cassava. At any rate, cassava for HFGS will also have to be high yielding with a high root dry matter content for maximal conversion.

The demand of starch is expected to continue to climb since it is required in the food (including monosodium glutamate), textile and paper manufacturing industries, all of which will develop in parallel with a growing population. Cassava therefore still has its traditional role to play, but improved starch yields will be the basic prerequisite of the new clones.

The use of cassava leaves as a leaf meal and protein source in animal feeding is nothing new. The possible use of these leaves as a vegetable, processed and canned like spinach or freshly cooked, should also be examined. It is necessary in such cases to select for cassava with high foliage production, showing persistence with frequent harvests of the leaves, and more importantly, to have leaves with low cyanide contents.

Peculiar to Malaysia is the prospect of planting cassava on peat. Needless to say, cassava will continue to face competition from more profitable crops for land. The alternative is to grow the crop on peat, which because of its low pH is not suitable for many other crops. Cassava on the other hand will grow quite well on peat, with only a minimal lime requirement to correct the soil acidity. Research, therefore, should give attention also to the screening and selection of cassava clones adapted to peat. High root yields and tolerance to some degree of water logging for short periods during the crop season are two objectives to be achieved. With better yields, it will be possible to offset the higher costs of fertilizer inputs (particularly nitrogen and copper) required for growing cassava on peat.

Need for Network Research and Cooperative Projects

An international center like CIAT can best serve national cassava research programs through the continued supply of elite germplasm, preferably in the form of hybrid seed, for *in situ* testing and selection. Better yet, if the hybrid combinations are of parents bearing desired genes for specific traits, such as high dry matter (starch content), low cyanide, disease resistance etc. To lend a helping hand to those national programs which have a limited research budget, improvement of nationally-used clones through crosses with elite CIAT material would be more useful in increasing the probability of more locally adaptable materials.

To maximize the use of selected clones on a regional basis, e.g. the ASEAN region, it would be helpful if inter-country trials of promising new clones may be carried out on a collaborative level with each country contributing a few entries, and including within such trials one or two currently popular varieties from each participating country as check clones. This will facilitate each cassava breeder in the collaborative network in appreciating how a particular new clone performs in relation to the clone/s he has in his own country. Such inter-country trials will also allow for genotype x environment analyses of the performance of cassava clones, and should also include adequate characterization of the test environment in the form of minimal soil and climatic data.

For an annual, the crop cycle of cassava is substantially longer than short-term crops such as peanut, soybean and maize. This lengthens the period required for the evaluation and selection of seeddlings and subsequent clonal generations right through to ex-station testing, usually involving at least five to six years. It would therefore be helpful if cassava breeders can pitch their expertise together and come up with the means of shortening the process of selection right through to release of new clones with no loss in efficiency. Perhaps, CIAT can play a leading role by organizing future workshops to discuss and deliberate on more specific areas of breeding and selection. To name a few: breeding methodology, selection criteria and early clonal generation screening, the importance of genotype x environment interaction on cassava breeding. I personally feel that the time has come for cassava breeders to seek for more basic information on their crop--*e.g.* answers to physiological questions, the genetics and heritability of desirable agronomic triats -- if the improvement of *Manihot esculenta* Crantz is to make greater headway in the future.

Summary

An important starch source in Malaysia, cassava has delined in area of production in the last decade, but recent renewed interest in the crop is apparent. New roles of cassava include partial substitution of grain maize in livestock feed rations and of sugar in the beverage and processed food industries.

Breeding and selection research has concentrated on clonal collection, characterization and evaluation in the 1960's, culminating in the endorsement of Black Twig as an industrial starch clone, of Medan as an edible clone, and of C5 as an early industrial clone. From the early 1970's, introduction of genetic materials (seeds and meristem cultures) from CIAT for local evaluation has become the main breeding and selection activity. This has resulted in the identification of a number of clones adapted to mineral soils or to peat. Local hybridization

work has been hindered by the lack of flowering in clones selected as parents, and by the limited research resources for the program.

While CIAT germplasm has made significant contributions to the success of the cassava breeding and selection program at MARDI, low starch content in many of the hybrid clones is of major concern, because of the requirements of the local industries related to cassava. The need for high root dry matter content is pressing for those industries that produce starch, livestock feed and high fructose glucose syrups. High yield will remain an important means of lowering production costs to render cassava production more competitive.

A network for cooperative projects coordinated by CIAT will best serve the interests of the participating countries with the continued supply of elite germplasm from CIAT, specially tailored to meet the requirements of local cassava industries. Inter-country trials of selected clones will provide useful information on genotype × environment influence on agronomic performance, and possibly maximize the use of newly developed clones. Specific technical and practical problems of breeders might be solved through joint efforts while CIAT can play a leading role in organizing future workshops addressing such problems and seeking solutions.

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CASSAVA VARIETAL IMPROVEMENT AND AGRONOMY RESEARCH IN SRI LANKA

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Introduction

Historical evidence indicates that cassava is relatively new to Asia, though it is considered to be a relic of primitive agriculture as it has been used as a food plant since prehistoric times (Darlington, 1969). It was introduced to Sri Lanka from Mauritius in the year 1796 by Van der Graef, a Dutch Governor (Greenstreet and Lambourne, 1933). Since then and upto now the cultivation of cassava has been mainly confined to peasant settlements using shifting cultivation (chena); it still is an important subsistance crop and forms an integral part of their diet and agriculture.

Sri Lanka is a country with a calorie-deficient low-income population strata experiencing a growing population pressure on land and available food. During the last 28 years the population of Sri Lanka has increased by 50%, and consequently the per capita land availability has been reduced by one third. Rice, although it is the main food crop of the nation, cannot further expand in area while yields are leveling off; to obtain an extra ton per hectare this crop needs high-cost energy-based inputs. Therefore, cassava remains an important food crop in the national agricultural development program, mainly because of its potential to produce more calories per unit of land.

Despite some evidence that cassava is still being used in some small scale industries (Jayawardena, 1984) the food balance sheet in Sri Lanka (Department of Census and Statistics, 1960 – 1984) indicates that there was no utilization of cassava, or any other root crop, in any industry during the last two decades, and thus the total production of cassava was assumed to have been consumed directly as human food. However, the contribution of root and tubers (except potato) to per capita calorie intake in Sri Lanka is low. The maximum contribution by these crops to the total per capita calorie consumption has been reported as 12.12% during the periods of acute food shortage in 1975, whereas at present it is around 6% (Table 1). In the assortment of root crops consumed, cassava dominates (Table 2) and it is clear that present consumption levels of cassava are well below the maximum quantities tolerable in the diet on nutritional grounds (Ministry of Plan Implementation). In this context cassava has a great potential to play an important role as a source of energy for the working population who really

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Table 1. Contribution of roots and tubers to daily per capita total calorie intake in Sri Lanka 1970 – 1980.

Year	Total	Cassava		SW potato + yams		Roots & tubers	
	Calories	Calories	% of the total	Calories	% of the total	Calories	% of the total
1970	2370	59.1	2.49	10.7	0.45	69.8	2.94
1971	2230	88.9	3.99	12.0	0.54	100.9	4.53
1972	2158	73.4	3.40	9.9	0.46	83.4	3.86
1973	2169	134.0	6.45	15.9	0.73	155.8	7.18
1974	2136	158.8	7.44	27.0	1.26	185.8	8.70
1975	2127	220.7	10.37	37.2	1.75	257.9	12.12
1976	2172	163.5	7.35	31.2	1.43	194.7	8.96
1977	2343	120.2	5.13	21.1	0.90	141.3	6.03
1978	2325	124.4	5.35	21.6	0.93	146.0	6.28
1979	2316	111.2	4.80	23.6	1.02	134.8	5.82
1980	2169	102.0	4.70	19.9	0.92	121.9	5.62

Source : Department of Census and Statistics. Food balance sheets, 1970 to 1980.

Table 2. Consumption of roots and tubers (kg) per capita per year in Sri Lanka, by income groups, 1970.

	Income per month (Rs)										
	0 25	26 50	51 100	101 200	201 400	401 800	801 1000	1001 1500	> 1501	Overall	%
Cassava	5.3	9.9	5.7	6.5	5.6	4.1	4.3	2.5	1.7	5.4	60.7
Potatoes	–	0.5	0.6	0.9	1.3	2.7	5.2	4.9	7.2	1.7	19.1
Sweet potato	–	0.1	1.2	0.9	1.1	1.1	0.7	0.7	1.8	0.9	10.1
Kiri Ala and yams	–	0.3	0.9	0.8	1.0	0.7	1.6	0.5	1.1	0.9	10.1
Total ex. potatoes	5.3	10.3	7.8	8.2	7.7	5.9	6.6	3.7	4.6	7.2	80.9
Total	5.3	10.8	8.4	9.1	9.0	8.6	11.8	8.6	11.8	8.9	100.0

Source : Central Bank of Ceylon "The survey of consumer finances, 1973."
Roots and tuber crops can be accommodated in the meals of anybody including children, and for adult males this can be increased beyond 50 kg per year (Ministry of Plan Implementation, 1983).

sustain the agricultural economy, in addition to being a potential raw material for various industrial uses in Sri Lanka (Samaratunge, 1987).

Climate and Soils of Sri Lanka

Sri Lanka is a comparatively small island with a total land of 6.56 million hectares lying in close proximity to and towards the south-east of the Indian subcontinent. On the basis of altitude the country is divided into low country (0 to 300 masl), mid country (300 to 1000 masl) and up country (1000 masl and above). Climatic features are basically determined by the geographical location of the country on the border of the equatorial belt. Sri Lanka receives rain from the south-west monsoon during May to September, which period is referred to as "yala season", and from the north-east monsoon from December to February. During inter-monsoonal periods rains due to convection occur and, in October/November these are supplemented by depressional activity moving in from the east. The period from October to February

is locally called the "maha season". Rainfall distribution follows an orographic distribution pattern, with yala rains limited to the south western quarter while maha rains benefit the whole country. Based on mean annual rainfall (MAR) 3 major climatic zones are identified, *viz:* wet zone (2280 mm to 5100 mm MAR), dry zone (890 mm to 1525 mm MAR) and intermediate zone (1525 mm to 2280 mm MAR) (Figure 1).

The climatic and topographic variations are further compounded by the distribution pattern of soil groups in the country. Nine out of the ten soil orders of the USDA soil taxonomic system are found distributed throughout the country. Reddish brown earths (Alfisols) predominate in the dry and intermediate zone, often in association with low humic gley (Inceptisols), or alluvial soils (Entisols). Red yellow podzolic soils (Ultisols), predominate in the wet and part of the intermediate zone, in association with bog (Histosols), half bog (Alfisols) and sandy regosols (Entisols) along the south-west coast. The intermediate zone displays a transition from reddish brown earths and non calcic brown soils (Alfisols) to red yellow podzolic soils (Ultisols) with immature brown loams (Mollisols) and reddish brown loams in association (Figure 2).

Based on the rainfall distribution patterns, cassava cultivation in Sri Lanka is mostly concentrated in the wet and intermediate zones, resulting in the formation of a very distinct natural cassava belt across the wet and intermediate districts (Figure 3). The dry zone is less favourable for successful cassava cultivation due to the poor distribution of rainfall, coupled with soils which harden upon drying. However, in the eastern coast of the dry zone where soils are light textured, 3 to 4 thousand hectares of land are cultivated to cassava during both seasons; in the other areas of the dry zone cassava is cultivated mainly during the Maha season (Figure 4).

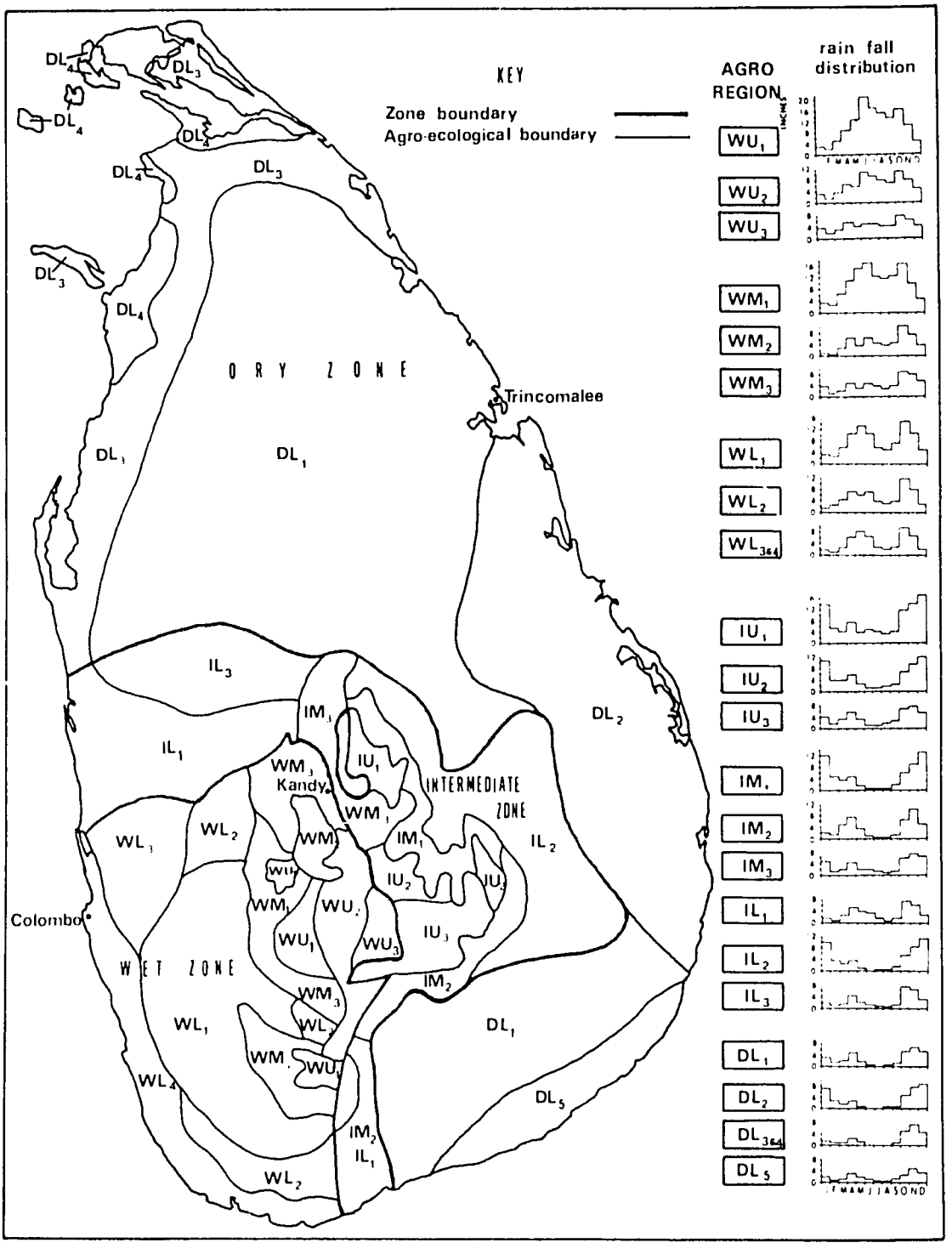


Figure 1. Agro-ecological regions of Sri Lanka.

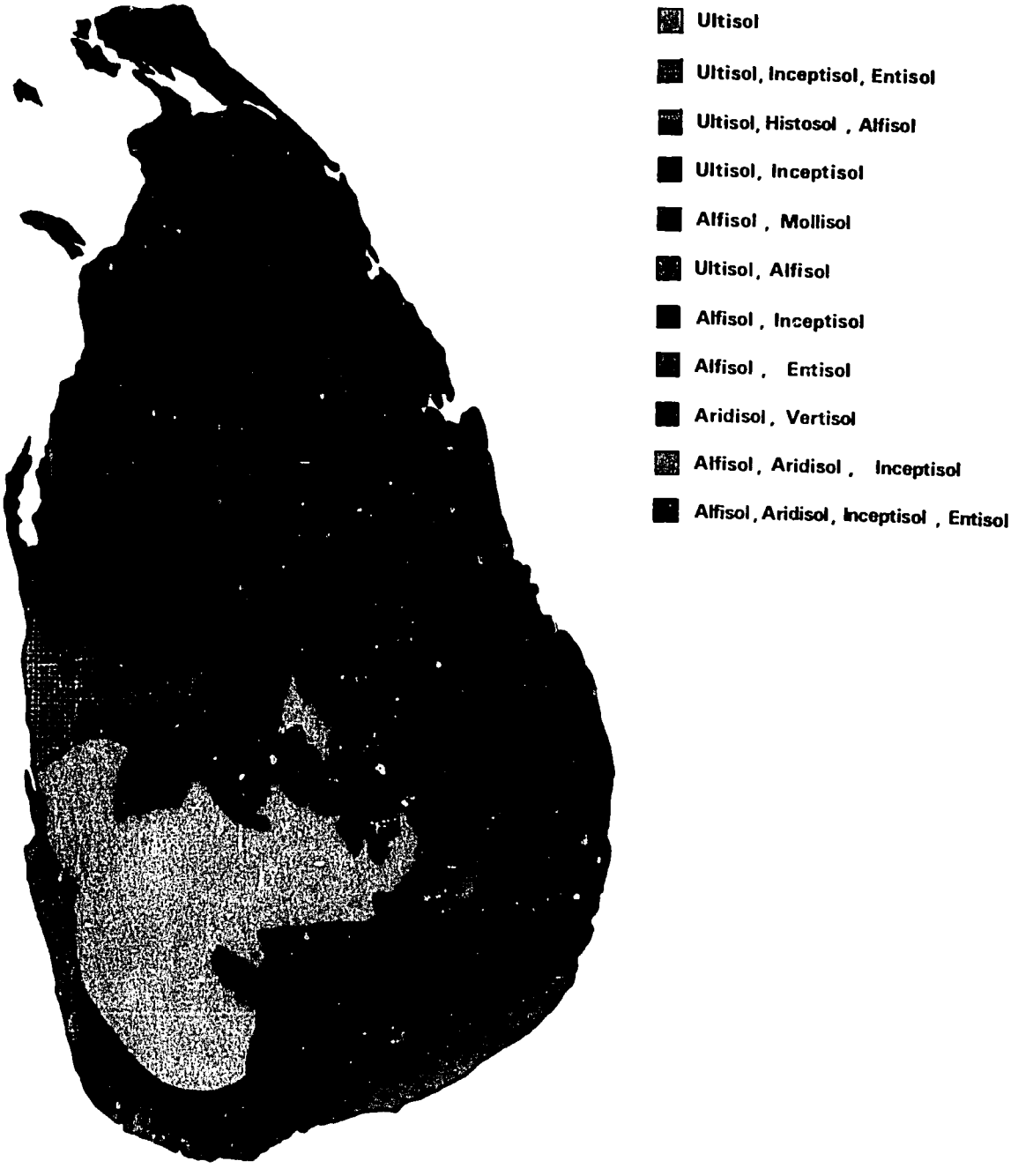


Figure 2. Soil map of Sri Lanka indicating the distribution of major soil orders of Soil Taxonomy system.

Source : Adapted from "Agro-ecological Map of Sri Lanka", Land and Water Use Division, Dept. Agric., Peradeniya, 1981, by R. Howeler.

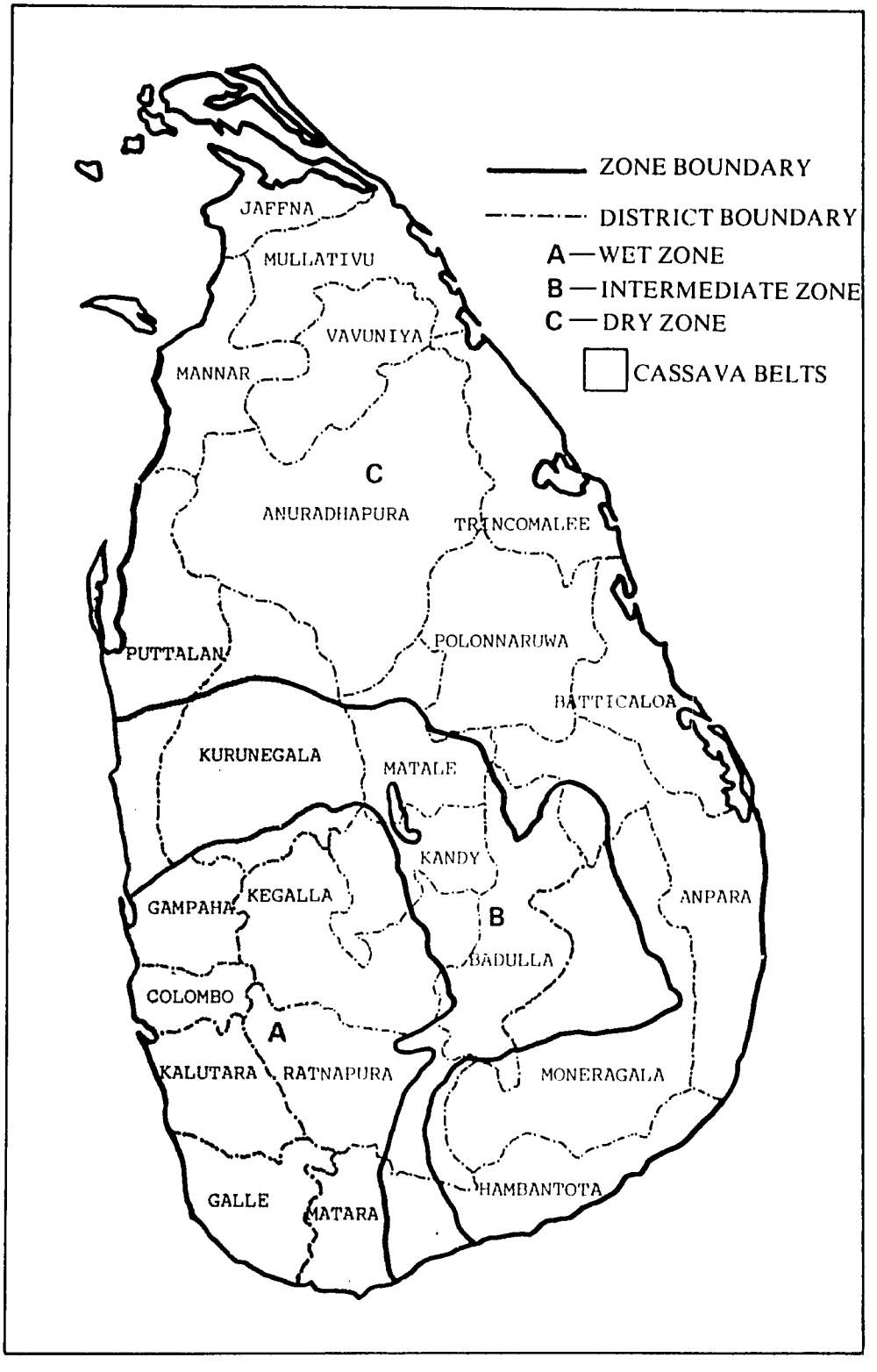


Figure 3. Cassava production zones in Sri Lanka.

Figure 4. Cassava production zones of Sri Lanka.
Each dot represents 1000 ha of cassava.

In the wet and intermediate zones cassava is cultivated during both seasons mainly as a backyard crop. However, in the districts where coconut plantations are in abundance cassava is intercropped with coconut. Considering the production potential and the area under cassava cultivation the districts Kurunegala, Colombo, Ratnapura, Kegalle, Kalutara and Kandy can safely be named as highly productive areas, having the most suitable physical as well as socio-economic environments (Table 3, Figure 3). In these areas cultivation of cassava has been found in peasant settlements, in shifting cultivation, and as a cash crop along with other seasonal crops or intercropped with rubber, coconut and pineapple.

Table 3. Distribution of land and the production of cassava among districts of Sri Lanka. Average for the period 1978 – 1982.

Districts	Cassava		
	Area (ha)	Production (tons)	Yield (t/ha)
Colombo and Gampaha	1993	25117	12.60
Kalutara	2244	17558	7.82
Galle	1991	14204	7.13
Matara	2020	15879	7.86
Ratnapura	4638	82206	17.72
Kegalla	4171	54011	12.94
Kurunegala	8609	90644	10.53
Puttalam	3037	18433	6.07
Kandy	1837	18785	10.23
Matale	2523	25327	10.04
N'eliya	808	4013	4.97
Badulla	2974	21532	7.24
Moneragala	4467	13441	3.01
Jaffna	1167	11363	9.74
Vavunia	303	3703	12.22
Mulatiwu	—	—	—
Mannar	—	—	—
A'pura	2342	13183	5.63
Polonnaruwa	1278	7478	5.85
Trincomalee	979	4572	4.67
Baticaloa	1650	16036	9.72
Ampara	2715	21275	7.84
Hambantota	1900	21455	11.29
Kalawewa	—	—	—
Udawalave	—	—	—
Sri Lanka	53646	522698	9.74

Source : Department of Census and Statistics.

Cultivation Practices

Presently cassava cultivation in Sri Lanka is done totally by small holders and cultivation is mostly confined to backyard production systems or as small rainfed cultivation in the high-lands. Under these cultivation systems, fertilizers, other purchased inputs, and labor intensive management practices are seldom used (Department of Agriculture, 1983). Apart from land

the only important input is labor, which consists almost entirely of family labor (Samaratunga, 1984). Hence, cultivation of cassava in Sri Lanka at present does not compete with other crops for land, labor or capital to any significant degree.

Depending on the soil and available rainfall conditions the root yields of cassava vary from 8 – 10 tons per hectare under these production systems. If the farmer harvests his product on his own and transports it to a nearby market he could sell his produce for about Rs* 2000 to 3000 per metric ton or Rs 2 to 3 per kilo. If the crop area is large, a middle man who has to uproot and transport pays the farmer about Rs 1000 to 1500 per metric ton. Therefore, cultivation of cassava as a backyard crop gives a considerable income to the village farmer, and also serves as an assured supply of food.

However, when cassava is cultivated on a commercial scale with the recommended package of practices, root yields of over 20 t/ha could be obtained. Due to difficulties in disposing large quantities of fresh roots in the market for direct human consumption, cassava in Sri Lanka is hardly cultivated on a large extent. Further, because of the lack of knowledge in post-harvest handling and unavailability of storage facilities, or transportation, etc., farmers grow cassava only on a small scale, mainly for subsistence.

Low cost of production and very high returns to land and labor indicate that cassava cultivation in Sri Lanka is highly favorable in terms of resource utilization (Table 4). It is important to note that the cost of production includes only family labor, thus not an actual monetary cost. As a result, return to capital becomes inapplicable to cassava under the present production systems in Sri Lanka.

Table 4. Costs and returns relating to cassava cultivation at farmers' and recommended management practices (per ha.).

Item	Farm[a]		Recommended[b]	
	Amount	Cost (Rs)[c]	Amount	Cost (Rs)[c]
Manual land prep.	43.9 (m. days)	1097	(by tractors)	1117
Planting	2.5 (m. days)	62	10.0 (m. days)	250
Fertilizer	—	0	269 (kg)	734
Earthing up	—	0	10.0 (m. days)	250
Weeding	12.0 (m. days)	300	20.0 (m. days)	500
Harvesting	8.8 (m. days)	221	20.0 (m. days)	500
Total cost (Rs/ha)	1680[c]		2351	
Yield (kg/ha)	7604		20000	
Farm price (Rs/kg)	1.50		1.50	
Gross return (Rs/ha)	11406		30000	
Net return (Rs/ha)	9726		26649	
Return per man day (Rs)	144.73		444.15	
Return per Rupee of working capital (Rs)	d		15.40	

a. **Source** : Department of Agriculture, Division of Agricultural Economics (1980).

b. **Source** : Department of Agriculture, Division of Botany (1984).

c. Includes only the value of family labor (Rs 25/day.)

d. Not applicable as no capital cost was incurred. The only input was family labor.

e. Exchange rate : 1 US$ = Rs 30.00

* Exchange rate : 1 US$ = Rs 30.00

Table 5 shows that during the last 10 years cassava cultivation in Sri Lanka showed changes in the production trend. From early 1970's onwards the area and the production of cassava increased reaching a peak during the acute food shortages in the period 1974 – 1976. However, with the increase in rice production and assured supply of wheat flour the production steadily declined until 1981, at which point the trend turned positive again. The total production minus post-harvest losses is reported to have been used totally for human consumption with no cassava usage for industrial purposes.

Table 5. Annual production, area and yield of cassava in Sri Lanka, 1975 – 1984.

	Production (000 tons)	Area (000 ha)	Yield (t/ha)
1975	996.87	164.842	6.05
1976	747.60	110.759	6.75
1977	556.65	95.801	5.81
1978	585.84	74.355	7.88
1979	534.54	53.591	9.97
1980	499.49	51.048	9.78
1981	526.01	56.116	9.37
1982	572.85	59.179	9.68
1983	722.11	55.373	13.04
1984	682.48	56.773	12.02

Source : Department of Census and Statistics.

Inspite of the importance of cassava in the food economy and its long period of cultivation in Sri Lanka, little attention has been paid to exploit its real potential. Therefore, a research project on root and tuber crops was started in 1978 with assistance from the International Development Research Centre (IDRC), Canada, and subsequently with the assistance of the CIAT Regional Cassava Program to strengthen the breeding program.

Accomplishments and Present Status of Varietal Improvement

Though it is not known how many genetically distinct clones had been introduced by the Portuguese, there are presently a fair range of cassava cultivars in Sri Lanka having different morphological, physiological and biochemical characters. The occurrence of these different cultivars, grown under different agro-ecological conditions in the island, suggests that some selection/adaptation had taken place. Although cassava has been cultivated in Sri Lanka for nearly 200 years, until the early 1940's no research attention had been focussed on the improvement of this crop. According to official records no introductions have been made recently. Hence, the available so-called "varieties" are farmers' selections from the original introduction or from its open-pollinated seedlings. In other words, most of the present cultivars are derivatives of original stocks, evolved through a process of natural and farmers' selection.

Chandraratne and Nanayakkara reported for the first time in 1948 on the production of 21 hybrids through sexual hybridization to increase yields and reduce the HCN content (Table 6). Further, they attempted to classify the cassava races occuring in Sri Lanka and identified 75 races; of these 6 races are reported to be recommended (Chandraratne and Nanayakkara, 1948). However, the work of these two researchers was short-lived; from 1948 to the

Table 6. HCN content of parents and hybrids of cassava.

Hybrid	Parents	HCN content in tissue (ppm)		
		Female	Male	Hybrid
Muh 3	Mu 41 × Mu 51	103	34	92
Muh 5	Mu 51 × Mu 41	34	103	76
Muh 7	Mu 51 × Mu 41	34	103	111
Muh 8	Mu 51 × Mu 41	34	103	133
Muh 9	Mu 51 × Mu 41	34	103	133
Muh 12	Mu 41 × Mu 59	103	46	70
Muh 14	Mu 59 × Mu 41	46	103	75
Muh 21	Mu 59 × Mu 41	46	103	103

Source : Chandraratne and Nanayakkara, 1948.

late 1970's little was done on cassava improvement and this lagged considerably behind when compared to the progress made in other crops. However, we cannot say for certain that the cultivars used today are of the same accessions as those produced in 1948. For example the present widely accepted cultivar "Peradeniya" is now called Mu-51 but according to the pioneer workers it was Mu-22.

Since 1978, a Root Crops Research Project at the Central Agricultural Research Institute (CARI) at Gannoruwa, funded by the International Development Research Centre (IDRC), paved the way for a nation-wide germplasm collection and evaluation of cassava cultivars, and applied hybridization. Achievements of the ongoing project could be summarized as follows:

1. As a result of evaluating open pollinated cassava seedling progenies, derived from hitherto unexploited local germplasm, two promising clones, namely CARI-555 and CARI-526, were identified with good plant type and excellent culinary qualities. They gave reasonably good yields in multilocation trials under different agro-ecological conditions. These new clones

Table. 7. Yield and quality comparison of CARI-555, CARI-526 and Mu-51.

Character	CARI-555	CARI-526	Mu-51
Fresh root yield[a] (t/ha)	35 0	33.5	35.0
Peeling habit	Very easy	Easy	Easy
Rind thickness (mm)	1.85	2.15	2.05
Bitterness of flesh	Sweet	Sweet	Sweet
Cooking time (min)	10 - 15	18 – 20	18 – 20
Color of flesh	White	White	White
Consistency & aroma of cooked roots	Mealy & aromatic	Mealy	Mealy
HCN content (ppm)	25 – 35	56 – 65	40 – 45
Dry matter content (%)	38 – 44	38 – 44	38 – 43
Palatability & acceptability[b]	4.40	4.03	4.10

a – Av. yields under experimental conditions.
b – Scoring for acceptance and taste of boiled roots were made using the rating of 1 to 5 with 5 representing the superior quality.

Source : Annual report, IDRC/Sri Lanka Root Crops Project, 1986/87.

are in the pre-release stage for general cultivation as "sweet" or "table" type cassava cultivars (Table 7), (De Silva *et al.*, 1986).

2. As the probability of obtaining superior segregants was considered to be low in the selection of naturally open-pollinated cassava seedlings, an intervarietal hybridization program was started by using locally available superior genotypes. 25 progenies were selected on the basis of yield performance and desirable agronomic characteristics for further evaluation (Table 8).

Table 8. Progeny means of yield parameters of cassava hybrids according to their crosses.

Cross	No. of progenies	Root wt (kg/plant)	Root no. /plant	Mean root wt (g)	HI (%)
Mu-51/Wagolla	3	2.95	6.33	466	65.7
Mu-51/CARI-555	3	5.78	10.00	578	65.7
Wagolla/Mu-51	6	4.84	9.33	519	59.8
Wagolla/CARI-555	5	5.49	9.60	572	69.0
CARI-555/Mu-51	4	1.73	9.00	192	59.2
CARI-555/Wagolla	2	4.20	7.50	560	63.5
Total	25	–	–	–	–
Mean	–	4.16	8.63	481	62.7

Source : Annual report, IDRC/Sri Lanka Root Crops Project, 1986/87.

3. Evaluation of a part of the local cassava germplasm has indicated a good deal of variation in root yield, shape and size of roots, but most of them were found to be of inferior quality as compared with the popular cultivar Mu-51.

4. Multilocation yield trials in various agroclimatic regions have demonstrated a vast potential for increase in production in most parts of the country by using improved cultivars and cultural practices.

5. While duplicates are being eliminated taxonomical characterization of local cassava germplasm was initiated again in order to identify the varietal differences.

Though there has been an impetus to improve cassava through selection and intervarietal hybridization during the last decade in Sri Lanka, progress toward goals such as high yields, yield stability and quality, disease and pest resistance, early maturity and resistance to environmental stresses has been slow due to lack of genetic variability. As the locally available germplasm variation is low, the first attempt to upgrade germplasm variation in Sri Lanka was made by the official introduction of genetic stock of hybrid seeds of 30 crosses (Table 9) received from CIAT, Colombia, in 1985 with the assistance of the CIAT Cassava Asian Regional Program.

Out of 752 hybrid seedlings derived from the introduced hybrid seed material, 74 clones of 20 crosses were identified as promising, based on yield parameters and other desirable characters in the preliminary evaluation stage (Table 9). The selected exotic hybrids showed extensive morphological variation, possessing apparently desirable characters such as high root yield, harvest index, and root number, low rind thickness, and erect, non-branching and vigorous growth habit, long leaf life and ease of harvest. In a comparison of progeny means of yield

Table 9. No. of progenies selected from CIAT cassava introductions in 1985 at seedling stage, and their mean yield parameters.

Cross	No. of progenies selected	Progeny means			
		Root wt. (kg/plant)	Root no/ plant	Mean root weight (g)	HI* (%)
CM 4009	12	3.70	08	462	70
CM 4011	08	4.20	08	525	67
CM 4012	none	–	–	–	–
CM 4054	02	8.50	17	500	67
CM 4105	02	4.10	10	410	73
CM 4397	03	3.93	09	437	69
CM 4504	01	3.80	11	345	55
CM 4830	05	4.54	08	568	64
CM 4836	04	5.18	10	518	63
CM 4912	none	–	–	–	–
CM 4992	01	2.90	12	242	74
CM 5007	05	6.62	09	735	71
CM 5046	03	6.36	14	454	75
CM 5371	02	6.05	08	756	74
CM 5436	01	5.60	08	700	57
CM 5452	05	6.75	13	519	57
SM 443	none	–	–	–	–
SM 445	01	5.80	08	725	56
SM 446	none	–	–	–	–
SM 450	02	2.70	11	245	62
SM 451	01	8.2	12	683	66
SM 452	none	–	–	–	–
SM 458	04	7.43	09	825	56
SM 462	04	5.78	10	578	62
SM 470	03	6.31	14	451	68
SM 474	03	3.36	10	336	64
SM 481	none	–	–	–	–
SM 534	02	7.30	08	912	71
SM 500	none	–	–	–	–
SM 536	none	–	–	–	–
Total no. of genotypes selected	74	–	–	–	–
Mean		5.12	10.4	540	66

*fresh weight basis.

Source : Annual report, IDRC/Sri Lanka Root Crops Project, 1986/87.

parameters with locally bred cassava seedlings (Tables 8 and 9), the CIAT hybrid selections were found to have superior values of mean yield parameters. These selections are being further evaluated in nonreplicated yield trials at CARI and could hopefully result in the emergence of some outstanding plant types.

Six cassava clones having reportedly desirable characteristics, such as high yield and dry matter content, low HCN content, resistance to cassava mosaic disease (CMD) and mealy bug,

and tolerance to moisture stress, were introduced in 1986 from IITA, Nigeria, in vegetative form as in-vitro plants, and they are being observed at CARI.

Genetic material of cassava from within and outside the country are being collected to build up a germplasm bank. So far among 223 collections maintained at CARI, 128 are native collections and 80 exotic accessions, including 74 CIAT hybrid selections and 6 IITA introductions. These collections are being evaluated and characterized with the aim of utilizing them as direct varieties or for breeding purposes.

Recent Agronomy Research in Cassava

Presently cassava is cultivated in Sri Lanka, mainly as a subsistance crop. Hence, it is realized that the cultivation of cassava could be encouraged only if technologies are developed that suit the village farming systems. During the past 10 years therefore, agronomic aspects of cassava research were mainly concentrated on low cost production technologies, particularly to generate information on cropping systems.

As cassava occupies the land for a period of over 9 months and it exhibits slow initial growth, it was thought feasible to utilize wide spacing between rows of cassava to raise an intercrop that could give an earlier extra income along with some agronomic advantages of arresting weed growth and soil erosion and to enhance soil moisture conservation. This was clearly demonstrated in a study of cassava-legume intercropping, where the combination of cassava cultivar Llanera and the legume intercrop bushitavo *(Vigna unquiculata)* recorded a significantly higher yield and monetary return (De Vaz and De Silva, 1982). In another study, the growing of vegetables during the early stages of cassava was shown to be very successful in the mid country wet zone and indicated a potential for generating higher income when cassava (Mu-51) was grown with tomato (Jayawardena and De Silva, 1984). Under the farmers' management conditions cassava-vegetable intercropping systems have shown that cassava-tomato and cassava-bushitavo combinations are economically as beneficial as those achieved under higher

Table 10. Yields of cassava (CARI-555) and vegetables and gross income in cassava-vegetable intercropping systems under a farmer's field condition (Location : Paangolla; Season : Maha 1986/87).

Crop combination	Cassava root yield (t/ha)	Intercrop yield (t/ha)	Gross income (Rs[e]/ha)
Cassava[a] (monocrop)	22.33		27,912
Cassava + Tomato[b]	20.34	8.20	66,425
Cassava + Bushitavo[c]	15.61	3.48	40.392
Cassava + Cucumber[d]	8.49	16.64	27.252
CV (%)	16.10	23.30	
LSD (0.05)	4.19	5.70	

[a]Price of cassava = Rs 1.25/kg.
[b]Price of tomato = Rs 5.00/kg.
[c]Price of bushitavo = Rs 6.00/kg.
[d]Price of cucumber = Rs 1.00/kg.
[e]1 US$ = Rs 30.00

Source : Annual report, IDRC/Sri Lanka Root Crops Project, 1986/87.

management conditions at experimental stations (Table 10). Thus, intercropping cassava with legumes and vegetables appeared a profitable agronomic practice.

Generally, after 5-6 months cassava tends to shed its lower leaves, allowing more sunlight to reach the ground. Hence, an investigation was carried out to determine the potential of intercropping vegetables at early and at later stages within a single crop cycle of cassava by changing its plant spacing. Overall data indicated that double-row planting of cassava intercropped with vegetables is more productive than conventional single-row cassava intercropped with vegetables as it generated an extra income throughout the long growth period of cassava (De Silva *et al.*, 1986) (Figure 5) (Table 11a and 11b)

Table 11a. Root yield (t/ha) of cassava (CARI-555) in monoculture and intercropped with vegetables.

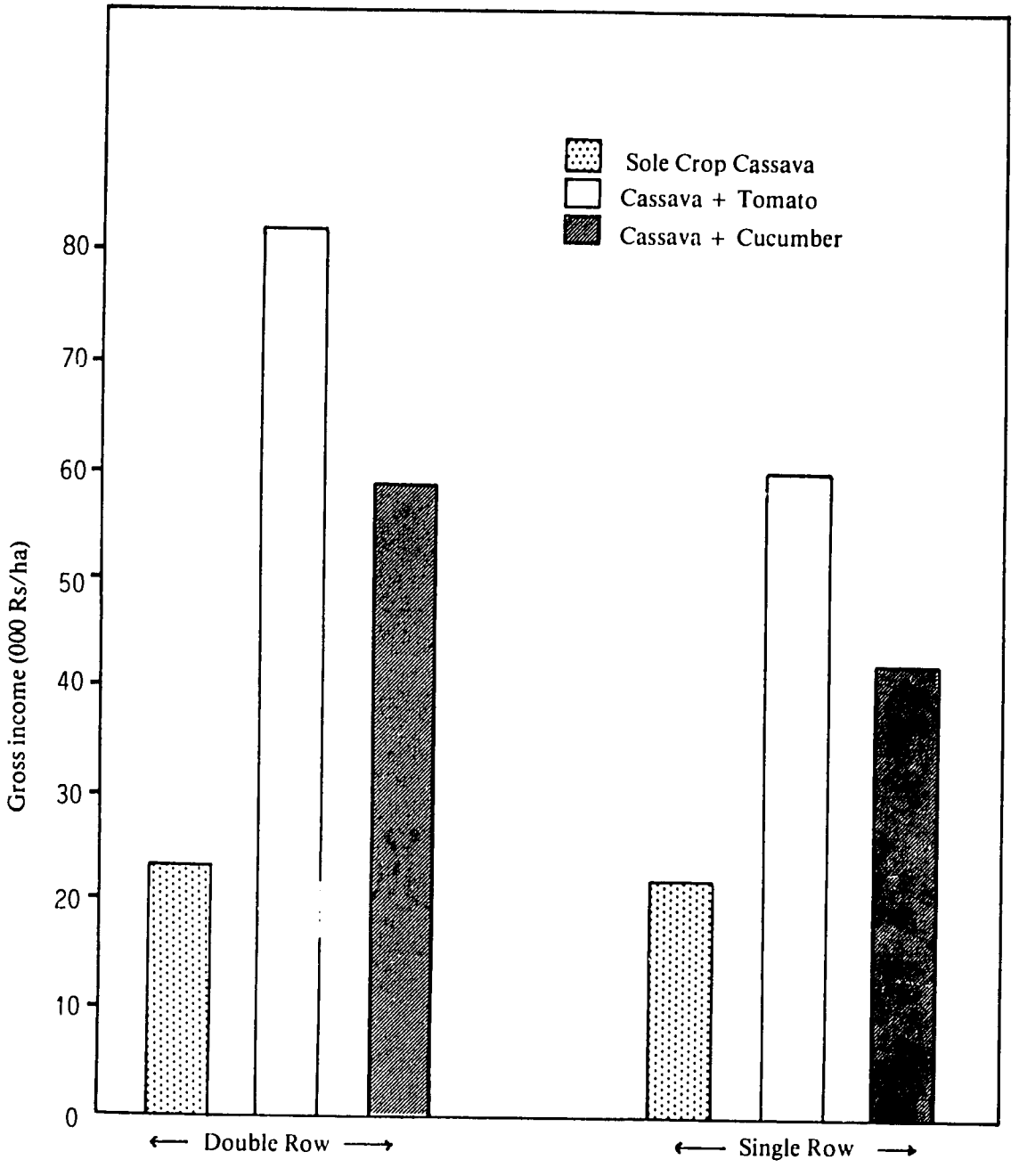
Crops	Single row cassava	Double row cassava
Cassava monoculture	32.35	33.15
Cassava + cucumber	18.31	23.56
Cassava + tomato	32.53	33.17
LSD (0.05)	3.44	
CV (%)	8.14	

Table 11b. Yields of vegetables (t/ha) intercropped with cassava (CARI-555).

Crop	Single row cassava		Double row cassava	
	1st intercrop	2nd intercrop	1st intercrop	2nd intercrop
Cassava + tomato	13.41	1.63	16.12	7.49
Cassava + cucumber	29.71	3.39	36.18	10.58
LSD (0.05)	3.37		1.49	
CV (%)	8.88		15.64	

Source : Annual report, IDRC/Sri Lanka Root Crops Project, 1986/87.

Cultivation of cassava for direct human consumption as fresh food is very profitable at present yield levels and market prices. Higher yields could be obtained with adequate fertilizer applications and use of high yielding cultivars. Investigations on yield response to N-fertilizer application have demonstrated a significant production potential at higher levels of nitrogen (Figure 6). However, in Sri Lanka cassava is rarely fertilized despite the fact that there is a recommendation for applying fertilizers, i.e., 115 N, 62 P_2O_5, and 112 K_2O in kg/ha applied in three splits. Table 12 shows that growing of cassava with a grain legume could also be beneficial in improving the soil fertility and could reduce the need for more fertilizer. When cassava was intercropped with black gram or cowpea over a long period, it was found that one top dressing of N-fertilizer could be eliminated, while still obtaining high root yields of cassava (Table 12 and Figure 7).



PRICES OF :-

1. Cassava Rs 750/t
2. Cucumber Cts 75/kg
3. Tomato Rs 2.50/kg

Figure 5. Gross Income (Rupees/ha) from cassava and vegetables intercropped in trials at CARI. Exchange rate : 1 US$ = Rs 30.00

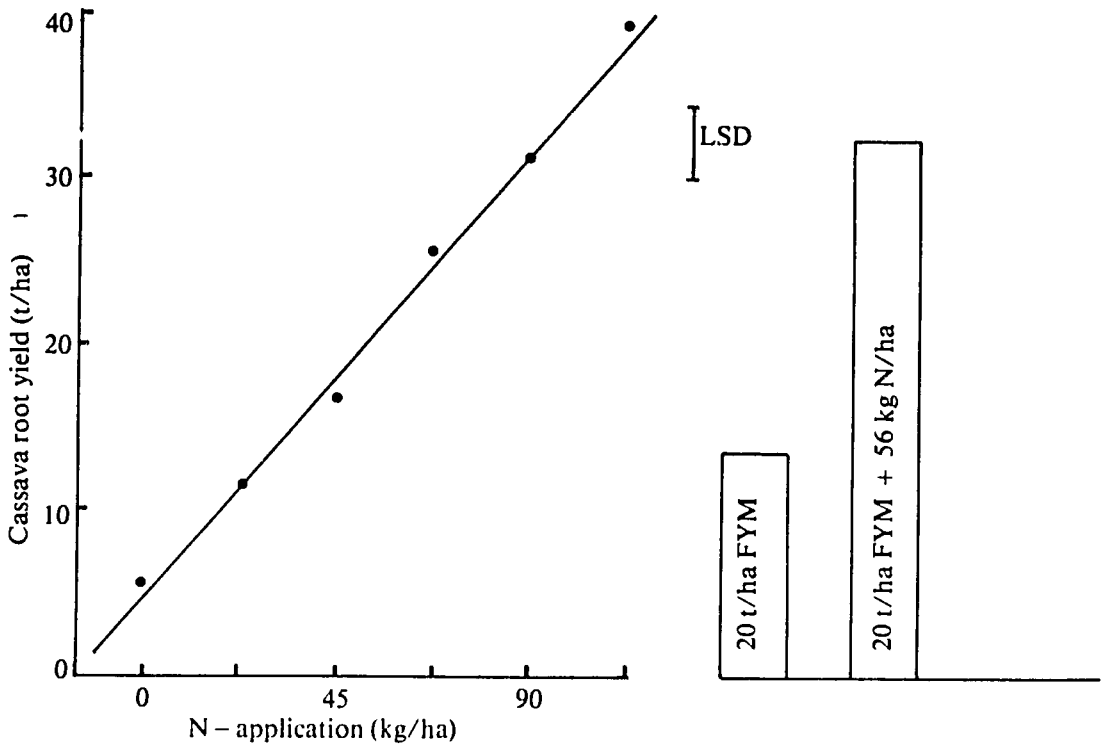


Figure 6. Response of cassava (Mu-51) to N application as urea as well as to application of organic manure on an Ultisol in Kuranegala, Sri Lanka.

Table 12. Root fresh weight of cassava (MU-51) as affected by intercropping with two grain legumes and by varying levels of fertilizer application. Crop period 1986 Yala to 1986/87 Maha.

Level of fertilizer Management	Legume intercrop			
	No-Legume (L_0)	Cowpea (L_1)	Black gram (L_2)	Mean
	Root yield (t/ha)			
F_0-No fertilizer	4.80e	8.25d	10.68c	7.91c
F_1-Basal[a] only	7.09d	15.03bc	11.57cd	11.23b
F_2-Basal + TD-1[b]	11.98cd	17.19ab	23.02a	17.39a
F_3-Basal + TD-1 + TD-2[c]	19.93ab	10.92c	11.78cd	14.21ab
Mean	10.95	12.48	14.26	
CV (%)		27.88		

Note : Means followed by a common letter are not significantly different at 5% probability level according to DMRT.

	Urea	Triple super phosphate	Potassium chloride
	kg/ha		
a. basal:	84	124	124
b. topdress – 1 :	84	–	62
c. topdress – 2 :	84	–	–

Source : Annual report, IDRC/Sri Lanka Root Crops Project, 1986/87.

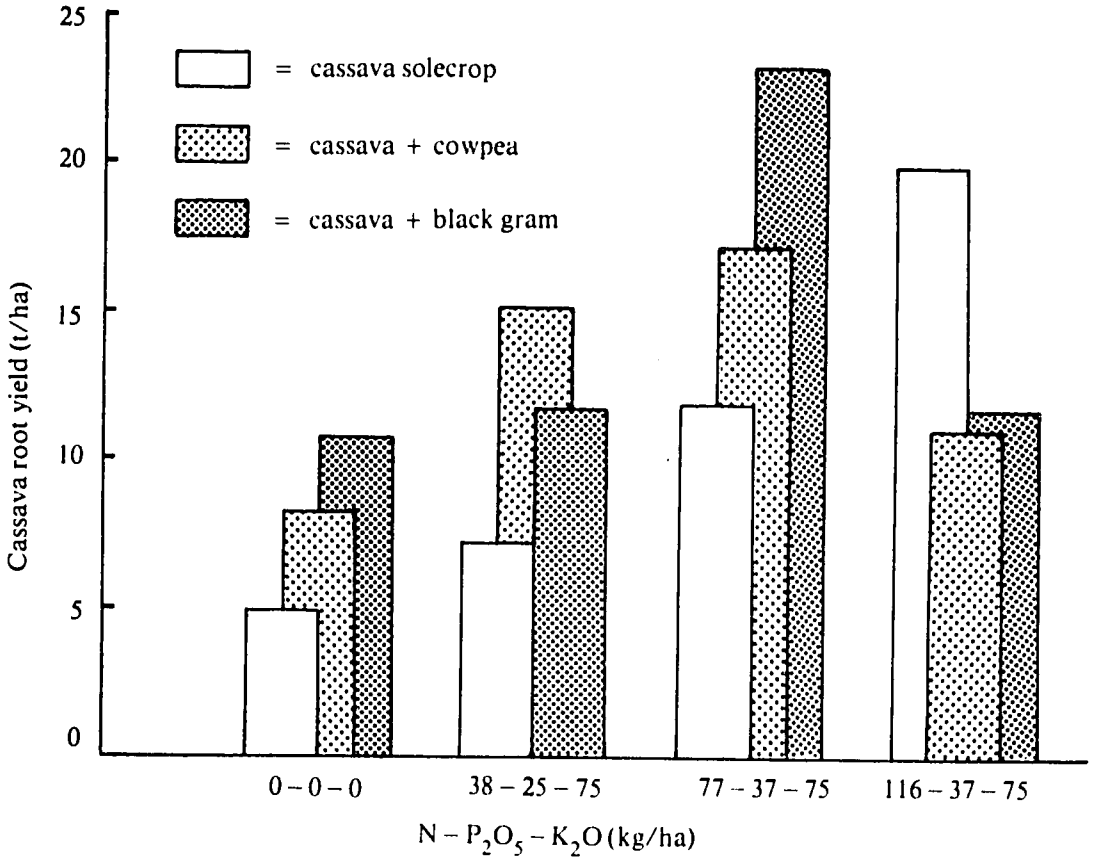


Figure 7. Response of cassava as solecrop or intercropped with cowpea or black gram to four levels of NPK-applications in Peradeniya, Sri Lanka.

Future Directions and Priority Areas of Research in Cassava

Though higher cassava yields could be obtained with adequate fertilizer application along with a high level of intercultural practices, such management practices cannot always be the standard technology for the farmer to increase yield per unit area. Hence, the main research objective should be to increase farmers' income level and not the root yield *per se*. In this respect, further research on cropping systems must be carried out with the idea of reducing the need for weeding, chemical inputs and labor-intensive cultural practices. Nevertheless, developing high yielding cultivars could be considered as the cheapest technology to obtain maximum profits.

Varietal improvement programs should be directed towards developing early maturing cultivars with reasonably high yields and field tolerance to drought, so that areas with low rainfall could be exploited for cassava cultivation. In this context an inexpensive source of food energy is an urgent need for the dry zone subsistance farmer in Sri Lanka, whose calorie deficit level is much higher than the national average. The short rainy season in the dry zone requires cassava cultivars which can be harvested at 6 months. This type of cultivars will be highly useful also in multiple croppling systems in this area.

Inspite of its low current price, the demand for cassava is low due to the fact that consumers are very selective and prefer to purchase very fresh roots within one or two days of its

harvest with acceptable eating and marketing qualities. Therefore, in order to promote cassava consumption as an inexpensive source of food, a crop improvement program should be directed towards developing cultivars with specific characters that are needed to meet the demand for marketing, storage, processing and utilization. High fresh root yield, protein and dry matter content and low HCN content and acceptable loss in storage and good keeping qualities are the major characters to be considered in future programs. More efforts must be directed toward promoting cassava utilization as a source of processed food and as industrial raw material by using low energy consuming technologies, which would result in significantly expanded cultivation of this crop.

Network Research and Cooperative Projects

In our efforts to establish network research and identify areas for cooperative projects we should first try to diagnose the genuine needs of different countries. Cooperative research becomes very vital for those countries that have limited resources and personnel and that can benefit from the results of other countries which are stronger and better established in certain areas of research and development. Therefore, network research and cooperative programs could hasten and assist the country programs to achieve their national goals.

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CASSAVA BREEDING - CIAT HEADQUARTERS

Clair H. Hershey[1/]

Introduction

The CIAT Cassava Program collaborates with national research and development agencies to ultimately increase farmers' incomes and food supplies, as well as to improve food availability for the overall population of tropical developing countries. Improved germplasm is an integral part of the strategy to meet these objectives. This paper gives an overview of cassava breeding and related activities at CIAT headquarters in Colombia, with emphasis on anticipated relevance for Asian research programs.

Cassava Origin and Evolution Related to Breeding Strategy

Cassava originated and underwent the major part of its evolutionary development in the American tropics. By the time of the arrival of European explorers in the 15th century, cassava was widely distributed throughout the American lowland tropics and subtropics. The crop was transported first to West Africa from eastern Brazil by the Portuguese in the 16th century. Introductions to Asia are not well documented, but some of the earliest seem to have been to the Philippines from Mexico, and to the Indian subcontinent from Brazil, in the early 18th century. By 1800, the crop was widely established throughout South and Southeast Asia. At present, Asia and Africa each account for about 40% of world production, with about 20% from Latin America.

Genetic variation in a crop is the result of selection forces during evolution, both pre- and post-domestication. In the diverse evolutionary environment of Latin America, farmer selection resulted in broad genetic differentiation and adaptation of individual clones to specific local conditions. In addition, the development of a wide range of forms of processing and utilization led to strong discrimination and selection on the basis of root quality traits. The end result was the creation and maintenance of many thousands of locally selected cultivars, each propagated vegetatively, often adapted to very specific soil, climatic, disease and pest conditions, and for given end uses.

In contrast to Latin America, initial introductions of cassava into Africa and Asia were apparently from a quite restricted genetic base. Although considerable differentiation undoubtedly occurred by way of occasional recombination and propagation from botanical seed in farmers' fields, the level of genetic diversity must necessarily be considerably less outside the area of origin.

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Breeding Objectives

Cassava research must operate within an evolving context where principal constraints on the development of the crop often shift from production to utilization to processing and marketing. Setting of breeding objectives should focus on the complete commodity system, with an understanding of the role of increased or stabilized crop productivity on national agricultural policy. Breeding is just one component of an integrated research and development approach to solving problems of cassava production, processing and marketing. Thus, setting objectives can only be elaborated after these macro-economic issues are considered. Nevertheless, it is outside the scope of this paper to look at these issues, and the remainder of the discussion is based on the assumption that new cassava cultivars have a significant role to play in a cassava-based development policy.

Cassava is a low input, rainfed crop in virtually all parts of the world where it is grown, and thereby faces an array of production constraints. The biological problems are generally more diverse in the center of origin of the species, but individual pests or diseases may be even more severe outside the center of origin, such as the case of cassava mosaic disease in Africa. This diversity of constraints imposes severe difficulties for breeders. The rate of progress in genetic improvement is inversely proportional to the number of breeding objectives. Therefore breeders should not expect to make rapid progress in simultaneously improving a wide array of traits. A careful prioritization of objectives is essential.

The definition of cassava breeding objectives at CIAT is focused on national research programs and their perception of the needs of farmers and consumers in their area of influence. Our experiences have demonstrated important areas of complementarity between an international center and national programs. An international center has particular advantages in cordinating activities at the international level, and in activities where centralization is beneficial due to economies of scale. National programs on the other hand have distinct advantages in establishing a germplasm base of locally adapted clones, and selecting cultivars for specific local needs.

On the basis of these advantages, CIAT develops working relationships with national programs, which aim to optimize the use of resources on both sides. As needs vary widely from one country to another, so also does CIAT's approach to collaboration with different programs.

CIAT emphasizes breeding work in five principal areas: 1) improvement of characters considered of "universal" importance; 2) adaptation and resistance characters required for specific combinations of climate and soil conditions; 3) improvement of specific characters requested by national programs; 4) development of breeding methodologies with broad applicability across national programs; and 5) collaboration in networking activities.

An Improvement Strategy

Crop breeding, broken down into its most basic elements, consists of accumulating and/or creating a source of genetic variation, and subsequently selecting superior genotypes within this range of variation.

Formation of the germplasm base :

A vital part of any plant breeding program is adequate genetic diversity for all the traits for which improvement is sought. For some programs, especially those near centers of diversity in the Americas, this diversity might be obtained locally. For others, especially outside the centers of diversity, where new characteristics need to be introduced, introduction of exotic[1/] germplasm may be advantageous or even essential to breeding progress.

CIAT is in a unique position to collect, characterize and conserve the world's cassava germplasm in such a manner that it can be readily used by other agencies. Thus, CIAT has been assigned responsibility within the international agricultural research center system for collection and conservation of cassava germplasm from the centers of diversity. The collection of germplasm was one of the first steps taken by CIAT, even before the formal establishment of a Cassava Program. Extensive initial collections were carried out in 1969 and 1970 in the Andean Zone and in Meso-America, bringing to about 2,600 the number of accessions.

A major impetus to further expansion of the collection came about when the International Board for Plant Genetic Resources (IBPGR) decided to assign high priority to financing *Manihot* collection expeditions. With this new initiative the CIAT cassava germplasm collection has grown steadily to now include about 4,500 accessions (Figure 1). The large majority of these accessions are form Latin America, but recent introductions have also been made from Asia and Africa (Table 1).

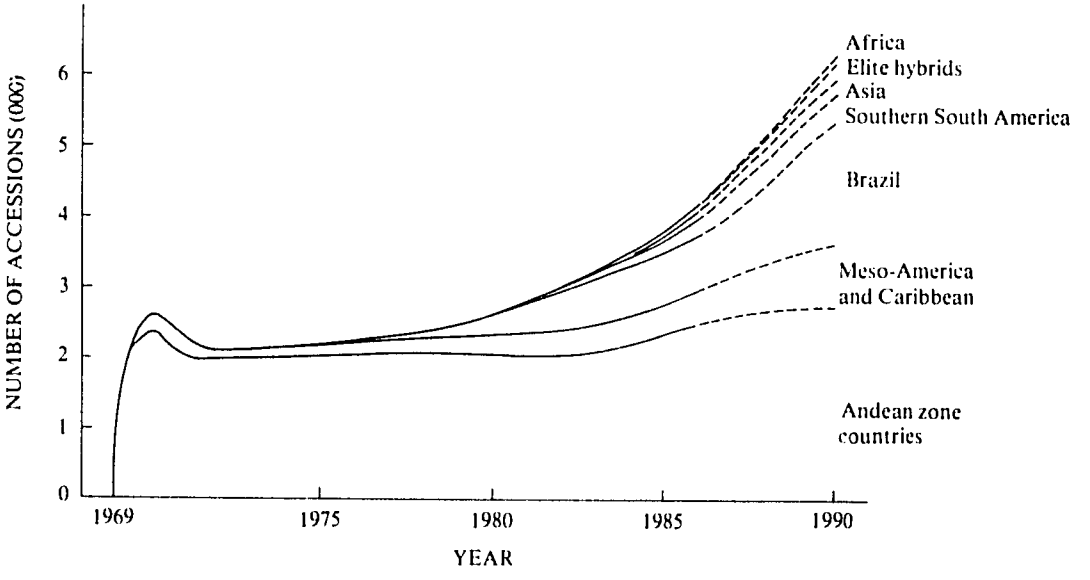


Figure 1. Actual and projected regional composition of CIAT'S cassava germplasm collection.

1/ The term "exotic" is used in the traditional plant breeding sense to mean any germplasm introduced from a different region.

Table 1. Asian clones in CIAT's cassava germplasm collection.

Country of origin	Clone name	CIAT code	Other codes
China	South China 205	M Chn 1	
Indonesia	No. 53	M Ind 1	UJF 45[1]
	W 1435-83	M Ind 2	UJF 21
	Kretek	M Ind 3	UJF 29
	M 31	M Ind 4	UJF 22
	W 236-29	M Ind 5	UJF 61
	B-61	M Ind 6	UJF 82
	M 30	M Ind 7	UJF 3
	Ketan Merah	M Ind 8	UJF 10
	SL 13	M Ind 9	UJF 95
	W 1510	M Ind 10	UJF 81
	X 396	M Ind 11	UJF 26
	WV 65	M Ind 12	UJF 4
	B 6-2	M Ind 13	UJF 83
	SL 44	M Ind 14	UJF 93
	B 16-3	M Ind 15	UJF 85
	B 18-1	M Ind 16	UJF 87
	SL 26	M Ind 17	UJF 97
	SL 1	M Ind 18	UJF 88
	SL 15	M Ind 19	UJF 91
	Kelam Hitam	M Ind 20	UJF 74
	W 1672	M Ind 21	UJF 24
	W 1058	M Ind 22	UJF 12
	Martolepo	M Ind 23	UJF 8
	W 236-41	M Ind 24	UJF 63
	SL 37	M Ind 25	UJF 99
	W 1435-87	M Ind 26	UJF 20
	Faroka	M Ind 27	UJF 6
	SL 4	M Ind 28	UJF 89
	W 1166	M Ind 29	UJF 16
	Adira 1	M Ind 30	UJF 27
	SL 7	M Ind 31	UJF 90
	No. 1-B2	M Ind 32	UJF 30
	No. 734-5	M Ind 33	UJF 52
	CM 3998-13 UJF	M Ind 34	
	CM 3993-28 UJF	M Ind 35	
	CM 3997-26 UJF	M Ind 36	
	CM 3970-4 UJF	M Ind 37	
	CM 4013-3 UJF	M Ind 38	
	CM 4031-10 UJF	M Ind 39	
	CM 4045-6 UJF	M Ind 40	
	CM 4050-2 UJF	M Ind 41	
	CM 4058-9 UJF	M Ind 42	
	CM 4066-2 UJF	M Ind 43	
	W 236-22	M Ind 44	
	SL 31	M Ind 45	UJF 92

Table 1. (continued).

Country of origin	Clone name	CIAT code	Other codes
Indonesia (Cont.)	Manaiag 1	M Ind 46	UJF 72
	SL 10	M Ind 47	UJF 94
	CM 4049-7 UJF	M Ind 48	
Malaysia	M4	M Mal 1	
	Black Twig	M Mal 2	
	C5	M Mal 3	
	C4	M Mal 4	MM 152[2/]
	C3	M Mal 5	MM 151
	C2	M Mal 6	MM 150
	C1	M Mal 7	MM 149
	Tiga Bulan	M Mal 8	MM 156
	I.T.V. 8/1 426/2	M Mal 9	MM 155
	Pantai	M Mal 10	MM 154
	C5	M Mal 11	MM 153
	Bangkok 1	M Mal 12	MM 101
	Betawi	M Mal 13	MM 104
	Fowlfat 146 42/A	M Mal 14	MM 110
	Green Twig	M Mal 15	MM 112
	Jurai	M Mal 16	MM 116
	Lemak	M Mal 17	MM 124
	Llanera	M Mal 18	MM 125
	Merah Bercabang	M Mal 19	MM 128
	Pulut	M Mal 20	MM 132
	Perancis	M Mal 21	MM 131
	Paka	M Mal 22	MM 130
	Putih 1	M Mal 23	MM 133
	Putih 2	M Mal 24	MM 134
	Sakai	M Mal 25	MM 135
	Sembawa Biru	M Mal 26	MM 136
	Silon	M Mal 27	MM 137
	Tangkai	M Mal 28	MM 138
	Telur	M Mal 29	MM 139
	Trinidad 146 52/A	M Mal 30	MM 140
	UBI Ladang	M Mal 31	MM 141
	UBI Melaka	M Mal 32	MM 142
	Variety "A"	M Mal 33	MM 143
	Variety "C"	M Mal 34	MM 145
	Variety "D"	M Mal 35	MM 146
	Variety "E"	M Mal 36	MM 147
	Yellow Twig	M Mal 37	MM 148
	Suting	M Mal 38	MM 158
	Fowlfat 146 42 20/1B	M Mal 39	MM 159
	Lohot	M Mal 40	MM 160
	Teroh	M Mal 41	MM 161
	Peteh	M Mal 42	MM 162
	Thai	M Mal 43	MM 164

Table 1. (continued).

Country of origin	Clone name	CIAT code	Other codes
Malaysia (Cont.)	Melaka (JP)	M Mal 44	MM 167
	Melaka (UPM)	M Mal 45	MM 168
	Lemak (JP)	M Mal 46	MM 169
	Lemak (UPM)	M Mal 47	MM 170
	Red Twig	M Mal 48	MM 171
	Batak	M Mal 49	MM 165
	Yellow Twig (UPM)	M Mal 50	MM 166
	Bangkok 2	M Mal 51	MM 102
	Brazil 146 56/A	M Mal 52	MM 106
	Buluh	M Mal 53	MM 107
	El Salvadore 8/1 326/2	M Mal 54	MM 109
	Del Dr. Hamilton	M Mal 55	MM 111
	Jantung	M Mal 56	MM 115
	Halban	M Mal 57	MM 113
	Kemenyan	M Mal 58	MM 117
	Kerdil	M Mal 59	MM 118
	Keriting	M Mal 60	MM 119
	K.G.T. 44	M Mal 61	MM 120
	Kucir	M Mal 62	MM 121
	Kuning 2	M Mal 63	MM 122
	Kunyit	M Mal 64	MM 123
	Markona	M Mal 65	MM 126
	Merah Jambu	M Mal 66	MM 129
	Variety B	M Mal 67	MM 144
	Black Twig	M Mal 68	MM 105
	Bangkok 3	M Mal 69	MM 157
Thailand	Rayong 1	M Tai 1	
	Rayong 2	M Tai 2	
	Rayong 3	M Tai 3	
	OMR 23-29-15	M Tai 4	
	CMC 76 × V43	M Tai 5	
	27-77-10	M Tai 6	
	29-77-5	M Tai 7	
	Rayong 60	M Tai 8	

1/ UJF = Umas Jaya Farm, Sumatra.
2/ MM = MARDI.

Germplasm collections are useful to breeders only insofar as they are evaluated for pertinent traits and are readily available for use in evaluation trails, multiplications or recombination. CIAT maintains its cassava collection both as field-grown plants and as *in vitro* cultures kept under aseptic, slow growth conditions. This dual maintenance system, though costly, gives a high level of security to guard against germplasm losses, permits continual availability of planting material (field genebank), and provides continual availability of virus-indexed material (*in vitro* genebank) for international exchange.

Selection environments :

It is a maxim of plant breeding that screening variables should be in accordance with those of the target production environment. Given that the target environments for cassava are highly diverse, it follows that selection sites in a breeding program must accomodate this variability through decentralization of selection.

With this in mind, CIAT has subdivided the cassava growing world into six loosely defined categories of soil and climatic descriptions (Edaphoclimatic Zones (ECZs)), based on factors which strongly affect the adaptation of cassava (Table 2). As the presence and severity of biological problems are closely linked to climate and soil factors, characteristic disease and pest complexes are associated with each ECZ description, and tend to further limit a cultivar's adaptation across zones.

Table 2. Edaphoclimatic zones for cassava production and their main characteristics.

Edaphoclimatic Zone	General description	Regions in Colombia for germplasm evaluation and technology testing	Major yield constraints
1	Lowland tropics with long dry season, low to moderate annual rainfall, high year-round temperature.	Magdalena, Atlantico, Bolivar, Sucre, Cordoba	Drought, mites, thrips, mealybugs, termites, CBB, root rots, viruses.
2	Acid soil savannas with moderate to long dry season, low relative humidity during dry season.	Meta	Low soil fertility, drought, CBB, superelongation, anthracnose, leaf spots, mites, mealybugs, lace bugs.
3	Lowland tropics with no pronounced dry season, high rainfall, constant high relative humidity.	Caqueta	Low soil fertility, leaf spots, root rots.
4	Medium-altitude (800-1,500 msl) tropics with moderate dry season and temperatures.	Valle, Cauca	Thrips, mites, mealybugs, CBB, anthracnose, root rots, viruses.
5	Cool, tropical highlands (1,600-2,200 msl) with mean temperatures of approx. 17-20°C.	Cauca	Low temperatures, *Phoma* leaf-spot, anthracnose, mites.
6	Subtropical areas, with cool winters and fluctuating day-lengths.	None	Low winter temperature, CBB, superelongation, anthracnose.

Fortunately, Colombia, where CIAT is headquartered, is geographically and climatically very diverse, and includes climatic, soil, and pest and disease conditions reasonably homologous to those of many parts of the tropics. The one major environment not found in Colombia is the subtropics.

A basic part of the cassava improvement strategy has been to identify sites in Colombia which best represent the characteristics, and especially the stresses, of large cassava growing areas world-wide (Figure 2; Table 3). Selection under high stress environments should result in germplasm widely adapted across both high and low stress environments. On the other hand, selection under favorable conditions would result in insufficient tolerance or resistance to stress factors present in less favorable environments.

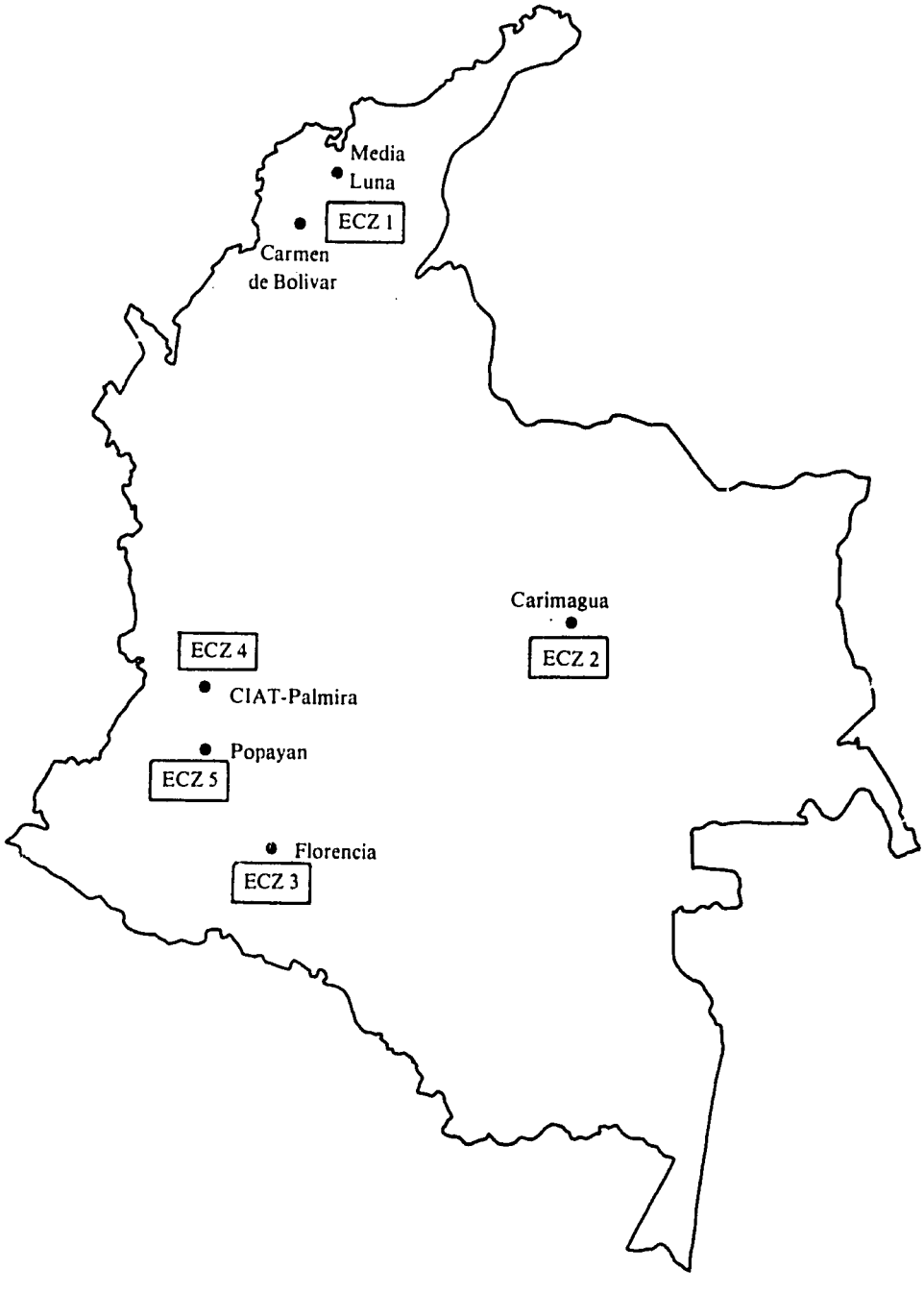


Figure 2. Evaluation sites in Colombia representing five distinct edaphoclimatic zones (ECZs).

Table 3. Soil and climatic characteristics of evaluation sites in Colombia.

Location	Edapho-climatic zone[1]	Altitude (masl)	Mean temper. (°C)	Mean annual rainfall (mm)	Soil characteristics				
					Organic matter (%)	P (ppm Bray II)	K (me/ 100 g)	pH	Texture
Media Luna, Magdalena	1	10	27.2	1,000	0.6	6.5	0.09	6.8	Sandy loam
Carmen de Bolivar, Bolivar	1	152	26.8	1,200	2.7	17.0	1.15	7.3	Clay
Carimagua, Meta	2	200	26.2	1,970	3.5	4.0	0.14	4.5	Clay loam
Florencia, Caqueta	3	450	25.0	3,000	3.8	7.2	0.30	4.3	Clay
CIAT-Palmira. Valle	4	1,000	23.8	1,020	3.6	49.0	0.60	6.7	Clay
Popayan, Cauca	5	1,760	18.0	2,120	25.6	5.0	0.28	5.0	Loam

[1]See descriptions in Table 2.

The description of cassava-growing environments is being refined at CIAT by extensive agroecological studies. Mapping of climate and soil types based specifically on criteria related to cassava adaptation will permit more precisely directed germplasm shipments.

Germplasm evaluation :

CIAT systematically evaluates all germplasm accessions in diverse sites in Colombia, to obtain a broad characterization of adaptation to different soils and climates, resistance to many pests and diseases, and quality traits. The information is used primarily to select parents which can potentially contribute characters requested by national programs. Based on these evaluations, some generalized conclusions can be drawn regarding the genetic potential of cassava landrace varieties.

Within the cultivated species *M. esculenta* a wide range of diversity exists for nearly all traits so far studied, including morphological, agronomic, resistance, and quality traits. Variation in physiological traits has not been widely studied, but there are indications of high variability for sensitivity to temperature and photoperiod, photosynthetic rate, and stomatal sensitivity to air humidity.

Yield potential of the majority of accessions is low and is manifested particularly as a low harvest index. Most landrace cultivars of Latin American origin have evolved with multiple resistance to the local pests and diseases. However, these resistance levels are generally low, since pest control in traditional cultivation systems is accomplished not only by varietal resistance, but also by isolation in space, intercropping, burning and other cultural practices. The

overall conclusion of the evaluations is that few landrace varieties combine all the traits required for more intensified (but low input) cultural systems. Therefore, genetic recombination will play the major role in the future for producing acceptable genotypes. A significant number of landrace varieties have favorable characteristics that have not yet been exploited in breeding programs.

Gene pool improvement :

The use of germplasm by other agencies, in particular national breeding programs, is most efficient if desirable characters for specific ecosystems or end uses are already concentrated in elite gene pools. Given that an international center cannot directly select varieties for specific local adaptation, we instead develop improved, broad-based gene pools from which national programs can directly derive new varieties, or which serve as sources of specific characters for use in local hybridization schemes.

The gene pools developed at CIAT consist of selected clones (landrace varieties or hybrids) which may or may not be genetically related. Components of gene pools are selected on the basis of adaptation to one (or more) of the combined conditions of a given edaphoclimatic zone. Usually, to enter a gene pool, a clone must demonstrate a *combination* of favorable traits. Selections are infrequently made on the basis of very high levels of expression of a single trait, but rather on moderate levels of many traits (Figure 3).

	Germination	Initial Vigor	Flowering*	Pest and Disease Incidence	Lodging	Plant Height	Height of First Branch	Levels of Branching	Leaf Retention	No. of Planting Stakes Produced	Ease of Harvest	Root Length	Root Neck Length	External Root Color	Root Flesh Color	Root Form	Root Constrictions	No. of Commercial Roots	Rotted Roots	Root Yield	Foliage Yield	Root Specific Gravity	Root HCN	General Evaluation – Roots	General Evaluation – Foliage
F_1 and F_1C_1	F	F		F				F				F								F				F	F
Observational Trial	A	A		A	A	A	A	A	A	A								S	S	S	S	S		A	A
Preliminary Yield Trial	A	A	A	A	A	A	A	A	A	A	S	S	S	S	S	S	S	A	A	A	A	S	S	A	A
Advanced Yield Trial	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

F = Subjective evaluation on a family basis
S = Evaluation of selected clones only
A = Evaluation of all clones in the trial
* = Evaluation at CIAT-Palmira only

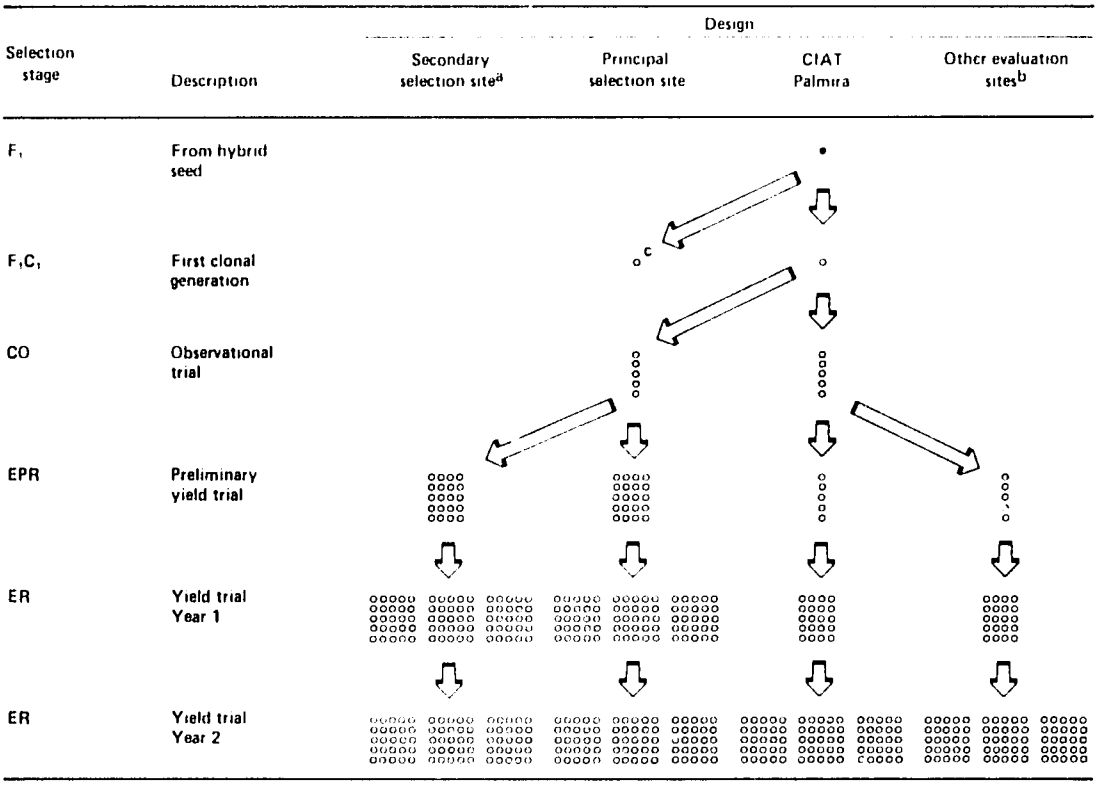
Figure 3. Data taken on CIAT cassava breeding trials.

These pools are not closed populations, however. New parents from outside the pool may be added at any time. Selection of genotypes for inclusion in a given gene pool may be based on phenotypic or genotypic values, which in turn are estimated from one or more of several possible criteria: 1) performance of a clone in CIAT's Colombia-based trials; 2) estimates of general or specific combining ability from progeny trials in Colombia or in target regions of national programs; or 3) recommendations of a national program based on their experience with given clones.

A major selection goal is to produce genotypes adapted across the variations *within* an ECZ, but not necessarily *across* different zones. Initially, few of the individual components of a given gene pool were suitable as recommended varieties. Rather, these clones had complementary traits, which in the recombination process could produce superior progeny. Thus, the gene pools are subjected to cyclic improvement through recurrent selection. Virtually all selection takes place in decentralized selection sites (Figure 2), while recombination is done at CIAT headquarters where adequate facilities and personnel are available. The principal form of recombination is through open pollination in polycross blocks. Controlled cross pollination is used also for cases where a national program requests recombination of specific characters or specific clones.

The gene pools are loosely defined, and the ECZ descriptions used only as general guidelines for targeting germplasm shipments. Some clones, due to exceptionally broad adaptation may be included as parents in more than one gene pool. Considerable genetic interchange among gene pools is permitted in order to transfer desired characteristics.

Both year to year and long term yield stability are basic criteria for cassava growers. Many factors can influence stability, and especially pests and diseases, and decline in soil fertility. Thus, stability is a function of both appropriate agronomic practices and cultivar. To assess stability there is no substitute for evaluations across several sites and several years. CIAT



[a] Same ECZ as principal selection site

[b] Different ECZ than principal selection site

[c] Selection in principal selection site, but stakes for CO from CIAT Palmira

Figure 4. Stages of selection in CIAT Cassava Breeding Program.

incorporates this methodology into its system for parental selection (Figure 4), but each national program must also evaluate for stability under local conditions.

In summary, the objectives of gene pool development are: 1) general upgrading of broadly relevant traits such as yield potential and root dry matter content: 2) upgrading within specific gene pools of edaphoclimatic zone-specific traits such as climatic adaptation, and pest and disease resistance: and 3) maintaining wide genetic diversity within each gene pool for those traits which are locally or regionally important, such as plant architecture or root quality, so as to allow sufficient flexibility for adaptive selection by national programs.

Breeding Advances and Expected Contributions to Asian Programs

In a previous workshop involving Asian cassava breeders (Kawano *et. al.*, 1986), common important objectives were summarized as:

1. substantial yield increases to acquire higher competitiveness with other sources of carbohydrates;
2. early maturity to give additional alternatives to the production systems;
3. higher root dry matter or starch content; and
4. diversification of cultivars to gain resistance to diseases and pests.

There are many indications that new introductions of Latin American germplasm have the potential to contribute in all these areas. This topic is treated in greater detail in the presentations of our Asian national program colleagues in these same proceedings. Advances in cassava breeding at CIAT are reported in detail in CIAT Annual Reports. Only two specific examples are cited here for purposes of illustration.

The north coast region of Colombia is an area of poor soils, low rainfall, and a dry season of 4-5 months. The principal selection of the ECZ 1 gene pool is done in Media Luna in the Magdalena Department. Hybrids and selected germplasm accessions commonly outyield

Table 4. Selected results from advanced yield trial, Media Luna, Mag., Colombia (Edaphoclimatic Zone 1); 1986-87.

Clone	Root yield (t/ha)	Root dry matter (%)	Root HCN (1-9)
CG 915-1	26	32	7
CM 3268-1	23	31	5
SG 455-1	23	36	8
CM 3320-4	23	30	8
M Bra 12	22	30	8
CM 3780-2	22	29	7
CM 1533-19	22	29	7
CM 3372-4	20	30	7
Black Twig	20	34	8
M Bra 191	20	34	5
Local check (Venezolana)	10	37	6
Trial mean (71 clones)	15	32	7
LSD (5%)	6.7		

the local clone by 100% (Table 4). In this particular region, there are strict requirements for very high dry matter and low HCN, since the primary market is for fresh consumption. Some of the new clones meet these stringent requirements, and many more have potential for less demanding, industrial markets. The ECZ 1 gene pool is most useful for areas of poor soils and a long dry season, and where mites and insects are yield limiting factors.

The eastern plains (Llanos Orientales) of Colombia are an area of high rainfall, acid infertile soils, and very high disease pressure (bacterial blight, anthracnose and superelongation disease) (ECZ 2). This is an area of low human population density and cassava is cultivated mainly as a backyard crop. When placed under more intensified cultural practices, we found that no local clones combined the necessary pest or disease resistance and yield potential for the region. With intensive selection over more than ten years, a broad range of genotypes now exists with good disease resistance and yield potential of two to three times greater than local clones (Table 5). These selections form the basis of the ECZ 2 gene pool, which is especially useful for areas of acid soils and high pressure from the mentioned diseases.

Table 5. Selected results from advanced yield trial, Carimagua, Meta, Colombia (Edaphoclimatic Zone 2); 1985-86.

Clone	Fresh root yield (t/ha)	Root dry matter (%)	Root HCN (1-9)	Bacterial blight (1-5)	Super-elongation disease (1-5)
CM 2909-36	31	35	8	2.7	1.7
CM 2766-3	30	33	7	2.0	2.0
SG 104-283	29	34	7	3.0	2.0
SG 104-264	29	33	9	2.7	3.0
CM 2668-6	29	32	8	2.0	2.0
CM 2772-3	27	30	5	2.0	2.7
CM 2766-5	27	33	4	2.0	1.0
CM 2770-7	26	30	6	2.0	3.0
CM 2952-2	26	29	4	2.7	3.0
SG 107-35	25	31	5	2.3	2.0
Local check (Llanera)	11	32	5	3.0	3.3
Trial mean (48 clones)	21	32	7	2.6	2.5
LSD (5%)	7.6				

From evaluations of the very limited number of Asian clones maintained at CIAT up to two years ago, some interesting comparisons have been made with the CIAT-developed gene pools. The four clones (Rayong 1, M-4, Black Twig and Green Twig) all performed quite well in ECZ 1 (low rainfall, long dry season) (Table 6). Rayong 1 and Black Twig have been incorporated into the ECZ 1 gene pool, but due to their limited flowering, have not been used as extensively as desired in recombinations. All the clones are susceptible to bacterial blight and superelongation disease, however (Table 7), and improvements in disease resistance might be an important breeding objective for cultivars to replace these clones in their native areas.

Table 6. Performance of several Asian clones in advanced yield trial, Media Luna, Magdalena, Colombia, 1982-83.

Clone	Fresh root yield (t/ha)	Root dry matter (%)
Top yielding clone	21	30
M 4 (Malaysia)	18	26
Black Twig (Malaysia)	17	31
C 5 (Malaysia)	16	26
Rayong 1 (Thailand)	15	28
Local check	16	36

Table 7. Evaluations of Asian clones for disease and insect resistance.

		Evaluation[1]			
Clone	Origin	Green cassava mite	Thrips	Bacterial blight	Super-elongation disease
Rayong 1	Thailand	3	3	4	4
M 4	Malaysia	4	4	4	4
Black Twig	Malaysia	3	3	4	4
C 5	Malaysia	4	5	4	5

[1] 1 = low damage; 5 = high damage.

Evaluations in progress of a broader range of Asian clones (Table 1) will give us a better grasp of areas of strength and potential vulnerability of these materials, and will provide further guidelines for the CIAT and Asian breeding programs.

Effective Use of Exotic Germplasm by National Programs

While CIAT can make progress in certain areas of breeding through its headquarters program, the selection and release of new cultivars is a national program responsibility. Developing a superior new cultivar, which will be widely adopted by farmers and accepted by consumers, is, as any breeder knows, a major undertaking. The time and money resources which go into developing new varieties obligate the breeder to maximize chances of success. Unfortunately it is all too common for public sector breeders to spend many years developing cultivars under experiment station conditions, only to realize at the advanced stages that some unanticipated problem of acceptance arises when taken to farmers.

Farmers grow particular cultivars because they know them to have certian desirable characteristics. They usually consider them to be "good" cultivars for their purposes. Plant breeders have too often made the assumption that any introduced germplasm must necessarily be an improvement over locally selected clones, while ignoring farmers's criteria for growing certain cultivars.

Several general principles apply for making effective use of exotic germplasm. The use of introduced genetic variability generally implies moving useful genes from unadapted to adapted germplasm. In cassava, virtually all agronomically important traits are multigenically controlled, so transfer of traits is a complex process. In general exotic germplasm should be introduced for the purpose of introducing characters not available, or at a low frequency in local germplasm, or for decreasing genetic vulnerability. This implies a thorough evaluation of local varieties to fully understand their strengths and weaknesses. If the characters desired already exist in local clones there may be little justification for introduction of foreign germplasm.

Because cassava is often selected for adaptation to very specific edaphoclimatic conditions and end uses, it is normally expected that introduced germplasm may have certain problems of adaptability or acceptability. These problems can be minimized by introducing germplasm from similar ecosystems, and by introducing a broad range of genotypes so as to increase the probability of finding some which are acceptable. Given these probable difficulties in management of exotic germplasm, its introduction may normally be considered a medium-to long-term solution to varietal improvement, rather than a means of quick results.

The highest potential contributions for exotic germplasm are: 1) outside the area of origin (where genetic diversity is limited); and 2) in situations where cassava will be expanded into new areas, or adapted to new cultural systems or end uses. In these situations local clones may not exist, or may have been selected on the basis of criteria completely distinct from present objectives.

Building a Cooperation Network

CIAT offers training and technology preferentially through network activities. In the case of Asia, the CIAT input to the networks is primarily through the CIAT Regional Office in Bangkok.

Network activities are numerous. However, in cassava, in all cases, networks are organized rather loosely at present. It is not the intent of this paper to develop a complete account of network activities, but rather to highlight the principal ways in which CIAT headquarters breeding is made effective through networks, and specifically in germplasm and information interchange. Basic components of this interchange are illustrated in Figure 5.

Germplasm interchange :

International centers have traditionally placed considerable emphasis on germplasm distribution as a one-way flow from a headquarters breeding program to national programs. This has undoubtedly been an effective strategy in some cases. However, it is not an optimal strategy for cassava in Asia. Many Asian Programs already have quite respectable cultivars and strong breeding programs. Therefore CIAT must be able to offer well-defined germplasm for Asia's specific needs. Often this germplasm will not be used directly but rather in crosses with local material. Alternatively, many of the local cultivars and locally improved hybrids are now available at CIAT headquarters, and can be used in a hybridization program to incorporate specific traits, for sending segregating populations back to the national program.

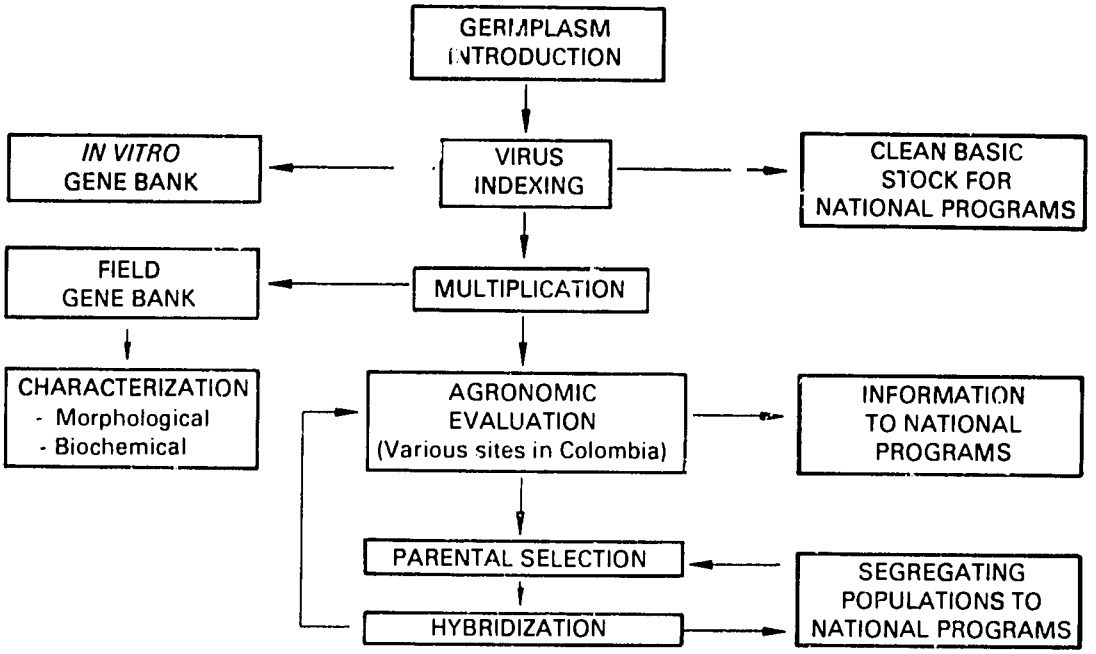


Figure 5. Germplasm and information flow between CIAT and National Programs.

The preferred and predominant method of germplasm exchange between CIAT and Asian programs is in the form of botanical seed. This form is characterized by two overriding advantages: 1) large genetic diversity available for local selection; and 2) ease of handling. Nevertheless, sending vegetative material has been successful in the past, and continues to be an option, in the form of aseptic *in vitro* plantlets.

Having the Asian local clones centralized at CIAT offers the possibility of facilitating movement of clones across national borders within Asia. As Asian quarantine laws tend to be quite strict, such movement is often difficult directly between countries. In this sense, processing by a third entity, such as CIAT, where advanced disease indexing techniques are utilized, is the only present alternative. This arrangement requires an understanding by each donor country that the germplasm provided to CIAT will be freely available to any other country world wide.

Recently CIAT has been able to introduce to its Colombian headquarters some of the promising new hybrids derived from CIAT or CIAT × local crosses and selected in different Asian breeding programs. The performance of these materials in diverse sites in Colombia will give us a good perception of similarities or differences between CIAT's selection sites and specific cassava-growing regions of Asia. In addition, the clones can be recombined with others having complementary traits, for even further improvement.

Information exchange :

An essential component of the process of cassava genetic improvement at CIAT is an efficient system of information exchange. To be effective, this information exchange must be timely and relevant to the acceptability criteria of farmers, processors and consumers. In most cases, this depends on informal interchange through correspondence and visits, and more formally through reports and workshops. However, there is still much room for improvement in information gathering and reporting.

It is common, worldwide, to find vast numbers of cassava varietal trials reported in which only root yields are given. The applicability of this information is very limited in terms of recommending new cultivars or even for selecting parents in a breeding program. We know that a wide range of other criteria are important to varying degrees to farmers and to consumers. Plant architecture, root form and quality, and pest and disease resistance are traits which should be recorded whenever possible. In addition, in order to understand something of the edaphoclimatic adaptation of a genotype, the experimental conditions should be reported--at minimum, soil analysis of major nutrients, monthly rainfall, and mean temperature. With these data, a much more realistic analysis can be made of the potential of given clones as parents.

Since segregating populations have become the most common form of germplasm interchange between CIAT and national programs, it is crucial to design information systems specific for this methodology. Evaluations of F_1 families can provide useful early feedback on parental suitability. This evaluation of suitability can take various forms; however, two of the most useful of these are: 1) mean family performance ("performance" defined for any criteria of local importance); and 2) the proportion of selected individuals. By knowing which cross combinations give best (or worst) results, we can make rapid adjustments to the parental composition of the gene pools at CIAT. This feedback is most crucial when making seed introductions to an area for the first time, and little previous information exists on the characteristics required.

Training :

There are important advantages for Asian national program cassava breeders to have the opportunity to spend time at CIAT headquarters in Colombia. These visits provide learning opportunities for both the national program and international center scientists.

In Colombia, the presence of most of the world's cassava pests and diseases, as well as the world's largest cassava germplasm collection, can be of special interest for programs working outside the center of origin of cassava. Although many of the pests and diseases may not exist in a particular country, they can represent future threats if introduced. In addition, the array of management techniques used for different pests may give insight on how to best manage given local problems. An important advantage to training at CIAT is for national program breeders to provide firsthand information to CIAT scientists on how CIAT can better satisfy the germplasm needs and provide other services to individual countries.

Summary

Cassava breeding at CIAT headquarters in Colombia is relevant to national programs only if objectives coincide with needs of producers/processors/consumers in target regions. This information can only be provided by the national programs. An international center cannot provide a definition of local objectives, or finished cultivars for all cassava-growing regions. An international center can, however, in collaboration with national programs, provide an array of benefits, including: 1) centralized germplasm maintenance; 2) comparative evaluations under diverse conditions; 3) advanced clones with defined characteristics; 4) segregating populations from selected parents; 5) mechanisms for international germplasm movement; and 6) training in many aspects of cassava breeding.

Reference

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CIAT CASSAVA GERMPLASM DEVELOPMENT IN ASIA - COOPERATION WITH NATIONAL PROGRAMS

Kazuo Kawano[1/]

Introduction

During the first ten years of the CIAT Cassava Program (1973-1982), CIAT offered cassava germplasm and trainig/communication opportunities to Asian cassava researchers. Since the opening of the CIAT Cassava Program Regional Office in Bangkok, Thailand in 1983, cooperation with Asian national programs has been greatly strengthened. These activities contributed to the establishment and improvement of national cassava research programs in many Asian countries. In 1973, cassava breeding work was non-existent, just starting, or nearly dormant in Asian countries except at the Central Tuber Crops Research Institute in India. Now, cassava varietal improvement programs are highly functional in many of these countries (Table 1).

Varietal improvement objectives common to Asian national programs are :

1. Higher yielding capacity under low-and medium-input conditions.
2. Higher root dry matter content.
3. Early harvestability.
4. Disease and pest resistance and tolerance to adverse soil and climatic conditions.
5. Lower root cyanide content.

Increased production efficiency rendered by improved yielding ability and higher processing efficiency by higher root dry matter content will lead to higher competitiveness of cassava products. Higher yield per unit area may help cassava production retreat from erosion threatened sloping areas and early harvestability may lead to better land use efficiency. Far from the center of origin and diversification of the species, cassava in Asia (except in India and Sri Lanka, where cassava is infected by African mosaic disease) is less troubled by diseases and insect pests than cassava in tropical America. Yet, diversification of cultivars with respect to resistance factors is much needed for the long-term stability of cassava cultivation. The importance of cassava for fresh human consumption is relatively less in Asia than in Latin America or Africa; nevertheless, the demand for improved low-cyanide cultivars continues to be significant in Asia as well.

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Table 1. Development of Cassava Breeding Programs in Asia.

Country / Institution	Situation of Cassava Breeding program in 1973	1987
Thailand		
Dept. Agr.	+	+ + + + +
Kasetsart Univ.	0	+ + +
Indonesia		
CRIFC	+	+ + +
Brawijaya Univ.	0	+
China		
SCATC	+	+ + +
GSCRI	0	+
Philippines		
VISCA	0	+ + +
UPLB	+	+ +
Malaysia		
MARDI	0	+ + + +
Sir Lanka		
CARI	0	+
India		
CTCRI	+ + +	+ + + +

0 : Non-existent
+ + + + + : Functioning in desired capacity

CIAT Cassava Germplasm and the Need of On-site Selection

Genetic variability in a given crop species is richest in the center of origin and diversification of the species. The advanced cassava breeding materials provided by the CIAT cassava program are developed on the basis of the whole Latin American germplasm in an attempt to increase the frequency of genes that are commonly desirable to national breeding programs. The following example appears to confirm these general characteristics of CIAT cassava germplasm.

Cassava bacterial blight (CBB) caused by *Xanthomonas manihotis*, brown leaf spot caused by *Cercosporidium henningsi*, and mite damage caused by *Tetranychus* spp. are the most commonly observed diseases and pest of cassava in Southeast Asia, although their real effects on root yields are not clearly documented. CIAT clones which had been selected for yielding capacity were evaluated for these diseases and pest by a leading Indonesian cassava breeder at one evaluation site in Lampung, Sumatra (See Table 3 of section "Cassava Breeding in Indonesia"). It was found that the CIAT clones possessed resistance to these diseases and pest in high frequencies while the local clones were largely susceptible.

Edapho-climatic conditions of cassava growing areas vary from one region to another within a country, eventhough they might be classified under the same macro-edapho-climatic

zone. Quality requirements also vary depending on utilization and location. Latin American germplasm on the whole offers much wider genetic variation, but it contains genes for local adaptation in much lower frequencies than the local germplasm. This seems to be well supported by the following experience. Germination of CIAT and local clones was evaluated under scarce rainfall conditions at Rayong Research Center in Thailand in 1983 (Table 2). Planted with irrigation, all CIAT-crossed clones, locally crossed clones, and Rayong 1, the leading local cultivar, germinated reasonably well. However, planted without irrigation, the germination of CIAT clones was extremely poor compared with that of the local clones. The germination of Rayong 1 was virtually the same with and without irrigation. Although the average germination of CIAT clones was low, some CIAT clones germinated very well without irrigation. Unreliable rainfall is a common phenomenon in Thai cassava production areas, but CIAT cassava breeding materials have not been thoroughly screened for germination under such conditions.

Table 2. Comparison of germination percentages between CIAT and Thai crosses in Rayong, Thailand, 1983.

Planting system	Clone	Site of hybridization	Number of clones	Average germination (%)
Irrigated	CM	CIAT	165	68.4
Irrigated	CMR and OMR	Rayong	1,323	75.8
Irrigated	Rayong 1 (local cultivar)		1	89.2
Not irrigated	CM	CIAT	249	42.7
Not irrigated	CMR and OMR	Rayong	135	60.4
Not irrigated	Rayong 1 (local cultivar)		1	86.6

Source: Field Crops Research Institute, Thailand.

Obtaining a recommendable cultivar selected from a small number of clones introduced from CIAT is unlikely. Local germplasm, on the other hand, may be an excellent source of adaptation of traditional cultural environments and requirements of the locality. Yet a significant jump, either in yield or resistance factors, is not expected as long as the breeding program uses only local germplasm: by nature it possesses limited genetic variability (Hershey, 1987). Incorporating Latin American germplasm into Asian breeding populations is the most appropriate way to improve cassava production. Thus, local selection from large numbers of introduced CIAT seed populations, selection from local × CIAT crosses, or the combination of both, becomes the most logical alternative (Mariscal, 1986; Sinthuprama and Tiraporn, 1987).

Germplasm Exchange

Introduction of germplasm always involves a combination of potential benefits and potential risks. Benefits may result from increased productivity of a crop. This must be weighed against the risks of accidentally introducing pests or pathogens. Neither the benefits nor the risks are easily assessed.

Three types of germplasm materials, i.e., germplasm accessions, hybrid clones, and hybrid seeds are available from CIAT in the form of 1) stakes, 2) meristem cultures, and

3) true seed. Advantages and disadvantages of each method are summarized as follows: stakes are the easiest to handle but the risk is highest; meristem cultures are less risky and offer reproduction of indentical genotypes, but are not suitable for transferring a large number of genotypes, and their handling requires certain skills and facilities at the receiving end; sexual seed is the least risky and offers easy handling of a large number of genotypes although the identical genotype cannot be obtained (Kawano and Hershey, 1985). Lozano and Jayasinghe (1982) have described pathological problems disseminated by sexually and asexually propagated materials.

From a stake introduction from CIAT to the Philippines in 1978, a cultivar, VC-1 (CM 323-52, crossed at CIAT in 1973), was selected by PRCRTC, VISCA and released by the Philippines Seed Board in 1986. From a meristem culture introduction to China in 1981, a cultivar Nanzi-188 (CM 321-188, crossed at CIAT in 1973) was selected, multiplied through a simplified tissue culture technique, and released by the South China Institute of Botany. From seed introductions to Thailand, Rayong 3 (CM 407, crossed at CIAT in 1974) was selected by the Field Crop Research Institute and released by the Department of Agriculture in 1984, and Rayong 2 (CM 305, crossed at CIAT in 1973) in 1985. From crosses made locally between local germplasm and selected CIAT clones, Rayong 60 was selected from the Rayong 1 × M Col 1684 cross and will be released in 1988.

Emphasis in recent years has shifted from sending clonal materials to sending hybrid seeds from selected parents. CIAT now intends to pass elite parental clones through meristem cultures to be used for hybridization in Asian breeding programs rather than as candidates for immediate varietal release. As national cassava breeding programs are strengthened, seeds will continue to increase in importance as a means of exchanging genetic material. Crosses will continue to be more precisely tailored to the needs of national programs by incorporating feedback information.

During the past years, approximately 140,000 hybrid seeds from some 2,300 crosses have been distributed to cassava breeding programs in Asia (Table 3). In many national programs, these seed populations are regarded as sources for immediate varietal selection while programs such as the one in Thailand have also selected cross parents from the seed populations to be used in their hybridization programs. These materials are being processed through established evaluation stages in each national program (Table 4).

Table 3. CIAT cassava F_1 hybrid seeds distributed to Asian programs.

Country \ Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	Total
Thailand	900		6,170	7,720		3,050	1,400	7,450	7,900	8,000	9,300	8,000	59,890
Indonesia	900			700					4,600		6,000	4,950	17,150
Philippines	900			950			5,100	4,700	5,500	2,350	5,000		24,500
China								2,300	6,100		3,500	1,800	13,700
Malaysia	900		1,500			2,050	1,250	4,050				200	9,950
India	900			850					1,050	7,900			10,700
Vietnam									1,900				1,900
Rep. China (Taiwan)	500							1,200					1,700
Total	5,000		7,670	10,220		5,100	7,750	19,700	27,050	18,250	23,800	14,950	139,490

Table 4. Evaluation of CIAT cassava materials in Asian national programs - 1986/87. (Expressed in number of genotypes).

	Thailand*	Indonesia	China	Philippines	Malaysia
F_1 seedling	17,050	3,050	1,229	2,200	169
Single-row trial	2,667	990	134	110	–
Preliminary trial	164	20	19	165	–
Advanced trial	44	13	5	13	118
Regional trial	23	–	–	7	10
On-farm trial	6	2	–	–	–
Multiplication	5	10	–	1	1
Varietal release	3	–	1	1	–

*Most of good Thai materials are Thai × CIAT type crosses.

CIAT intends to remain a primary source for genetic diversity in cassava, with the national programs taking an increasing role in local selection and incorporation of improved characteristics into local cultivars.

Selection for High and Low Input Environments

Among major tropical food crops, cassava is unique in that harvest index is an important factor for yield, not only under high but also under low (poor soil fertility, long dry season) yielding environments (Kawano and Jennings, 1983). Selecting for higher harvest index had been

the main strategy of yield breeding in the early days of the CIAT cassava varietal improvement program (Kawano, 1978). This resulted in distinctly higher harvest indices demonstrated by selected CIAT clones which are now being evaluated by Asian national programs (Table 5 and 6).

Table 5. Yield characteristics of selected CIAT clones in Malaysia.

Clone	On mineral soil (Serdang, 1985/86)					On peat soil (Jln. Kebun, 1986/87)				
	Fresh root yield (t/ha)	Total plant wt. (t/ha)	Stem leaf wt. (t/ha)	HI	Starch content (%)	Fresh root yield (t/ha)	Total plant wt. (t/ha)	Stem leaf wt. (t/ha)	HI	Starch content (%)
Traditional cultivar										
Black Twig	42	92	50	.45	27	21	35	14	.61	24
C5	37	90	53	.41	26	22	37	15	.58	24
Average of 18 CIAT clones	43	77	34	.56	26	21	32	11	.65	22
Outstanding CIAT clone CM 2527-7	62	110	49	.56	27	42	68	26	.62	24

Source : Tan S.L., MARDI.

Table 6. Yield characteristics of selected CIAT clones in Indonesia.

Clone	Fresh root yield (t/ha)	Total plant wt. (t/ha)	Stem & leaf wt. (t/ha)	HI	Root dry matter (%)
Traditional cultivar					
Kretek	25	52	27	.48	31
Local selection					
Adira-I	24	40	16	.60	38
M-30	42	62	20	.68	33
Adira-IV	33	53	20	.62	37
Average of 30 CIAT clones	35	56	21	.63	36
Outstanding CIAT clone					
CM 4013-3 UJF	47	75	28	.63	36

Source : R. Soenarjo, CRIFC; Hardono N., P.T. Umas Jaya Farm,. Experiment was conducted at P.T. Umas Jaya Farm, Lampung, Sumatra.

In many parts of tropical Asia, as in the American tropics, traditional cassava cultivars are mainly used for fresh human consumption and are well adapted to small-scale plantings

often in backyards, where the major selection criteria are eating quality and yield per plant rather than yield per unit area. These cultivars, such as Hanatee in Thailand, Kretek in Indonesia, and Golden Yellow in the Philippines, usually have a low harvest index. When the need arises for more efficient genotypes for large-scale production, new high yielding cultivars are attained usually by improved harvest index (Cock *et al.*, 1979; Hershey, 1987; Tan, 1987). Rayong 1 in Thailand, South China 205 in China, Lakan in the Philippines, and Black Twig in Malaysia belong to this category (Figure 1).

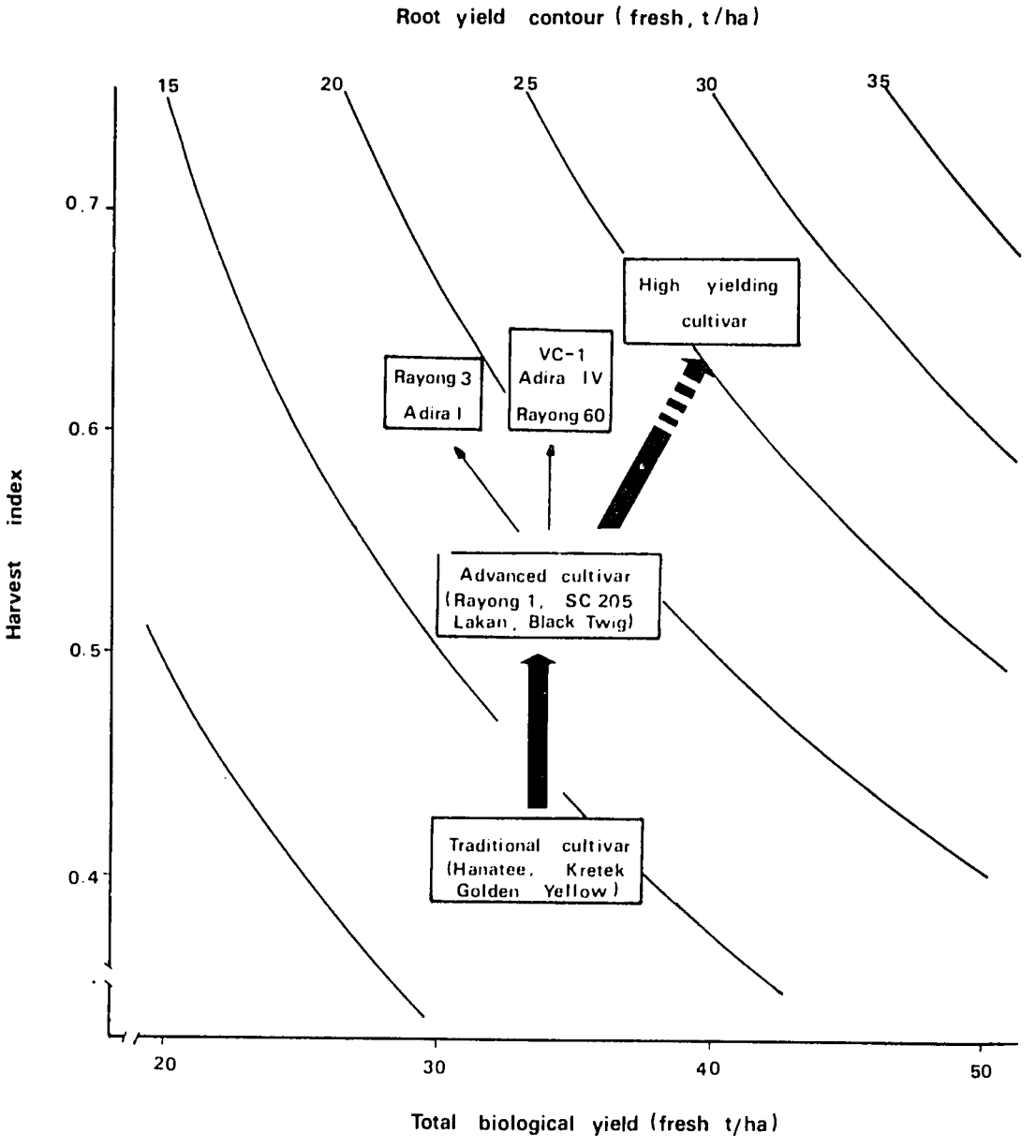

Figure 1. Schematic presentation of root yield improvement by breeding for low-input growing conditions.

Further increasing harvest index is not difficult, especially by selecting from CIAT breeding materials, but it becomes increasingly difficult to maintain the same canopy strength, and occasionally high harvest index types result in reduced total biological yield (Figures 1 and 2, Tan 1987). This type of clones are usually well-adapted to high yielding environments but not to low yielding environments due to deficient canopy strength. Rayong 3 may belong to this category.

Our immediate selection target is to improve harvest index while maintaining the same total biological yield. A new cultivar Rayong 60 in Thailand seems to qualify for this category (Figure 2). Due to higher harvest index under the same total biological yield, this type of clones inevitably result in lesser canopy strength (represented by stem and leaf weights) compared to their local counterparts. While it leaves little doubt that this type of clones do very well under favorable growing conditions, the question remains whether they are as versatile under high-stress conditions.

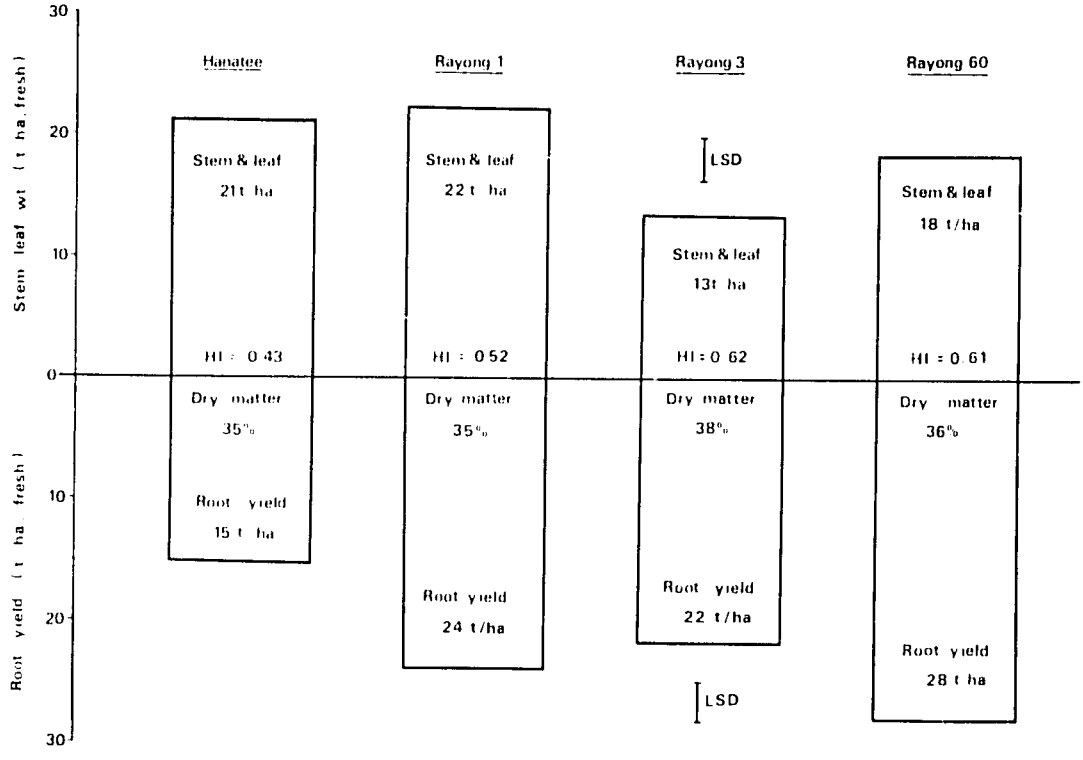

Figure 2. Schematic demonstration of yield characters in four clones in Thailand
(Data : average of 29 experiments; Source : Field Crop Research Institute).

The most ambitious selection goal in cassava yield improvement is to improve harvest index while maintaining the same canopy strength of traditional cultivars (Tan, 1987). This means a simultaneous improvement in both harvest index and total biological yield. Such a genotype, if realized, would give significantly higher yield than currently available cultivars, not only under high but also under low yielding environments. Selected clones such as CM 2527-7 in Malaysia (Table 5) or CM 4013-3 UJF in Indonesia (Table 6) tend to show selection in this direction, although the number of experiments with these promising clones is far too

small to conclude that simultaneous selection for harvest index and total biological yield is possible. All these experiences, nevertheless, strongly support the idea that canopy strength must be treated with the same importance as harvest index in cassava breeding for higher yields.

Selection Environment

One of the greatest difficulties in tropical agricultural research is the transfer of experiment station results to farm production. This difficulty is even greater with cassava, which has its main areas of commercial cultivation in marginal agricultural areas.

Much of the earlier activities of the CIAT cassava breeding program was spent in defining selection sites. CIAT headquarters are located in the Cauca Valley of Colombia, characterized by fertile soils, a favorable rainfall pattern, and modest temperature regimes, where very little cassava is grown commercially After a couple of years of breeding and selection at the headquarters, spectacular yield increases were demonstrated (Kawano, 1978). However, it was soon evident that the elite materials were useless in more representative cassava-growing areas of the Colombian North coast, where soil fertility was low and the dry-season pressure was high. A different set of genotypes was selected which showed significant yield improvement on an experiment station located in the North coast. However, even these new elites were not as readily useful in farmers' fields as originally expected. The cultural environment at the experiment station was far better than that of the farmers so that the selection environment was not truly representative of the farm conditions. We suffered from a typical "experiment station vs. farmers' fields" syndrome (Kawano and Jennings, 1983). It was only after the major selection sites were moved to a more typical cassava field on the North coast and to one of the most difficult cassava-growing areas, characterized by extremely poor soil, a long dry season, and a broad spectrum of diseases and pests, cassava-growing areas in the Colombian Llanos that truly useful genotypes for difficult cassava-growing conditions were identified.

The Thai cassava research program has its breeding headquarters in the Rayong Field Crop Research Center, where the soil fertility is generally low, the dry season is long, and rainfall is erratic-well representing the vast cassava areas managed mostly by small, poor farmers. Hybrid clones selected in Rayong seem to perform equally well outside the station.

We can conclude that selection sites must be located in the most representative cassava production areas and the cultural practices of the selection plots must be adjusted to be within reach of the average farmer. If breeders are given a choice between easily manageable growing conditions and difficult growing conditions for the selection site, they are advised to take on the greater challenge of the latter.

Summary

With more than ten years of cooperation between Asian national cassava research programs and CIAT, it is increasingly evident that CIAT-Latin American germplasm on the whole offers much wider genetic variation, but it contains genes for local adaptation in much lower frequencies than the local germplasm. Local selection from large numbers of introduced CIAT seed populations, selection from local × CIAT crosses, or the combination of both, is the recommended breeding strategy for the Asian cassava research programs.

The immediate selection target of breeding for higher yields is to improve harvest index while maintaining the same total biological yield. There is sufficient evidence to indicate that this is an attainable target. The most ambitious selection goal is to improve harvest index while maintaining the same canopy strength of the traditional cultivars, meaning simultaneous improvement in both harvest index and total biological yield. To approach this target, the same importance in breeding and selection must be given to canopy strength as to harvest index.

Special care must be taken in defining selection sites and accompanying cultural practices. Selection sites must be located in the most representative cassava production areas and the cultural practices of the selection plots must be adjusted to be within the reach of the average farmer.

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RAPPORTEUR'S SUMMARY OF DISCUSSION ON "PRIORITY AREAS IN BREEDING"

Tan Swee Lian[1/]

Priority areas in breeding were identified as those traits which each country representative listed to be important breeding objectives in their respective national programs. It was noted that some of these priority areas are common to all seven countries, while certain others apply specifically to one or more countries.

The common priority areas include high root yield, earliness or early harvestability, and root quality (mainly high dry matter content or high starch content). While high yield and dry matter content are easily understood and easily measurable traits, the concept of earliness is not fully definable. Much discussion had transpired previously around the interpretation of this "parameter", and it was generally agreed that earliness is reflected by early root bulking, indicated by reasonably high yield of commercial-sized roots after 6, 8 or 9 months from the time of planting. It is not to be confused with physiological maturity of the crop. Basically, early high yielders tend to be high-yielding as well after the normal 12-month growth period.

It was suggested that other than considering early harvestability, another parameter, to be called "duration of harvestability", be given some attention. Duration of harvestability describes the span of time over which commercial-sized roots may be harvested without any loss in root quality. A durable clone by this definition would provide greater flexibility in its harvesting schedule, something which is particularly useful to and desired by small farmers who wish to have better control over fluctuating prices of fresh roots. Harvesting of the clone may then be carried out earlier or delayed until the price of roots is more profitable. Screening for duration of harvestability may be achieved by recording root yields at, say 6, 12 and 18 months.

Also common on the list of priorities is adaptation of the clones. Adaptation, however, refers to different conditions in individual countries. Adaptation may mean tolerance to drought (in Indonesia, the Philippines, Sri Lanka and Thailand), to strong winds and low temperatures (in China), to waterlogging (e.g. in peat in Malaysia), to acid soils (in the Philippines), and to shade (for intercropping under tree crops, e.g. in India and the Philippines).

Resistance to pests (especially mites) and diseases (especially cassava bacterial blight) is regarded to be important in Indonesia, India, the Philippines and Thailand. India has the added problem of cassava mosaic disease.

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Plant type was also mentioned as being a significant breeding objective in China, India, Indonesia, Malaysia and Thailand. This may imply a non-branching habit, considered suitable for intercropping with shorter term field crops (Thailand, India), or it may ascribe to short low-branching plants resistant to wind damage (China). Under the general term plant type may also encompass root shape which should be blocky or compact to facilitate harvesting, or be amenable to mechanized harvesting (Indonesia, Malaysia). Roots with a discernible peduncle are favored in India as, when separated from the cutting, they expose less cut surface area for infestation by disease, and will therefore have better shelf life.

A priority area specific to such countries as Indonesia, India, the Philippines and Sri Lanka, where cassava is used as human food, is low root cyanide content. In contrast, Indonesia also regarded high root cyanide to be of importance in cassava plantations as this acts as a deterrent to damage by wild boars, a cause of yield loss.

Good germination is given priority by Malaysia, the Philippines and Thailand because it determines high plant stand and full yielding potential. To China, storability of planting materials during the cold winter months is another priority area.

Some concern was voiced over the matter of establishing priority areas. It was questioned whether the priorities had been drawn up on the basis of what the breeders believed to be the needs of the industry, or whether some systematic means of assessing the type of cassava materials required by the industry had been adopted. The concern stemmed from the possibility of developing clones which will be rejected by industry on the grounds of being unsuited to its needs. A brief discussion revealed that all breeders were very much guided by the needs of industry as they work closely with this sector, or remain in intimate contact with its every deve-

Table 1. Varietal improvement objectives in Asian national cassava programs.

	Thailand	Indonesia	China	Philippines	Malaysia	India	Sir Lanka
High root yield	×	×	×	×	×	×	×
Early harvestability	×	×	×	×	×	×	×
High root dry matter content	×	×	×	×	×	×	×
Low root cyanide		×		×		×	×
High root cyanide		×					
Good germination	×			×		×	
Good plant type*	×	×	×		×	×	
Drought tolerance	×	×				×	
Shade tolerance				×		×	
Cold tolerance			×				
Acid soil tolerance				×			
Wind tolerance			×	×			
Waterlogging tolerance					×	×	
CBB resistance	×	×	×	×			
Mites resistance	×	×		×			
ACMD resistance						×	×

*Plant type may be non-branching (general) or low-branching and short (for wind tolerance).

lopment. In some cases, surveys of an informal nature had been conducted to gauge these needs from growers of the crop as well as the processors of the roots.

Table 1 gives a summary of the priority areas by country. With several priority areas common to the participating countries, the idea was mooted of sharing or exchanging within Asia clones developed or incorporated with the desired trait or combination of traits. In this respect, India and Sri Lanka would not be able to contribute their new clones as these two countries are the only ones in Asia with recorded occurrences of cassava mosaic disease. Inter-country trials, comprising newly developed clones contributed by participating countries, tested against the respective local check clone or clones were suggested as a means to maximizing the use of clones resultant from individual country's breeding efforts and research investment. These trials will also be able to supply valuable information on the performance of clones in interaction with different climatic and edaphic conditions. Such a program would only be possible (from the phytosanitary and quarantine points of view) with elite materials exchanged and disseminated in the form of meristem cultures. It was generally felt that not all countries were equally equipped with facilities and trained staff to handle meristem materials at this point in time. Moreover, the present rate of multiplication of planting materials from meristem cultures to secure sufficient amounts for field evaluation remained too slow to serve the needs of inter-country trials. While unanimously agreed upon the advantages of inter-country trials, the workshop made it clear that the preparation of clean planting materials of common entries would need much longer time than generally believed.

CIAT's role of coordinating cassava germplasm movement (as seeds and meristem cultures) had traditionally been from CIAT to Asian countries. Lately, germplasm (meristem cultures) has moved also from Asia to CIAT in an attempt to maintain a gene bank reflective of worldwide genetic resources. For a start, all the currently best clones from each Asian country will be deposited in CIAT's germplasm collection. A logical next step would be the movement of germplasm materials (meristem cultures) from one Asian country to the next via CIAT. In other words, CIAT will try to fulfill requests for any particular clone or clones from one country to another. CIAT's role will also be increasingly enhanced by the provision of custom-made hybird seed (certain combination of desired traits at the request of a country).

CIAT will continue to disseminate research technology and basic information, particularly those related to breeding and selection methodologies, which will improve the efficiency and skills of Asian cassava breeders.

CASSAVA CULTURAL PRACTICES RESEARCH IN THAILAND

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Edafo-climatic Characterization of Major Cassava Growing Regions

In the past, the main cassava growing area of Thailand was in the east of the Central Plain region, but recently the major cassava area has shifted to the Northeast region, which now accounts for 60% of the total area, followed by the Central Plain region occupying 35% (mainly in the east of the Central Plain), and the north region occupying 5% (Table 1). Accordingly, the highest cassava production (57% of total production) is now in the Northeast, followed by that of the Central Plain (38%) (Table 2). The average yield of 14.4 t/ha in the Northeast region is lower than that of the Central Plain region, which has an average of 16.2 t/h (Table 3). Many factors are responsable for this, but the main ones are related to topography, poor soil/water conservation, and a longer and more intense dry season. However, both regions, the Northeast and the Central Plain, in general have similar edafo-climatic conditions. The normal period of rainfall is May to October, after which it is usually dry for 6 consecutive months from November to April (Figures 1 and 2).

In Thailand cassava is mainly grown on Gray Podzolic soils (Ultisols), which are highly leached with low base saturation (35-50%) and low levels of N, available P and K; they are light in texture (sandy loam to sandy) and moderately to excessively drained. Soil moisture storage capacity ranges from 60-80 mm per meter of soil. The surface soil pH ranges from 5.0-6.0 and decreases with depth, being 4.5-5.0 in the subsoil and 3.8-4.0 at the lowest depth.

Table 1. Cassava planted area (000 ha) in different regions of Thailand.

Year of harvest	Region			Whole Kingdom
	North	Northeast	Central Plain	
1983	49	813	507	1369
1984	64	817	524	1405
1985	78	885	513	1476
1986	69	758	412	1239
Average	65	818	489	1372

Source : Center for Agric. Stat., Agric. Stat. of Thailand, Crop year 1985/86.

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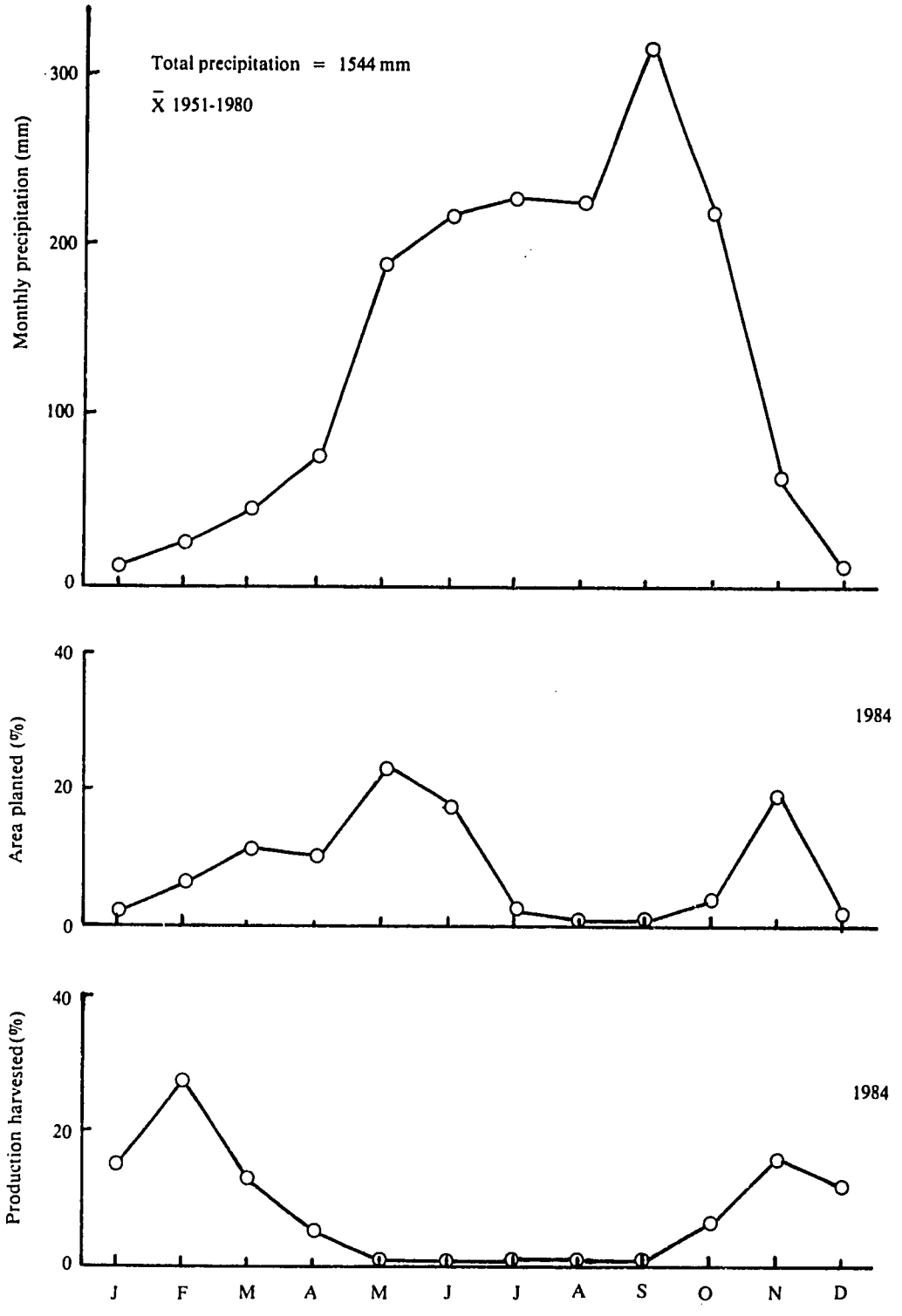

Figure 1. Monthly precipitation and the percent cassava area planted or production harvested in the Central Plains in 1984.

Source : Meteorological Dept. and Office of Agric. Statistics.

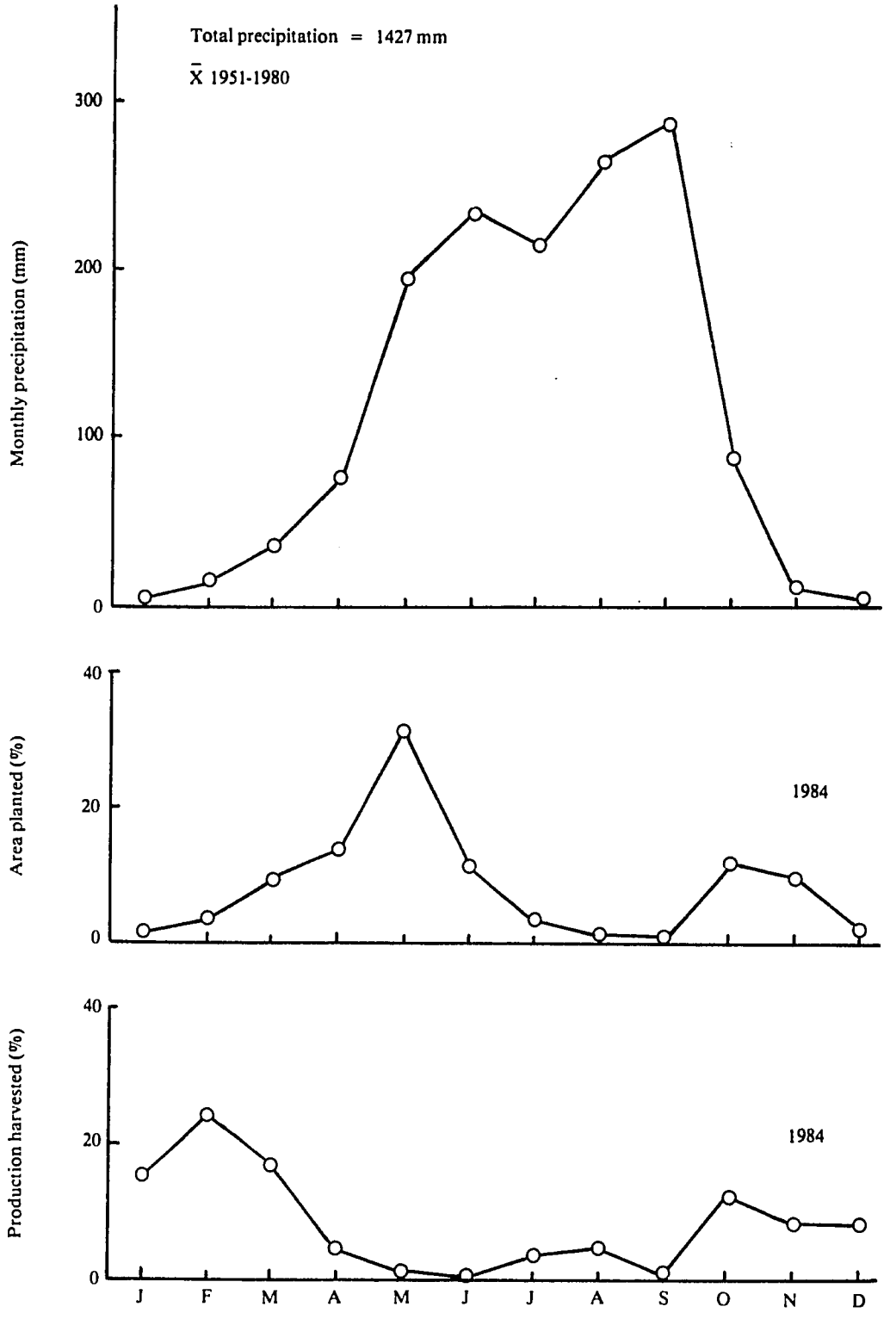

Figure 2. Monthly precipitation and the percent cassava area planted or production harvested in the Northeast in 1984.

Source : Meteorological Dept. and Office of Agric. Statistics.

Table 2. Cassava production (000 t) in different regions of Thailand.

Year of harvest	Region			Whole Kingdom
	North	Northeast	Central Plain	
1983	745	10985	7259	18989
1984	986	11080	7919	19985
1985	1073	10964	7226	19263
1986	968	8782	5505	15255
Average	943	10453	6977	18373
%	5	57	38	100

Source : Center for Agric. Stat., Agric. Stat. of Thailand, Crop year 1985/86.

Table 3. Average cassava yield (t/ha) in different regions of Thailand.

Year of harvest	Region			Whole Kingdom
	North	Northeast	Central Plain	
1983	16.6	17.8	20.5	18.6
1984	17.2	14.1	16.1	15.0
1985	15.2	13.7	14.4	14.0
1986	14.3	12.0	13.6	12.7
Average	15.8	14.4	16.2	15.1

Source : Center for Agric. Stat., Agric. Stat. of Thailand, Crop year 1985/1986.

Methods of Cultivation

Most cassava is grown continuously as monoculture without rotation or fallowing. Intercropping of cassava is practiced to a very limited extent, usually with maize, grain legumes, young coconut or rubber.

Land preparation :

On small farms, land preparation is usually done with animal power (bullocks) in the beginning of the rainy season. On large farms, land preparation is usually by contract using a tractor. Plowing is done as soon as possible after the harvest of the previous crop. A major problem in land preparation is the lack of tractors, which often results in delayed planting.

Stake preparation and storage :

Planting material is obtained by cutting stems from plants 8-12 months old; these are normally stored for less than 30 days, depending on the time of land preparation and rain. Longer storage tends to affect the quality of the stakes, resulting in poor germination and initial growth. Generally, stakes are not treated with chemicals. Stake length is usually 15-20 cm.

Planting time :

Cassava is planted year-round but principally in the beginning of the wet season. A survey in 1983 showed that in the Central Plain and Northeast regions 62 and 65% of cassava was planted in the early wet season from March to June, 8 and 18% in the heavy rains of July to October, while the remainings 30 and 17% were planted in the late rainy and dry season, respectively (Figures 1 and 2). The reasons for planting cassava in the late rainy season and the dry season are to minimize weed problems, to obtain higher prices at harvest because of higher starch content, a greater demand from buyers, and probably to avoid competition with rice for labor. Replacement of ungerminated stakes is usually done within 30 days after planting. Low germination, especially in the dry season plantings, results in high labor costs for replanting.

Spacing :

Cassava is generally planted at various spacings depending on the soil condition. Traditionally, a rather close spacing is used, ranging from 60 × 80 cm to 100 × 100 cm, to ensure a good initial stand and to reduce the need to replant; another reason is to avoid severe weed growth by a more rapid closing of the cassava canopy. Close spacing also reduces erosion.

Fertilization :

One of the most serious problems is the lack of fertilizer application to cassava. Nevertheless, fertilizer is applied to cassava fields at low rates in some areas, depending on the economic status of farmers, the price of cassava and the cost of fertilizer. The rate normally used is 150-190 kg/ha of 15-15-15 fertilizer in order to ensure a good initial growth, which in turn results in higher yields. Fertilizer application is usually done 1 to 2 months after planting. The problem is that on steep slopes cassava is rarely fertilized, resulting in increased soil erosion; in the long run, the loss of soil productivity caused by erosion may be the most serious problem.

Weeding :

Cassava is susceptible to competition from weeds, especially at the early growth stages. Failure of timely weeding can cause a total yield loss. Weed control is traditionally done 3-4 times during the crop cycle by animal-drawn plow and/or by hand weeding 1-2 times during the first 3 months after planting; this is followed by 1-2 hand weedings and/or post-emergent herbicide application.

Harvesting :

Cassava is harvested year-round, but principally in the dry season. The peak harvesting period in both the Central Plain and Northeast is in January to April, accounting for 62 and 60% of the total production harvested in each region (Figures 1 and 2). Very little cassava is harvested during the rainy period of May to September, because of the low starch content, low price, and low demand from buyers due to difficulty in drying. Plant age at harvest varies from 8 to 14 months, but most is harvested before 12 months.

Cassava Agronomy Research

Most research on cassava cultural practices was conducted to determine the best production technology to be recommended to cassava farmers. Research on cassava cultural practices has given the following results :

Land preparation :

Preliminary studies indicated that application of pre-planting herbicide without plowing gave a similar cassava yield to traditionally prepared land which was plowed by tractors and ridged by bullocks (Table 4). The minimum tillage concept may be introduced to protect the soil from erosion and to reduce labor costs, but the feasibility needs to be confirmed.

Table 4. Effect of land preparation on the yield of cassava, Rayong 1, at Rayong Field Crops Research Center, 1981.

Treatments	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.

Stake size and storage :

Stake length studies in 1974-1976 showed that stakes of 15 cm length gave higher survival percentage than shorter stakes of 5-10 cm length. Stakes cut from the middle and

Table 5. Effect of stake length and stem part 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	59.9
10	72.7
15	83.7
20	95.0
Part of Stem	
Upper	49.8
Middle	73.7
Lower	92.8

Source : Field Crops Research Institute. Annual Report 1976.

Table 6. Effect of storage time and method with different stem parts of Rayong 3 on percent plant survival at 30 days after planting at Rayong Field Crops Research Center, 1984.

Storage time (day)	Storage method			
	in sun		under shade	
	%			
	Basal Stem	Secondary Stem	Basal Stem	Secondary Stem
0	91.2	85.9	92.9	82.9
15	79.5	59.6	78.5	64.4
30	68.8	43.9	73.5	50.2
45	48.7	37.2	59.2	35.1
60	21.1	17.2	39.8	12.1

Source : Field Crops Research Institute. Annual Report 1984.

lower parts of the stem resulted in better survival than those from the top part (Table 5). Studies on stem storage with the leading cultivar Rayong 1 indicate that when stems were stored up to 30 days in the field the survival rate of stakes was about 80%, and storage under shade tended to be better than in the sun (Sinthuprama and Tiraporn, 1986). The same studies were repeated with a new cultivar, Rayong 3. The results showed that stakes from the basal stem gave higher survival percentage than those from the branches in every storage condition and period. Stems of Rayong 3, especially those taken from younger branches, could not be stored more than 15 days (Table 6). Storage under shade was confirmed to be the best method.

Planting method :

Root yields were not different for cassava planted on ridges, on flat ground, or on flat ground followed by earthing up 30 days after planting. Horizontal planting gave lower yields

Table 7. Yield (t/ na) of cassava, Rayong 1, grown with different methods, positions and depths of planting at Rayong Field Crops Research Center, 1977-1978.

Treatments	Depth of planting (cm)			Mean
	5	10	15	
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 depth of planting.
Mean separation : (DMRT, 0.01)

Source : Field Crops Research Institute. Annual Report 1979.

than vertical planting, mainly due to the initial lower survival rate. Vertical or inclined planting resulted in similar yields. Depth of planting (5, 10, 15 cm) had no effect when plantings were either vertical or inclined (Table 7); deeper planting in the horizontal position resulted in delayed sprout emergence, and caused deeper rooting and difficulty in harvest in every planting position.

Planting time :

Studies of planting time and age of harvest were carried out with Rayong 1 for 3 years from 1976 to 1978 and indicated that root yields were highest with June plantings and decreased with later planting. Root yields increased with age of harvest from 8 to 18 months. However, if harvesting were to be delayed to more than 12 months, the planting date of the next crop in the same area would be shifted and would not fit the annual cycle (Sinthuprama, 1980).

The same studies were carried out with Rayong 2 and Rayong 3 cultivars in 1983-1985. Figure 3 shows that the root yields of Rayong 2 and Rayong 3 were highest when planted in May. Root yields increased significantly with harvest age from 6 to 12 months. These results were similar to those of Rayong 1 discussed above. Planting earlier in the rainy season produced the highest yields, especially when the roots were harvested at 12 months.

Spacings :

Cassava spacing studies showed no significant differences in yield at spacings ranging from 60×60 cm (27,777 plants/ha) to 120×120 cm (6,944 plants/ha). A wider spacing facilitated intercultivation; the planting of cassava at 1×1 m was recommended (Charoenrath, 1983). Cassava spacing studies for Rayong 1 were repeated for another 2 years, as a component research for the introduction of the cropping system. It was found that when cassava populations were maintained at 10,000 plants per hectare, plants could be arranged in various spacings (100 × 100, 150 × 66, 200 × 50 and 300 × 33 cm) without significantly affecting the yield (Table 8).

Table 8. Effect of plant spacing on yield of cassava, Rayong 1. Combined analysis for 5 locations[1/], 1979-1980.

Spacing (cm)	Plants/ha	Yield (t/ha)
100 × 100	10,000	29.87
150 × 66.7	10,000	27.06
200 × 50	10,000	26.25
300 × 33.3	10,000	25.06
		NS

1/ Rayong, Loei, Sakonnakon, Supanburi, and Khon Kaen.
No significant interaction between location and spacing.

Source : Field Crops Research Institute. Annual Report 1981.

Research on spacing of the new cassava cultivars, Rayong 2 and Rayong 3, were conducted in order to redefine the best spacings for these new cultivars. The results showed that cassava yields were significantly different at various spacings in different locations, as shown for Rayong 2 in Table 9 and for Rayong 3 in Table 10. The different yield responses were due

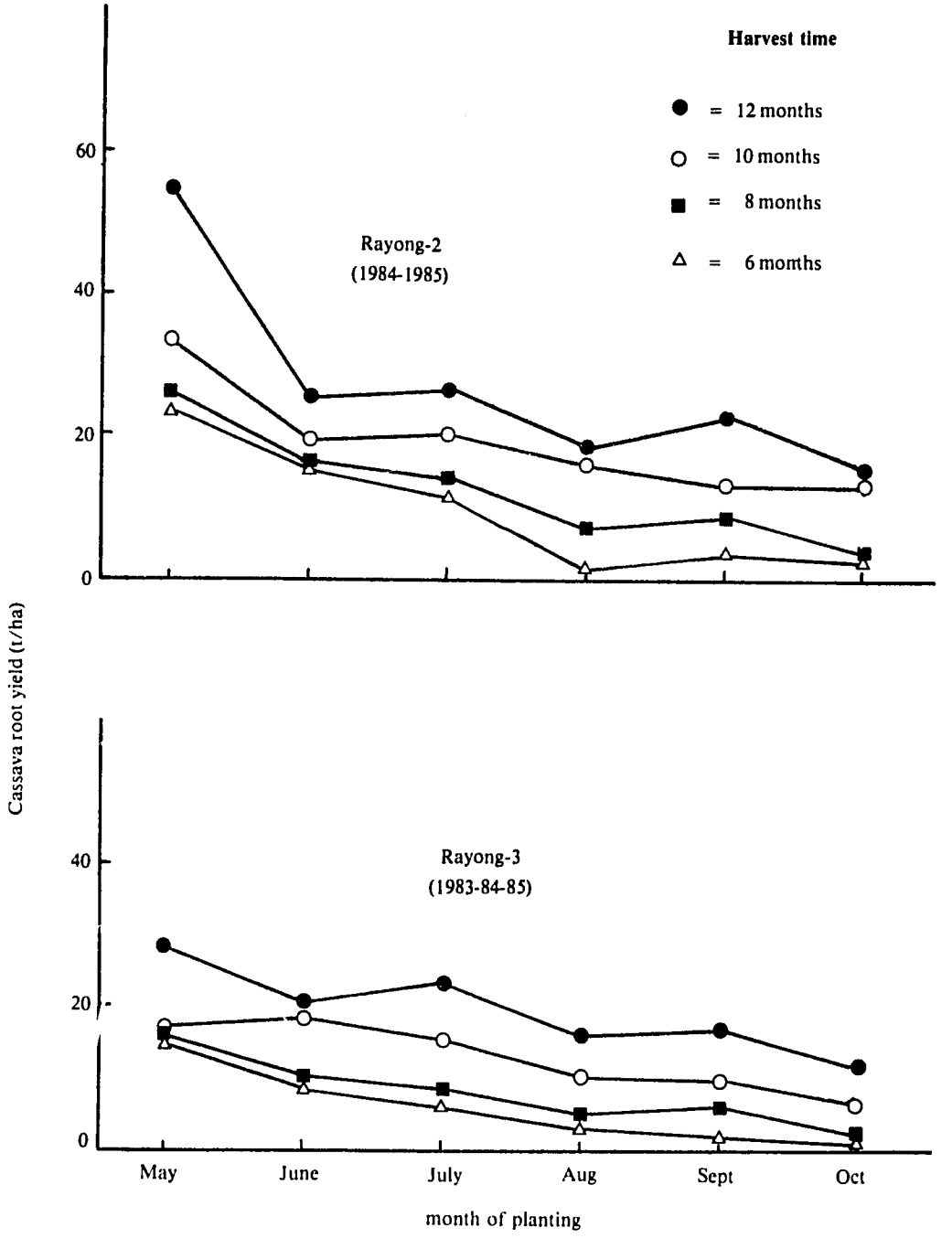

Figure 3. Effect of month of planting and age at harvest on root yields of cassava cultivars Rayong-2 and Rayong-3 planted in Rayong Field Crops Research Center.

Source : Field Crops Research Institute, Annual Report 1986.

Table 9. Effect of plant population and spacing on yield (t/ha) of cassava Rayong 2, in different locations, 1985.

Number of plants/ha	Spacing (cm)	Location			Mean
		Rayong	Khon Kaen	Banmaisamrong	
10,000	100 × 100	14.0	19.9	18.4	17.4
10,000	125 × 80	22.8	19.0	12.3	18.1
12,500	100 × 80	16.9	15.6	17.4	16.7
12,500	125 × 64	15.1	21.5	19.4	18.7
15,000	90 × 74	17.4	19.1	23.9	20.1
15,000	100 × 66	19.8	18.5	26.2	21.5
17,500	76 × 75	20.3	14.6	23.5	19.5
17,500	100 × 57	16.5	14.7	20.1	17.1

LSD (0.05) for spacing × location = 7.23.

Source : Field Crops Research Institute. Annual Report 1986.

Table 10. Effect of plant population and spacing on yield (t/ha) of cassava, Rayong 3, in different locations, 1985.

Number of plants/ha	Spacing (cm)	Location			Mean
		Rayong	Khon Kaen	Banmaisamrong	
10,000	100 × 100	17.7	20.1	15.2	17.7
10,000	125 × 80	15.3	18.1	15.1	16.1
12,500	100 × 80	20.8	14.2	16.1	17.1
12,500	125 × 64	20.3	13.8	12.6	15.6
15,000	90 × 74	17.7	12.6	13.5	14.6
15,000	100 × 66	19.3	12.3	17.5	16.3
17,500	76 × 75	22.0	9.9	16.5	16.2
17,500	100 × 57	16.7	11.7	19.9	16.1

LSD (0.01) for spacing × location = 7.18.

Source : Field Crops Research Institute. Annual Report 1986.

to different edafo-climatic conditions at each location. However, the results indicated that both Rayong 2 and Rayong 3 could be planted with ranges of population from 10,000-15,000 plants/ha. Arrangement may not be very important.

Intercropping :

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. In 1976-1978, in order to improve the system, cassava was intercropped with each species of legumes, planted in 1, 2 or 3 rows between cassava plants spaced at 1 × 1 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). The results of the studies on the effect of a wider row spacing of cassava in combination with different patterns of intercropping indicate that cassava yields were reduced by the presence

Table 11. Yield (t/ha) of cassava (C) and peanut (P) at different intercropping patterns in various cassava spacings at Rayong Field Crops Research Center, 1982-1983.

Cassava spacing (cm)	Cassava-peanut patterns						Monocrops	
	1 row peanut (5 cm between plants)		2 rows peanut (10× 10 cm)		2 rows peanut (20× 10 cm)			
	C	P	C	P	C	P	C	P*
100× 100	14.0	0.84	12.6	0.89	12.7	1.16	20.4	–
125× 80	13.8	0.74	14.2	0.90	15.4	0.88	17.1	–
150× 66	15.7	0.59	15.1	0.56	13.6	0.70	16.3	–
								1.52
Mean	14.5	0.72	13.9	0.78	13.9	0.91	17.9	1.52

* Monocropped peanut planted at 50× 20 cm.

Table 12. Yield (t/ha) of cassava (C) and mungbean (M) at different intercropping patterns in various cassava spacings at Rayong Field Crops Research Center, 1982-1983.

Cassava spacing (cm)	Cassava-mungbean patterns						Monocrops	
	1 row mungbean (5 cm between plants)		2 rows mungbean (10× 10 cm)		2 rows mungbean (20× 10 cm)			
	C	M	C	M	C	M	C	M*
100× 100	12.3	0.57	12.4	0.69	12.3	0.71	17.1	–
125× 80	14.5	0.56	13.6	0.67	12.9	0.81	17.3	–
150× 66	15.7	0.49	14.4	0.62	14.6	0.64	16.8	–
								0.75
Mean	14.2	0.54	13.5	0.66	13.2	0.72	17.1	0.75

* Monocropped mungbean planted at 50× 20 cm.

of the legumes and *vice versa*, (Table 11 and 12) but that the Land Equivalent Ratios (LER) were always above 1.00 (Tables 13 and 14), indicating the greater total productivity of the intercropping systems compared with the monocrops. Highest LER values were obtained for both legumes when cassava was planted at 125× 80 cm while two rows of either peanut or mungbean were planted between cassava rows at the spacing of 20× 10 cm.

Long-term intercropping trials with cassava have been conducted at Rayong and Khon Kaen Field Crops Research Centers since 1975 with the objective to study the effect of intercrops on soil nutrient depletion in continuously grown cassava without fertilization. Short duration crops such as sweet corn, mungbean, peanut and soybean were intercropped yearly with cassava and after 5 years only cassava was planted as a check crop. The results indicate that the yields of both cassava and the intercrop fluctuated due to different competitive effects with different climatic conditions in each year. After 5 years the yield of monocropped cassava in both locations was not significantly affected by the previous intercropping treatments (Tables 15 and 16). These results indicate that the intercropped legumes had no long-lasting

Table 13. Land equivalent ratios of different cassava-peanut intercropping patterns at Rayong Field Crops Research Center, 1982-1983.

Cassava spacing (cm)	Cassava-peanut patterns			Mean
	1 row peanut (5 cm between plants)	2 rows peanut (10×10 cm)	2 rows peanut (20×10 cm)	
100×100	1.23	1.20	1.38	1.27
125×80	1.30	1.42	1.47	1.39
150×66	1.36	1.30	1.29	1.31
Mean	1.29	1.31	1.38	

Source : Field Crops Research Institute. Annual Report 1984.

Table 14. Land equivalent ratios of different cassava-mungbean intercropping patterns at Rayong Field Crops Research Center, 1982-1983.

Cassava spacing (cm)	Cassava-mungbean patterns			Mean
	1 row mungbean (5 cm between plants)	2 rows mungbean (10×10 cm)	2 rows mungbean (20×10 cm)	
100×100	1.49	1.66	1.66	1.60
125×80	1.59	1.69	1.83	1.70
150×66	1.59	1.69	1.72	1.66
Mean	1.56	1.68	1.74	

Source : Field Crops Research Institute. Annual Report 1984.

Table 15. Yield (t/ha) of cassava (C) and intercrop (INT) species in a long-term cassava intercropping trial at Rayong Field Crops Research Center, 1975-1980.

Long-term intercropping pattern	Year										
	1975		1976		1977		1978		1979		1980
	INT	C	INT	C	INT	C	INT	C	INT	C	C
	Yield										
Cassava monoculture	–	26.8	–	18.7	–	35.5	–	20.2	–	9.2	22.0
Cassava + sweet corn*	40.9	24.8	27.5	16.6	38.7	26.3	26.8	20.5	20.7	10.1	24.4
Cassava + mungbean	0.82	27.9	0.46	20.9	0.86	27.8	0.93	16.8	0.87	9.3	22.0
Cassava + peanut	1.46	23.9	1.51	20.1	0.45	27.9	1.25	15.3	0.89	10.6	23.6
Cassava + soybean	1.09	25.8	1.08	15.5	0.98	24.6	0.87	18.9	0.45	8.8	26.4
											NS

Note : In 1980, only cassava was planted as check crop.

* : Sweet corn yield in 000 cobs/ ha.

Source : Field Crops Research Institute. Annual Report 1981.

Table 16. Yield (t/ha) of cassava (C) and intercrops (INT) species in a long-term cassava intercropping trial at Khon Kaen Field Crops Research Center, 1975-1980.

Long-term intercropping pattern	Year										
	1975		1976		1977		1978		1979		1980
	INT	C	INT	C	INT	C	INT	C	INT	C	C
	Yield										
Cassava monoculture	–	33.0	–	21.7	–	24.0	–	27.0	–	27.3	30.3
Cassava + sweet corn*	34.2	31.2	21.4	17.8	10.7	15.5	2.69	15.3	13.9	20.5	29.4
Cassava + mungbean	0.60	32.3	0.12	26.3	0.20	16.1	0.27	26.7	0.27	13.8	23.8
Cassava + peanut	0.98	18.3	0.79	18.7	0.85	5.9	0.92	11.5	0.60	14.6	30.1
Cassava + soybean	0.51	20.9	0.20	27.0	0.30	24.0	0.71	12.3	0.84	22.3	28.0
											NS

Note : In 1980, only cassava was planted as check crop.

* : Sweet corn yield in 000 cobs/ha.

Source : Field Crops Research Institute. Annual Report 1981.

effect on soil productivity. Nevertheless, the long-term effect of cassava intercropping still needs more research to confirm these results. Soil analyses are another important method to evaluate the system.

Present Status of Cassava Research in Agronomy

Most cultural practice studies conducted in the past have used only Rayong 1. Since new cultivars have been recommended, the optimum production technology has to be redefined. Studies on spacing, time of planting and planting methods for these new cultivars are currently conducted so as to recommend the most appropriate technologies.

Studies on intercropping cassava with legume species, the long-term effect of cassava intercropping, of cover crop species and crop rotations, and improvement of land preparation have also been conducted so as to improve or maintain soil fertility.

Future Directions and Priority Areas

The future directions of research on cultural practices will continue to define the most economically valid cultural practices for cassava production. The priority topics to be emphasized will be soil nutrient preservation and erosion control. Intercropping, crop rotation, improvement of soil preparation, and minimum tillage for cassava are the priority areas of research. The best cultural practices for newly available cultivars will also have to be redefined for the appropriate production systems.

The whole program of cultural practices needs more socio-economic and on-farm studies to evaluate the relevance of research results for improving the welfare of cassava growers.

Summary

The results of cassava cultural practice research can be summarized as follows :

1. Stake length: Stakes of 15-20 cm length, cut from the lower part of the stem are recommended, as these give a high survival percentage of plants. After harvest, the cassava stems should be stored in the shade. Stems of Rayong 1 can be stored up to 30 days while those of cultivar Rayong 3, especially stems taken from younger branches, should not be stored more than 15 days.

2. Planting time: Cassava should be planted early in the rainy season. The results of Rayong 1, Rayong 2 and Rayong 3 are similar. The cassava yield increased up to 12 months. Harvest should be done between 10-12 months.

3. Spacing: Cassava could be planted at populations ranging from 10,000 to 15,000 plants/ha. The spatial arrangement of plants may not be very important.

4. Intercropping: Intercropping cassava with mungbean and peanut increased the Land Equivalent Ratios to 1.83 and 1.47 , respectively. Cassava planted at 125 × 80 cm and intercropped with 2 rows of legume at 20 × 10 cm gave the best results.

5. Long-term Intercropping: Intercropping did not have a long lasting effect on soil productivity. These results should be verified.

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CASSAVA SOILS RESEARCH IN THAILAND

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Introduction

In Thailand, cassava has been cultivated continuously for more than 40 years. Originally it was cultivated in the Southeast, but after 1970 it spread to the Northeastern, Western and Upper Central parts of the country (Boonjit, 1986). Next to rice. cassava is the most important crop in Thailand. The total fresh root production as well as the total planted area, have gradually increased since the 1960's and increased dramatically from 1976 to 1980. In 1986 total fresh cassava root production was 15.3 million tons and the total area planted with cassava 1.24 million hectares. The average fresh cassava root yield was 12.6 t/ha.

During the past 40 years there has been wide-spread deterioration of production capacity of cultivated soils due to poor soil and crop management. With continuous cultivation in the high-rainfall and high-temperature tropical environment, soil properties change drastically; organic matter levels decline rapidly, nutrients leach out of the root zone and the soils become compacted. Thus, presently cassava soils in Thailand are low in fertility and have a coarse texture and low organic matter content. The limitations of most cassava soils are reflected in the following characteristics :

1. low to very low pH
2. low cation exchange capacity
3. low level of nutrients
4. low organic matter content
5. low moisture holding capacity
6. high bulk density
7. high susceptibility to erosion

Under such conditions improvement or maintenance of soil fertility is a most important objective for which integrated research is necessary. This paper intends to provide an overview of the current status of research by the Department of Agriculture and Kasetsart University.

Summary of the Early Research (1954-1980)

Since 1954 many fertilizer experiments have been conducted to determine the cassava crop's nutrient and fertilizer requirements in important soils of major cassava producing

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regions. In 1978 Sittibusaya and Kuramarohita reviewed the existing experiments based on information available from the Department of Agriculture Annual Reports of 1954-1976. These can be summarized as follows: The results obtained during the first period of 1954 to 1967 revealed that application of N, P_2O_5 and K_2O at level of 50 kg/ha each was economically benificial to cassava growers. The effects of K were found consistently not to be significant and only N application resulted in consistent yield improvements, while P showed a benificial effect only in some locations. Results of field trials during the second period of 1967 to 1972 on 3 soil series of the Southeast confirmed the earlier findings that the most frequent yield responses were caused mainly by N applications, while the frequencies of response to P and K applications were much lower and mainly observed in Sattahip soil series (Table 1). The amounts of N, P_2O_5 and K_2O generally recommended for application were 40-96, 13-80 and 21-46 kg/ha, respectively. Fertilizer trials during the third period of 1975 to 1980, covering 6 soil series, produced similar results as obtained previously. Table 2 shows that the smallest yield response to fertilization was obtained in the Warin soil and the responses increased in the following order: Warin, Huai Pong, Korat, Yasothon, Sattahip and Pattaya. The magnitude of the yield response was used as a criteria to measure the fertility status of different soils.

Table 1. Probability of response of cassava to application of N, P or K in three soil series of Southeastern Thailand (based on 3 years of trials in farmers fields, 1968-1970).

Soil Series	No. of replications	Probability of response* to		
		N	P	K
Huai Pong	14	+	–	–
Pattaya	25	+	–	–
Sattahip	82	+ +	+ –	+ –

* – not probable (<25% of trials showed response)
\+ – probable (25-49% of trials showed response)
\+ fairly probable (50-67% of trials showed response)
\+ + highly probable (>67% of trials showed response)

Source : Sittibusaya and Karamarohita, 1978.

Table 2. Fertility status of several soil series as indicated by the average response of cassava to fertilization in farmers field trials conducted in the Northeast and Southeast of Thailand during 1968-1977.

Soil series	No. of replications	Average response (%)	Rank
Warin	6	12	1
Huai Pong	14	16	2
Korat	4	27	3
Yasothon	4	28	4
Sattahip	82	41	5
Pattaya	25	52	6

Source : Sittibusaya and Kuramarohita, 1978.

Fertilizer experiments using high application rates of N, P_2O_5 and K_2O in exhausted Sattahip soils were initiated in 1975 and the results showed that the application of 375 kg/ha each of N, P_2O and K_2O almost doubled yields from 23 to 41 t/ha (Figure 1). The residual effect of those fertilizers was still significant for more than 3 years, and the effect of N was found to be significant even in subsequent croppings. The prolonged residual effect of N could be the result of nutrient recycling by leaf-drop.

Application of secondary and minor elements did not benefit root yield but increased the starch content of the root (Table 3).

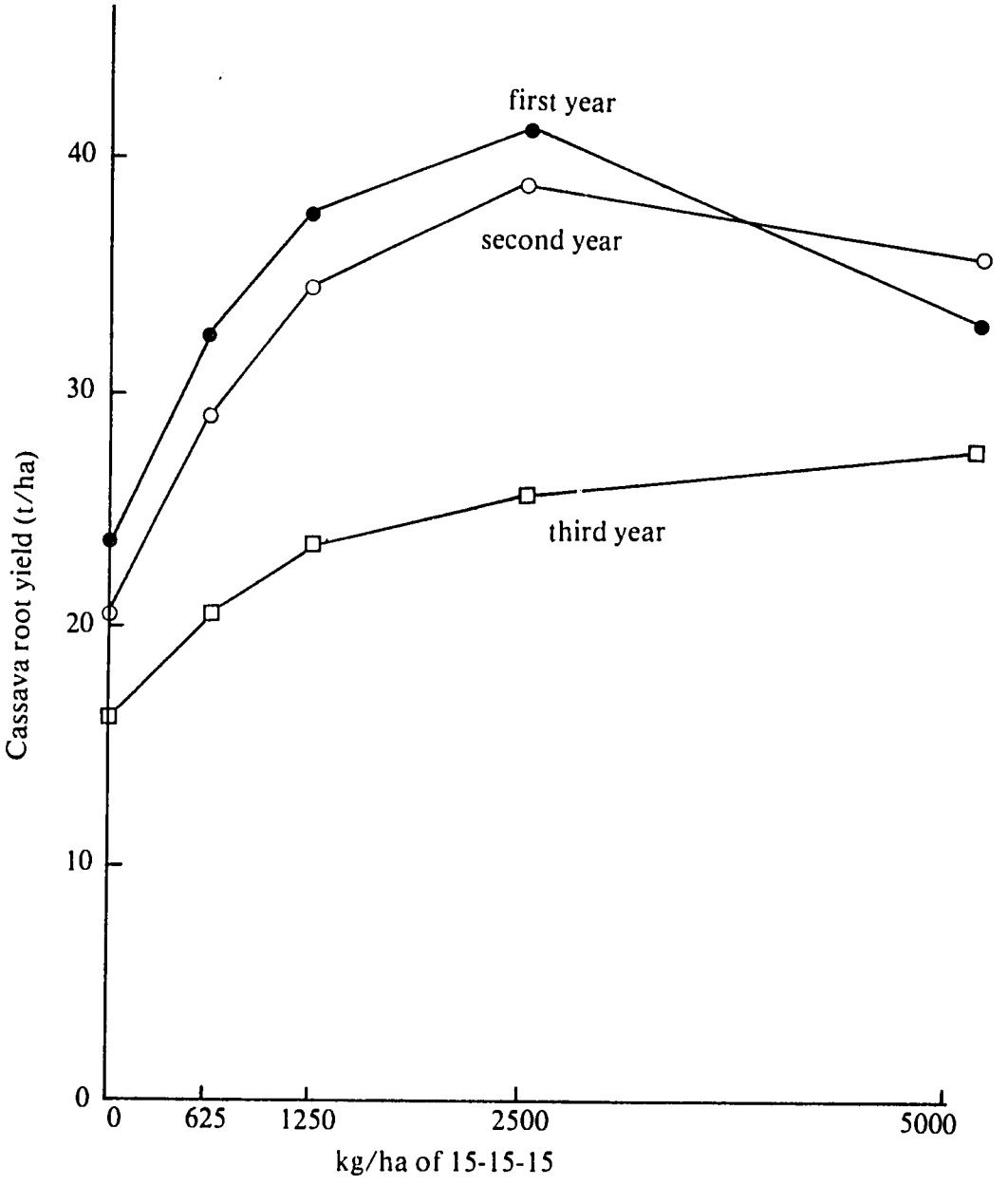

Figure 1. Responses of 3 consecutive crops of cassava to various levels of 15-15-15 fertilizer applied only to the first crop grown in exhausted Sattahip soil.

Source : Sittibusaya and Kuramarohita, 1978.

Table 3. Effects of minor element application on yield and starch content of cassava grown on Sattahip soil.

Treatment	Yield (t/ha)		% Starch in root*
	Root	Stem	
NPK	28.3 a	30.7	70.4 b
NPK + FeMn	28.7 a	30.3	75.1 a
NPK + ZnCu	28.7 a	28.9	75.4 a
NPK + BMo	22.7 b	28.3	74.2 a

* oven-dried basis.

Source : Sittibusaya and Kuramarohita, 1978.

Several methods of fertilizer application for cassava were also compared and it was found that any method; i.e., broadcasting, band placement under stake at planting, or side-dressing at 60 days, produced the same yields (Table 4). However, another similar trial showed that banding at 15 cm depth below the stake before planting gave the highest yields (Sittabusaya *et al.*, 1974).

Table 4. Effect of method of fertilizer placement on the yield[1/] of cassava grown in two soil series in 1975.

Method	Sattahip soil	Korat soil
	t/ha	
Broadcast before planting	22.6	31.0
Band placement under stake	24.8	32.9
Banding at 20 cm at 60 days	24.4	28.9
Banding at 50 cm at 60 days	25.0	29.6
L.S.D. 0.05	N.S.	N.S.
C.V. (%)	9.0	15.3

1/ Average of 50-50-50 and 100-100-100 kg N – P_2O_5 – K_2O/ha treatments.

Source : Sittibusaya and Kuramarohita, 1978.

It was found that soil productivity had steadily declined during the past 30 years, as yield responses to fertilization increased consistently from the first to the last period of trials. The steady decline in yield of the check plots in several fertilization trials conducted from 1955 to 1983 was also observed; yields decreased from nearly 30 to 18 t/ha on Sattahip soil in the Southeast (Figure 2). A similar yield decline was also observed in the Huai Pong and Korat soils, indicating a rapid initial loss of soil fertility in the first 15-20 years of continuous cassava production.

The nutrient removal by cassava has also been investigated in many occasions. The total uptake of N and K were similar, about 70 kg/ha per cropping, while P uptake was about half (Table 5). Cassava is often considered a soil-depleting crop, but it was found that it

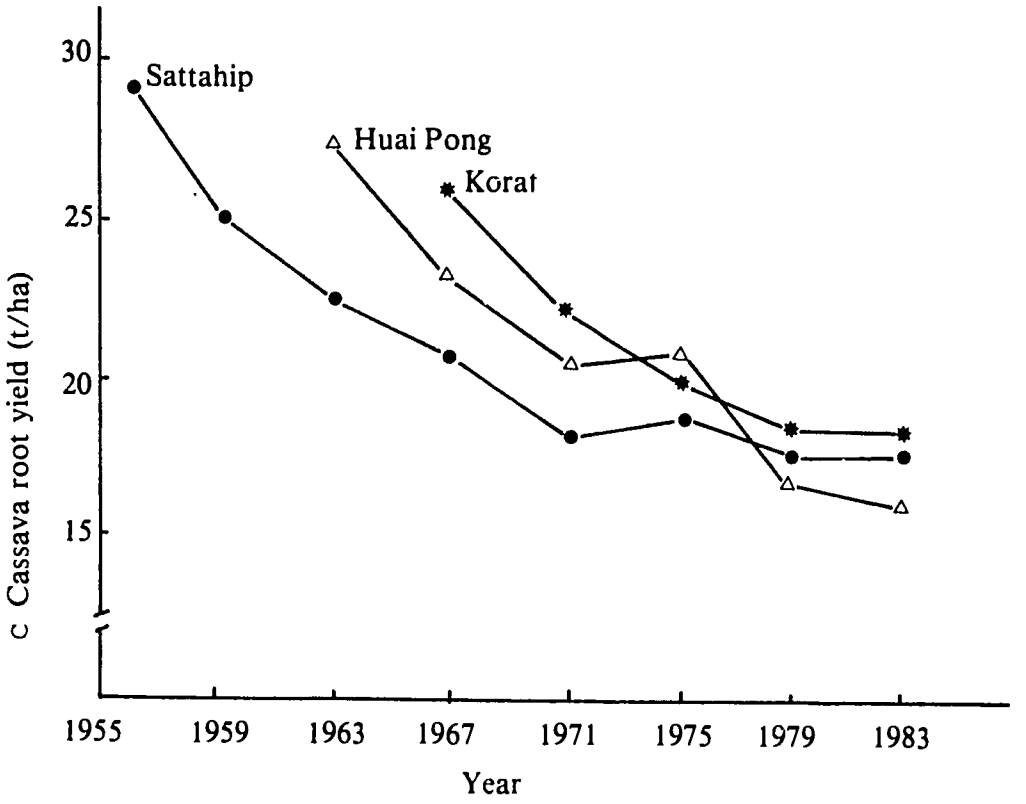

Figure 2. Yield of cassava in unfertilized plots of field experiments conducted from 1955 to 1983.

Source : Sittibusaya and Kurmarohita 1978; 1986.

Table 5. Average nutrient removal by a crop of cassava grown in 18 farmers fields in six soil series during 1975-1976.

Nutrient	Root	Stem + Leaf	Total
	----------	nutrient removal (kg/ha)	----------
N	31	42	73
P	19	13	32
K	47	25	72

Note : Based on average root yield of 31 t/ha.

Source : Sittibusaya and Kuramarohita, 1978.

removes plant nutrients from soils at levels comparable to that of maize, and it removes much less K than sugarcane. The decline in yield could thus be attributed mainly to the negligence of cassava growers to fertilize the land sufficiently and to the methods of cultivation used, which cause severe soil erosion and nutrient loss.

The results of fertilizer experiments conducted during this initial 25 year period, have been relatively well documented and a general fertilizer recommendation could be made. For the sake of simplicity, the fertility status of cassava soils was divided into two classes, "low" and "moderate". The optimal levels of N, P_2O_5 and K_2O recommended for the "low"

class were between 100 and 200 kg/ha each. The levels recommended for the "moderate" class were 50% of those used in the "low" class. Sidedressing or siderow banding 1 month after planting was generally recommended as the best method of application.

Recent Soils Research on Cassava (1980-1987)

Recent economic studies by the FAO Fertilizer Programme have clearly shown that the profitability of fertilizer use in Thailand is low, due to the high price of fertilizers. As a consequence, the quantity of fertilizers applied to many crops, including cassava, is very small. Greater use of mineral fertilizers is essential for the success of the government's policy of agricultural intensification. However, the current price of fertilizers in relation to that of the product is not very favorable. Therefore, the present research emphasizes more site-specific recommendations of fertilizers and proper soil management in order to improve the efficiency of fertilizer and maintain a desirable chemical, physical and biological soil environment. Some of the information obtained can be summarized as follows.

1. FAO fertilizer trials : During the period from 1982 to 1984, a large number of cassava fertilizer trials without replication were carried out on farmers' fields. The results were presented in the technical report by FAO/Thailand: "Yield Increase Through the Use of Fertilizer and Related Inputs" (FAO, 1985). In the report, emphasis was put on the recommendation of the most economically profitable rates of fertilizers. It was shown that fertilizer application can significantly increase both yield and income. In all areas a high response to N and a moderate response to P and K were recorded. Although the present data are insufficient to make very specific area recommendations a more general fertilizer recommendation could be made. Ho and Sittibusaya (1984) reported that levels of 50-100 kg/ha of N and K_2O but without P are recommended for the Quartzipsamment soil group. For the Paleustult soil group, ranges of 80-100 kg N/ha, 0-30 kg P_2O_5/ha and 30-50 kg K_2O/ha are recommended. The K and N recommendations can be further defined by soil testing as follows :

Exchangeable K (ppm)	Recommended K_2O rates (kg/ha)
< 30	100
31-50	30
> 50	0

Organic matter (%)	Recommended N rates (kg/ha)
< 0.51	100
0.51-0.92	50
> 0.92	0-25

No significant correlation was found between the level of available soil P and the response to P application. However, earlier experiments showed no significant response to N, P, or K when the organic matter was above 1%, the available (Bray II) P was above 8 ppm and exchangeable K was above 40 ppm (Yingchol *et al.*, 1970).

2. Mulching and green manuring : In many cassava areas with uncertain rainfall and low soil moisture holding capacity, mulching and green manuring is perhaps the most important practice to conserve soil moisture, especially during the dry period. Paisarnchareon (1988) established a long term experiment to study the effects of green manuring on water storage and cassava yields in an Oxic Paleustult in the Northeast. The two years' results show that the water storage capacity and cassava yields were highest by incorporation of cowpea, because cowpea *(Vigna unguiculata)* produced more biomass than pigeonpea *(Cajanus cajan)* or sunnhemp *(Crotalaria juncea)*, as shown in Table 6.

Table 6. Legume biomass and cassava rootyield produced in two years of various green manuring practices on Oxic Paleustult soil.

Green manuring	Legume biomass (t/ha)		Cassava yield (t/ha)[1/]	
	Year I	Year II	Year I	Year II
Control			4.77	13.99
Cowpea	17.91	21.20	10.46	17.58
Pigeon pea	1.73	10.92	5.43	12.91
Sunnhemp	4.31	18.24	5.66	13.43

1/ Cassava harvest at 10 months.

Source : Paisarnchareon *et al.*, 1988.

3. Crop rotation : Crop rotation is not widely practiced in the cassava growing area, primarily because of the lack of alternative crops that produce yields that give an economic return comparable with that obtained with cassava. Because of the importance of crop rotation to control soil erosion and maintain soil fertility, a long-term experiment was conducted on 3 major soils in the cassava growing area since 1975, to observe the effect of alternate legume-cassava crop rotation systems, on soil productivity. Table 7 shows that the cassava-legume rotation increased cassava yields in the 9th year of cropping only in case of the Yasothon soil, while annual fertilizer application increased yields both in the Yasothon and Huai Pong soils. Incorporation of the legume residues did not prevent a decrease of soil OM content after cropping in most soils, but did tend to maintain a higher level of OM as well as nutrient status of the soil. The cassava groundnut rotation was more effective than the cassava mungbean rotation (Sittibusaya *et al.*, 1984). Chaiwanakupt and Sittibusaya (1985) showed that the cassava rotation with legumes also increased the farmer's income, at least in case of the cassava-groundnut system, as compared to continuous cassava cropping.

4. Long-term fertility experiments : The effects of long-term fertilizer use for continuously grown cassava has been studied on 3 soil series since 1975. One of the aims of these trials is to monitor soil fertility changes under different combinations of NPK and compost application, as well as the effect of incorporation of plant tops. Sittibusaya *et al.* (1986) reported that the application of 50 kg each of N, P_2O_5 and K_2O/ha/year, plus incorporation of cassava top growth can maintain root yields at high levels, as shown in Figure 3.

Table 7. Effect of annual application of fertilizers or crop rotation on the yield of cassava and the soil organic matter content after 9 years of cropping in three soil series in Thailand, 1975-1984.

Cropping system	Soil series Yasothon	Soil series Korat	Soil series Huai Pong	Soil series Yasothon	Soil series Korat	Soil series Huai Pong
	----------Cassava yield (t/ha)----------			---------Organic matter (%)[3]---------		
Continuous cassava						
without fertilizers	11.8	28.2	20.0	0.62	0.80	1.41
with fertilizers[1]	19.8	20.7	25.1	0.60	1.14	1.68
Cassava-legume rotation[2]						
cassava/peanut + pigeonpea	27.4	27.8	22.9	0.68	1.41	2.10
cassava/mungbean + pigeonpea	22.5	26.2	23.2	0.63	1.14	1.68

1/ annual application of 50 kg/ha each of N, P_2O_5 and K_2O.

2/ no fertilizer applied; cassava and two consecutive legumes crops were grown in alternate years.

3/ initial (1975) OM contents were : Yasothon 0.87%, Korat 1.24%, Huai Pong 2.10%

Source : Sittibusaya, *et al.*, 1984

The application of NPK plus 12.5 t/ha of municipal compost per year, or NPK plus cassava tops incorporated, produced similar high yields of about 25 t/ha after 11 years of continuous cassava cultivation. But yields obtained with NPK plus incorporation of cassava tops tended to produce the highest yields, while the incorporation of cassava tops without NPK increased yields about 85% over the control. It is clear that without fertilizer application cassava yields declined very markedly. A similar decline in yield over time can be observed from the use of N and NP alone. Thus, the omission of K reduced cassava yield in the long run much more than the omission of P, while the application of NPK plus incorporation of tops or compost increased cassava production.

Soil test data obtained from a similar experiment on Huai Pong soil in Rayong indicate that under continuous cropping for 10 years several major plant nutrients in the soil were depleted (Table 8). Compared with the initial soil fertility status, average contents of organic matter, available P and exchangeable K decreased by 40, 39 and 73 percent, respectively, in the top 0-15 cm soil layer. This indicates that cassava depletes mainly the soils's K reserves and that the long-term productivity of the soil depends on the maintenance of desirable chemical, as well as physical and biological conditions.

Table 8. Changes in soil fertility status after 10 years of continuous cassava monocropping without fertilization on Huai Pong soil in the Southeast of Thailand.

Soil test[1]	Initial 1975	After 10 years 1984	Percent change
pH	4.8	4.7	2
Organic matter (%)	1.90	1.14	40
P-Bray 2 (ppm)	28	17	39
Exch. K (ppm)	45	12	73

1/ Data from surface soil samples taken before planting.

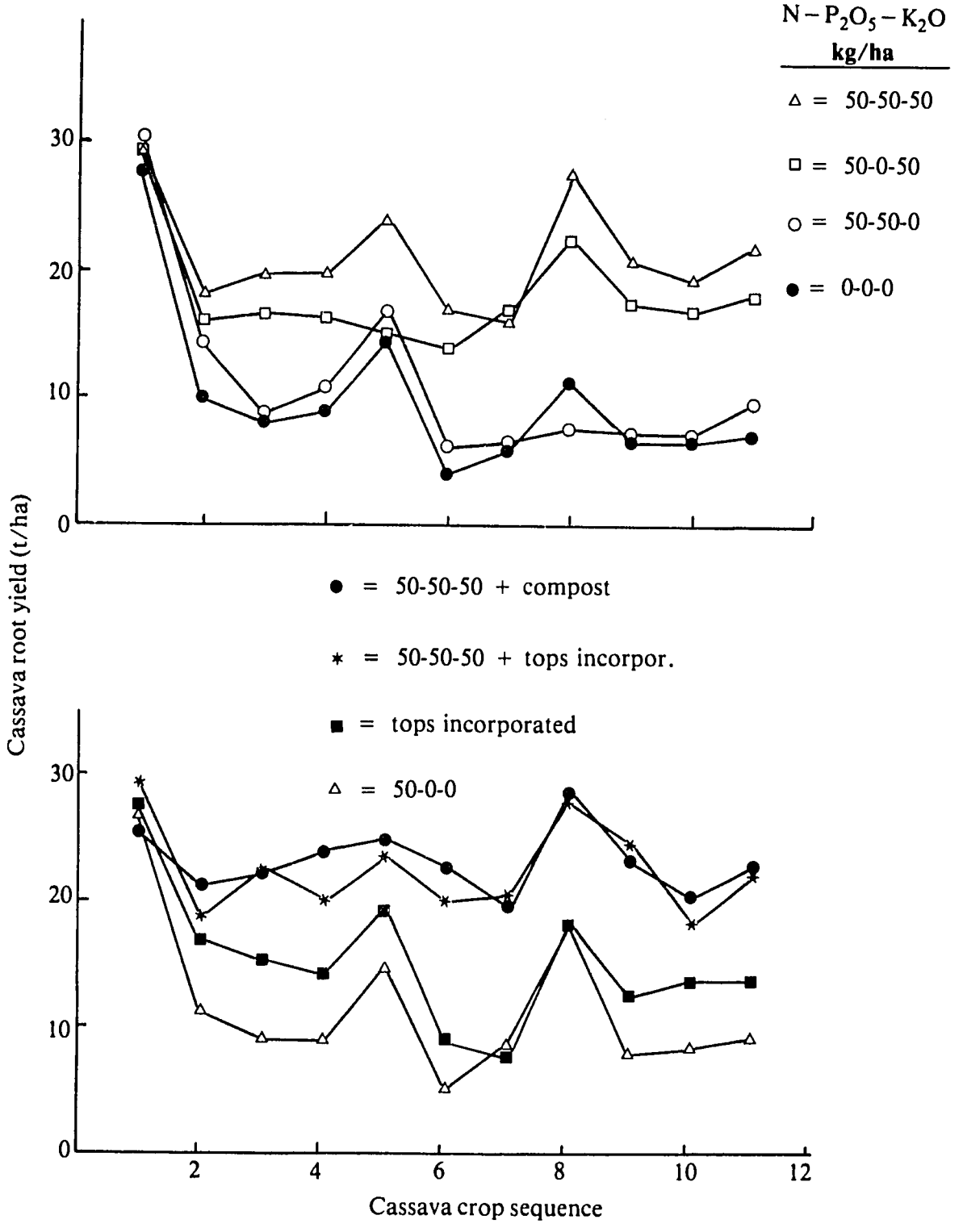

Figure 3. Effect of annual NPK fertilizer and compost application, and the incorporation of top growth on the root yield of cassava grown for 11 consecutive years in Yasothon soil in Khon Kaen.

Research Conducted at Kasetsart University

Soil and fertilizer research on cassava at Kasetsart University was initiated in 1977, or about a decade ago. The research conducted is rather limited in scope and comprises mainly two field trials conducted yearly, either in farmers' fields or at the University Research Farm in Chonburi province. Since 1977, and into the early 1980s this included studies on the individual and interacting effects on cassava of N, P, K and mixed fertilizer sources, rates, and time of application. The effect of nutrient ratios, the influence of secondary and micronutrient elements, as well as cassava soil characterizations were also studied during this period.

Duangpatra (1983), showed that the application of fertilizers to cassava grown on Sattahip soil in Sri Racha increased yields for 24.5 to 30.5 t/ha, but that this was not significant (Table 9). Among the different nutrient sources, urea appeared to be best N-source and DAP the best P source, while there was no difference between potassium chloride or sulfate. Neither the different levels nor sources of fertilizers had a significant effect on root yield or starch content.

Due to the fact that weed control and fertilization are some of the constraints most limiting cassava yields, the experiments during the past four years had the objective of assessing the impact of these two factors on cassava growth and yield, particularly on the maximum

Table 9. Effects of sources of fertilizer N, P and K on the yield and starch content of cassava grown on Sattahip soil in Sir Racha.

	Root yield (t/ha)	Starch content (%)
Check		
treatments		
O - O - O	24.5	17.9
O - P - K	27.2	19.0
N - O - K	28.9	17.6
N - P - O	30.5	16.2
N-Sources		
ammonium sulfate	29.3	17.3
ammonium chloride	29.8	17.5
urea	33.5	17.5
P-Sources		
triple super phosphate	31.5	16.8
rock phosphate	27.9	17.6
diammonium phosphate	33.3	17.4
monoammonium phosphate	30.8	17.9
K-Sources		
potassium chloride	31.2	17.7
potassium sulfate	30.6	17.2

The means of all check treatments and sources in both columns are not significantly different at the 0.05 probability level.

Source : Duangpatra, 1984.

economic yield. For future research needs, it seems justified to direct more efforts towards the study of integrated soil and crop management rather than of individual factors.

Future Research Needs

1. There appears an extreme need to do research on soil conservation and management, particularly research on management practices that reduce soil erosion and water runoff.

2. It seems justified to conduct a long term research project on "yield improvement and sustainability through nutrient recycling and soil-water conservation under various long-term cassava-based cropping systems". This is deemed justified in order to utilize more effectively biological and chemical fertilizers, rain water and soil resources so that cassava yields can be increased or at least sustained in the long run.

3. It is necessary to conduct more research to determine the best packages of cultivation practices.

4. Previous research has determined mainly the effect of N, P and K application. More research on secondary and micronutrients should be emphasized.

5. Nutrient balance should be studied as it appears to limit yield, especially under moisture stress.

Summary

Research on soil fertility and fertilization has been conducted with the purpose of developing new production technology for Thai cassava farmers for a number of years. Early research on soil fertility showed that fertilizer application can significantly increase yields and income, but the results were not entirely consistent. A better understanding of the factors that contribute to the overall efficiency of applied fertilizers is essential. A large number of fertilizer trials in farmers' fields showed a high response to N and moderate responses to P and K applications. The yield responses to N were well correlated with soil organic matter content for both Quartzipsamment and Paleustults soil groups, while the response to K have correlated with exchangeable soil K for Quartzipsamments only. A long-term experiment conducted for 10 crop years in three major soils showed the benificial effect of incorporating cassava residues and of adding compost. Green manure crop residue management techniques that are compatible with the rather strict soil and water conservation conditions in the cassava area also have to be developed. There is an urgent need to develop and select adapted legume species for use in flexible cropping systems, so that a significant portion of the N requirement of the cassava crop could be supplied through biological N fixation.

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SOIL AND CLIMATIC CHARACTERIZATION OF MAJOR CASSAVA GROWING AREAS IN THAILAND

Piya Duangpatra[1/]

Cassava ranks high among agricultural commodities in the Thai economy. In 1986 cassava export products had a value of 764.4 million US$, the third highest after fishery products (985.1 million US$) and rice (840.6 million US$) (OAE, 1987). The high value of cassava export products is not due to high product price but primarily due to large total production, coupled with a very low local consumption of less than 10 percent. Nevertheless, an average yield of about 13.5 t/ha in 1986 (Table 1) can be regarded as fairly low, compared with the high yields of about 30-35 t/ha obtained experimentally in the country. Under traditional cultural practices, some of the main factors causing low yields are erratic rainfall and little use of chemical fertilizers in poor soils, which predominate in the cassava growing areas. Apparently, the irregular distribution of rainfall during the growing season is more of a limiting factor than the total amount of annual rainfall, which is quite adequate. The low productivity of most cassava soils is related to their low fertility status, low nutrient and water retention capacity, and high erodibility. To increase cassava yields, soil productivity must be restored through whatever means appropriate. Also, the target soils in the area have to be classified and characterized thoroughly, so that from its physical and chemical properties the inherent fertility or suitability status of the soils can be precisely assessed.

Table 1. Planted area, production and average yield of cassava by regions in Thailand during 1985/86.

Region	Planted area		Production[1/]	Average yield[2/]
	(000 ha)	(% total)	(000 t)	(t/ha)
Northeast	758.0	61.1	8,782	12.0
East	333.0	26.9	4,492	13.4
West	46.7	3.8	616	13.7
North	69.4	5.6	968	14.3
Central Plain	32.5	2.6	397	13.9
South	–	–	–	–
Total	1,239.7	100.0	15,255	Average 13.5

1/ Fresh root weight

2/ Based on harvested area

Source : Office of Agricultural Economics, MOAC, 1986.

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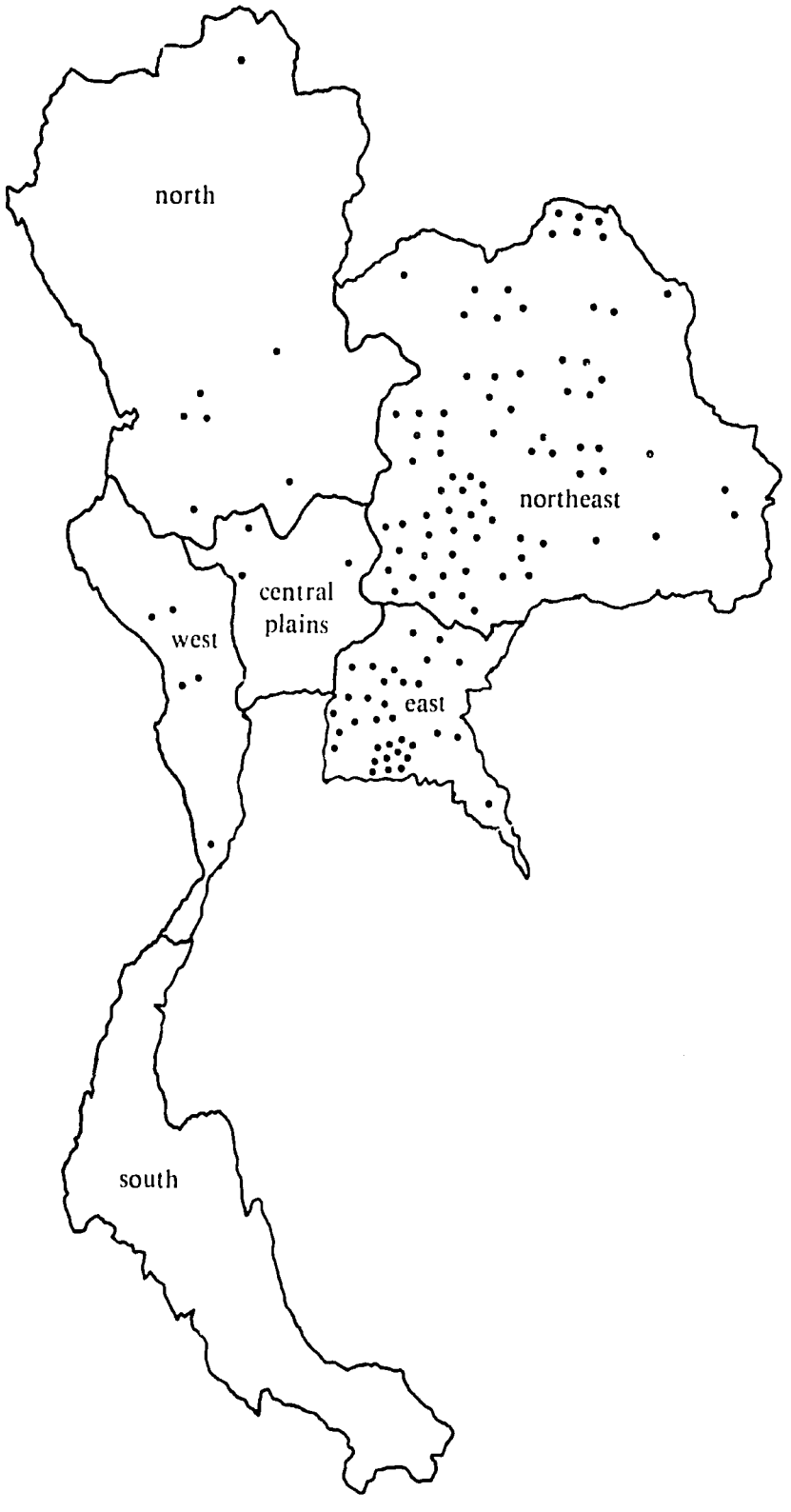


Figure 1. Cassava Production Zones of Thailand. Each point represent 10,000 ha of cassava in 1986.

The most recent cassava production data, show in Table 1, reveal that in the year 1985/86 88 percent of the cassava growing area was found in the Northeast and Eastern regions, whilst the cassava area in the West, North and in the Central Plains accounted for only 3.8, 5.6, and 2.6 percent, respectively (Figure 1). For this reason, the following discussion on the characterization of soils, climates and other pertinent features will be focussed mainly on the Northeast and Eastern regions.

Climatology

Climate :

The climate in Thailand comprises three major seasons: the dry and cool season extending from November to February, the hot season from March to May, and the rainy season from May to October. The country's average annual rainfall varies from 1,100 to 1,500 mm. Figure 2 shows that high rainfall zones are found in the southern Peninsula and in the extreme Southeast coast, which have an average annual rainfall of more than 2,000 mm, while areas with an average annual rainfall of less than 1,100 mm are found in the rain shadow of the Western Continental Highlands.

The seasonal variation in air temperature is not large i.e. the mean annual temperature in the country ranges from 24 to 30°C (Figure 3). Except for the Central Plain and some parts of the upper North the mean annual temperature of all other areas varies only from 26 to 28°C.

Figure 4 shows that in the majority of areas in the Northeast, North and East the mean annual relative humidity varies from 70-75%, whilst lower values from 60-65% are recorded in some areas in the West, lower North, Central Plain and Central Highlands. In the South and Southeastern coastal regions the average annual relative humidity is higher, ranging from 75 to 85 percent.

According to the Koppen's classification (Griffiths, 1978), the climate of the Northeast is classified as Tropical Savannah. The rainy season extends from May to October. The pattern of rainfall is of double-bell shape, or bimodal, with the first peak occurring in the period from May to June, and the second from July to October (Vorasoot, 1987). The first rainy season (May-June) derives mainly from the Southwest monsoon and is usually less intense than the second phase (July-October), which usually brings in heavier and more frequent cyclonic rains from the south China sea (KKU-FORD, 1982). Based on the isohytes for mean annual rainfall (Figure 2), three distinct zones can be distinguished i.e above 1400 mm to the North and East; below 1,200 mm to the west; and a central band of 1,200-1,400 mm. According to the 30 year climatic and evapotranspiration data, obtained by Akratanakul (1987) as shown in Table 2, it appears that the average precipitation in 11 Northeast provinces ranged from 1,137 mm to 2,278 mm with the overall average of 1,443 mm. Other climatic data are also presented, including temperature, water vapor pressure, relative humidity, wind speed, sunshine solar radiation, and potential evapotranspiration.

The climatic conditions in the Eastern regions can be divided into two types, as classified by the Koppen's classification (Changprai, 1987a). The first comprise the Tropical Savannah climate, which covers the western part of the region and includes Rayong, Chonburi, Chachaengsao and Prachin Buri provinces. The average rainfall there ranges from 1,200-1,600 mm

Table 2. Annual climatic and evapotranspiration data[1/] at various climatological stations in the Northeast and Eastern provinces (Thirty year records 1951-1980).

	P (mm)	T-Mean (°C)	T-Max (°C)	T-Min (°C)	ED (m bar)	RH-Mean (%)	U (m/sec)	n/N (%)	RG (cal/cm^2/day)	PET (mm)
Northeast										
Nakhon Ratchasima	1137	26.4	32.9	21.5	25.4	73	1.5	43.4	397	1619
Chaiyaphum	1218	27.4	32.1	22.0	24.3	66	2.6	44.4	398	2055
Khon Kaen	1196	27.0	32.6	21.7	25.4	70	1.8	46.4	404	1779
Udon Thani	1495	26.1	32.1	21.5	25.3	74	1.5	46.6	401	1632
Roi Et	1408	27.0	32.0	21.9	26.0	72	2.1	44.3	397	1774
Mukdahan	1523	26.6	31.7	21.1	25.2	71	2.5	43.3	392	1847
Sakhon Nakhon	1497	26.5	31.5	20.8	25.2	72	2.0	47.8	406	1788
Nakhon Phanom	2278	26.0	31.2	20.8	26.0	76	1.7	44.9	395	1596
Loei	1236	25.8	31.9	19.7	24.3	72	1.7	49.5	412	1718
Surin	1298	27.2	32.6	21.6	26.6	73	1.7	37.4	376	1600
Ubon Ratchathani	1587	27.2	32.4	22.0	26.4	73	–	41.5	389	1412
Average	1443	26.6	32.1	21.3	25.5	72	1.9	44.5	397	1711
East										
Prachin Buri	1997	28.4	33.0	23.1	28.0	72	2.2	37.5	377	1769
Aranyaprathet	1519	27.6	33.1	22.4	27.8	75	1.5	44.1	402	1654
Chonburi	1348	27.9	32.2	23.7	28.0	74	2.9	40.5	390	1924
Sattahip	1321	27.9	32.8	24.6	28.9	77	3.6	37.7	381	1888
Chanthaburi	2977	26.5	31.6	22.7	28.5	82	1.5	32.9	364	1398
Average	1832	27.7	32.5	23.3	28.2	76	2.3	38.5	383	1727

1/ P = Annual precipitation; T-Mean, T-Max, T-Min = Mean, maximum and minimum daily temperature, respectively; ED = mean daily water vapor pressure; RH-Mean = Mean daily relative humidity; U = Mean daily wind speed; n/N = Percentage of bright sunshine hour with respect to the maximum possible sunshine hours; RG = Solar radiation; PET = Annual potential evapotranspiration by modified Penman method.

Source : Akratanakul (1987)

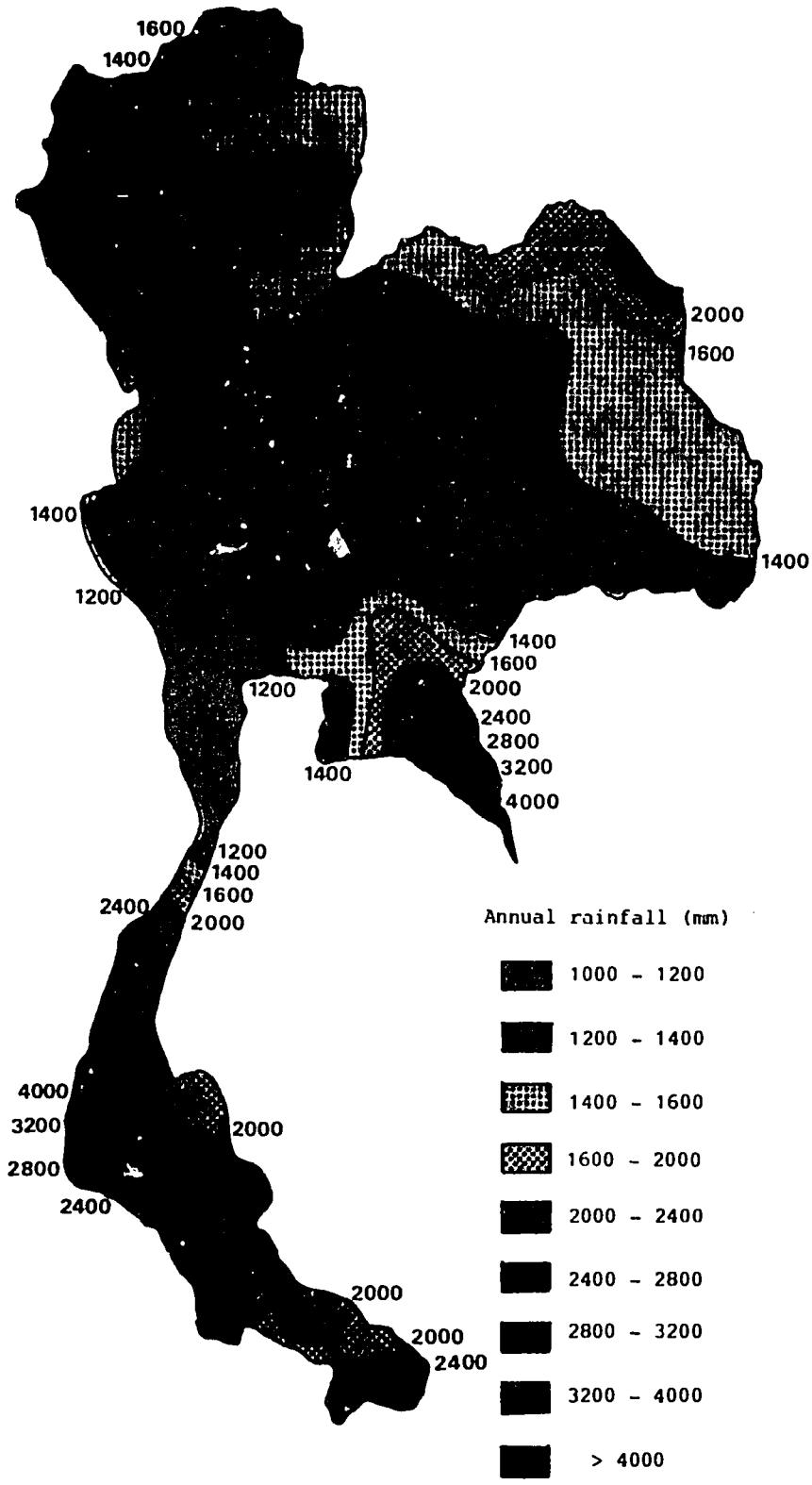


Figure 2. Isohytes for the mean annual rainfall in Thailand.

Source : Meteorological Department, data for 1951-1980.

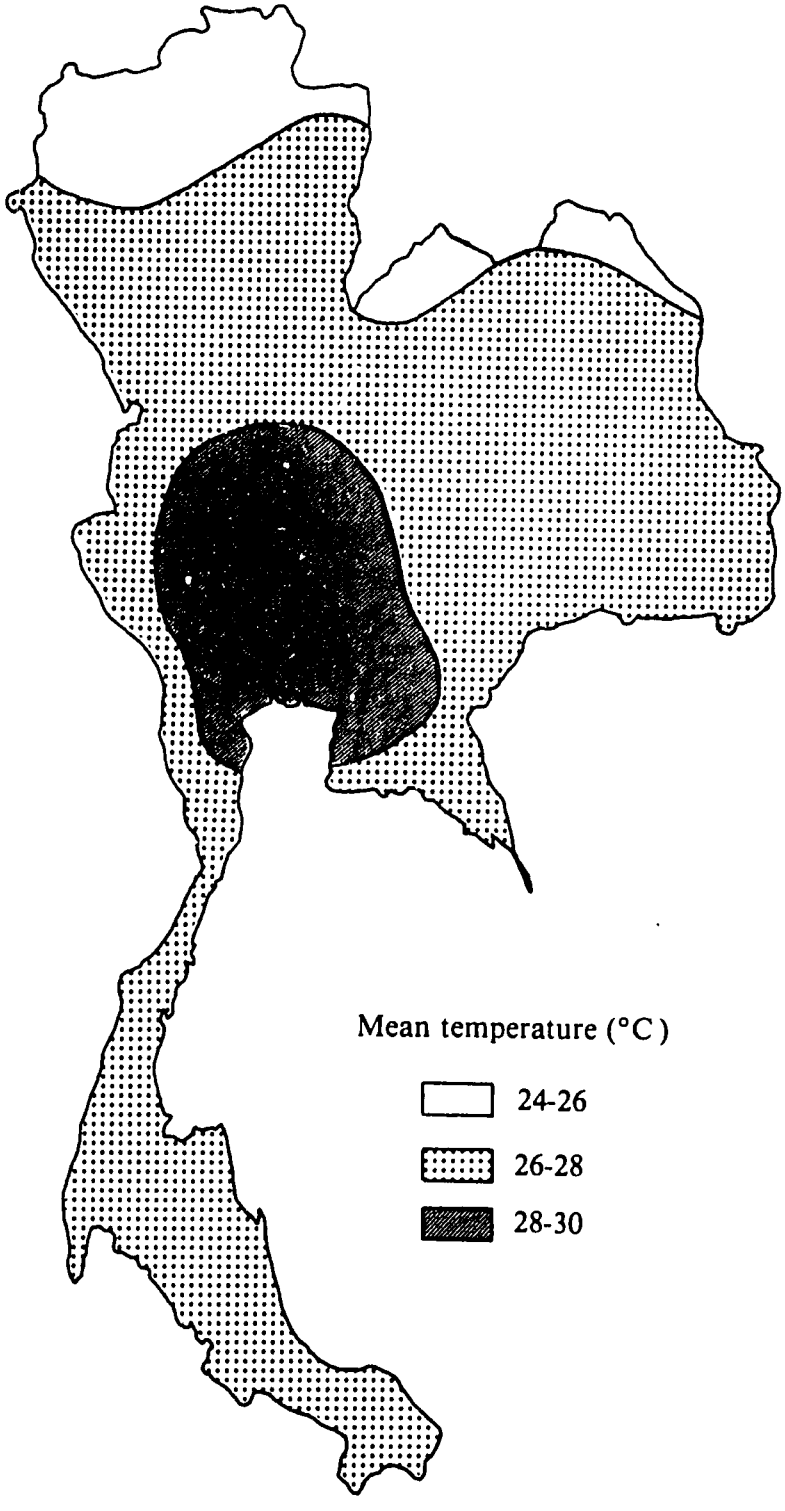


Figure 3. Isotherms for the mean annual temperatures in Thailand.

Source : Meteorological Department, data for 1951-1980.

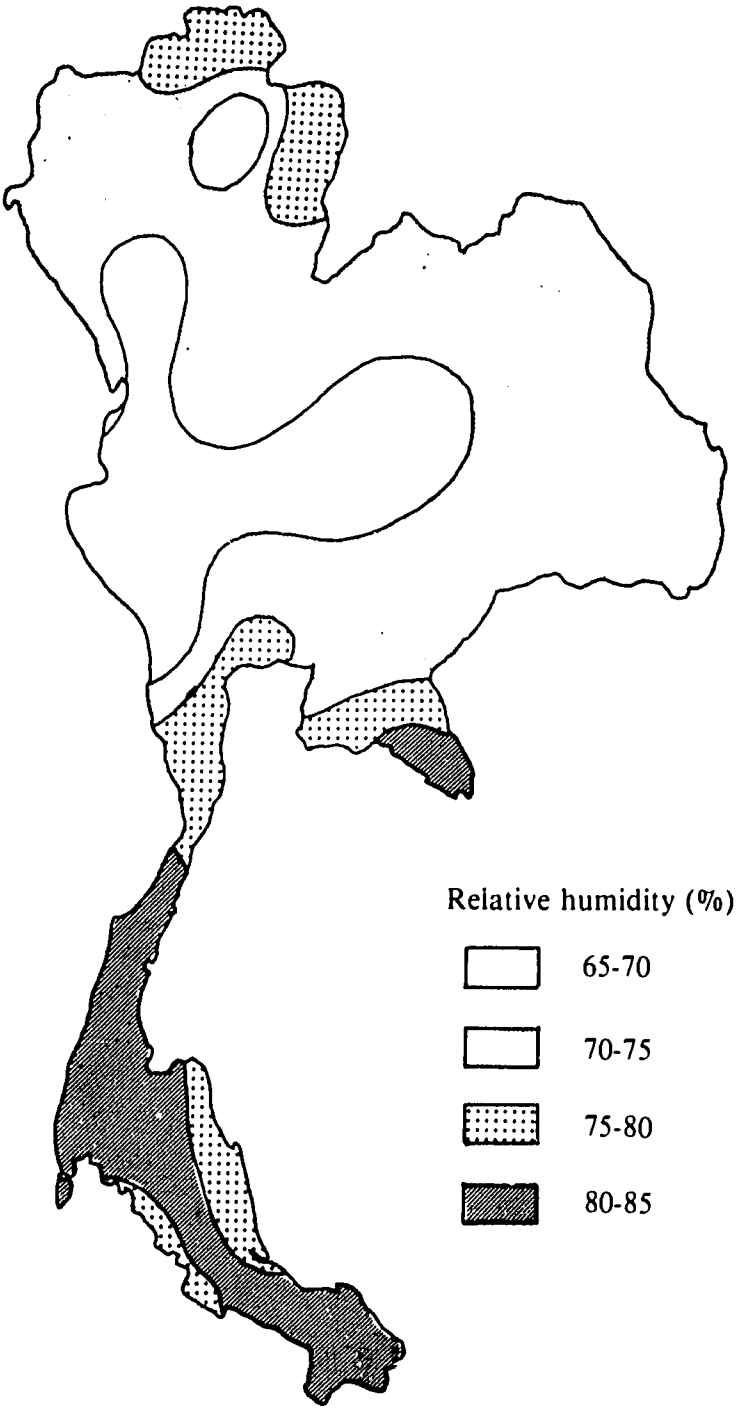


Figure 4. Isohomes for mean annual relative humidity in Thailand.

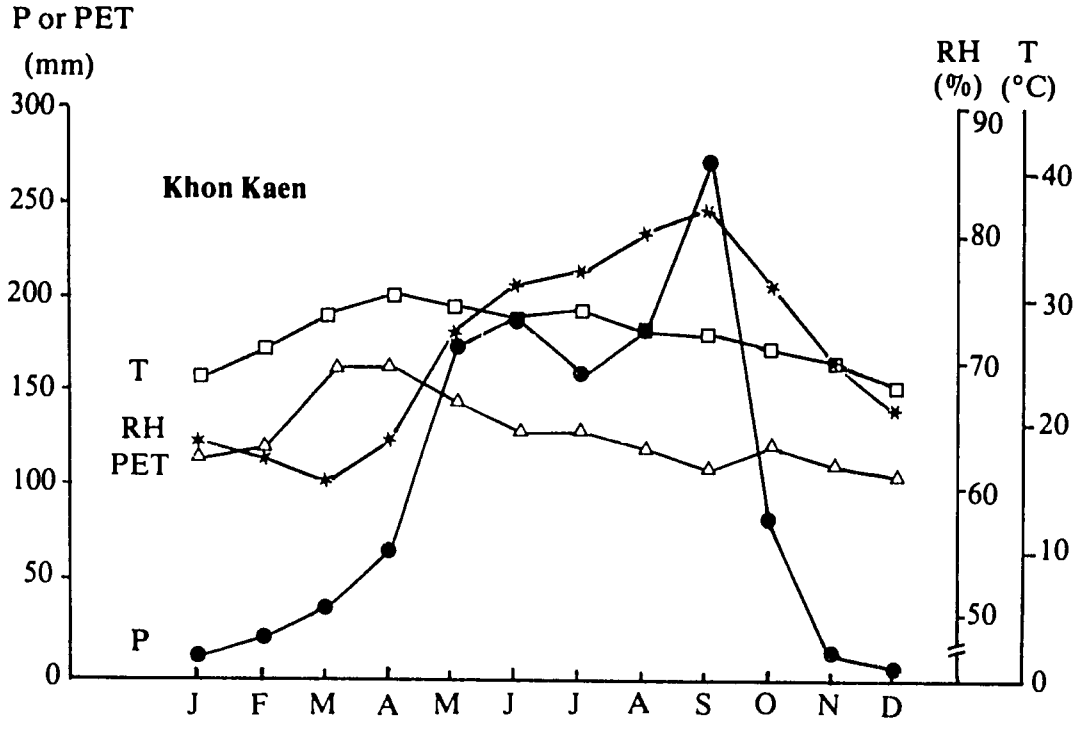
Source : Meteorological Department, data for 1951-1980.

with a distinct difference between the dry and rainy season periods. Normally, this area has been used for cultivating various upland crops such as cassava, sugar cane and pineapple. The second type of climate is the Tropical Monsoon climate, which usually has more intensive rainfall and shorter dry periods. This areas extends over the South Eastern provinces of Rayong, Chantaburi and Trat. The average rainfall is normally in the range of 1,600 to 4,000 mm with the highest mean annual value of >3,000 mm obtained in Klongyai district of Trat province. Due to the higher rainfall, the majority of the land in these provinces has been used for growing trees, especially fruit trees.

Figure 5 shows the monthy variations in precipitation, temperature, relative humidity and potential evapotranspiration in the cassava growing areas of the northeast and eastern provinces. Data for Khon Kaen province are very representative for the entire northeastern region, while those for Chonburi province are representative for the entire eastern region. Note that in both regions the rainy season has two rainfall peaks, normally occurring in June and in September, in contrast to the potential evapotranspiration which shows a maximum in March-April and a minimum in September. Likewise, in both regions the mean relative humidity values are highest in September-October and lowest in December-March.

Soil climate :

Since the data on soil temperature at various meteorological stations are not always available and all soils in the country are classified in one soil temperature class of Isohyperthermic (>22°C), soil climate will be discussed mainly in terms of soil moisture regimes of the country as a whole and of the cassava regions in particular. Based on the combination of factors, such as depth to groundwater table, soil drainage, rainfall and vegetation, three classes of soil moisture regimes can be recognized in Thailand, i.e., Aquic, Udic and Ustic soil moisture regimes (Changprai, 1987b). Figure 6 shows that the Aquic class is normally found in the lowland areas used for rice cultivation, which can be characterized by its wetness or water saturaton for at least six months of each year. On the contrary, the Udic and Ustic soil moisture regimes are predominant in upland areas of the whole country. The Udic regime is mainly found in upland soils of peninsular Thailand, the southeast coast and in some areas of high altitude in the north and west Continental Highland regions. With moderate to well-drained soil drainage classes, the areas are usually covered with evergreen forest type vegetation. The Ustic soil moisture regime is predominantly found in upland soils of the Northeast, North, Central Highlands, north and west Continental Highlands regions. It is clear that the majority of cassava soils in the northeast and eastern regions fall under this Ustic class of soil moisture regime. These soils are usually well drained or somewhat excessively drained. During the entire year soils dry out to a considerable depth for a total period of more than 90 consecutive days. Thus, one of the principal constraints for cassava production is insufficient soil moisture during the dry period, particularly if this occurs within the first two months after planting.



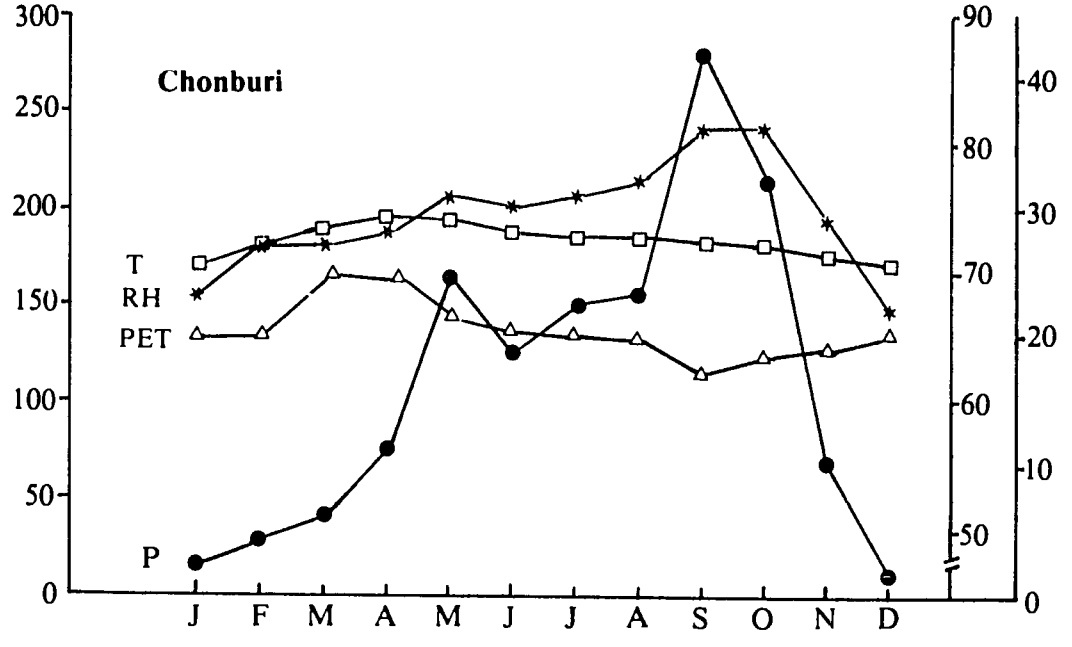


Figure 5. Mean monthly precipitation (P), potential evapotranspiration (PET), relative humidity (RH), and temperature (T) of Khon Kaen and Chonburi provinces (average 1951-1980).

Source : Akaratanakul, 1987.

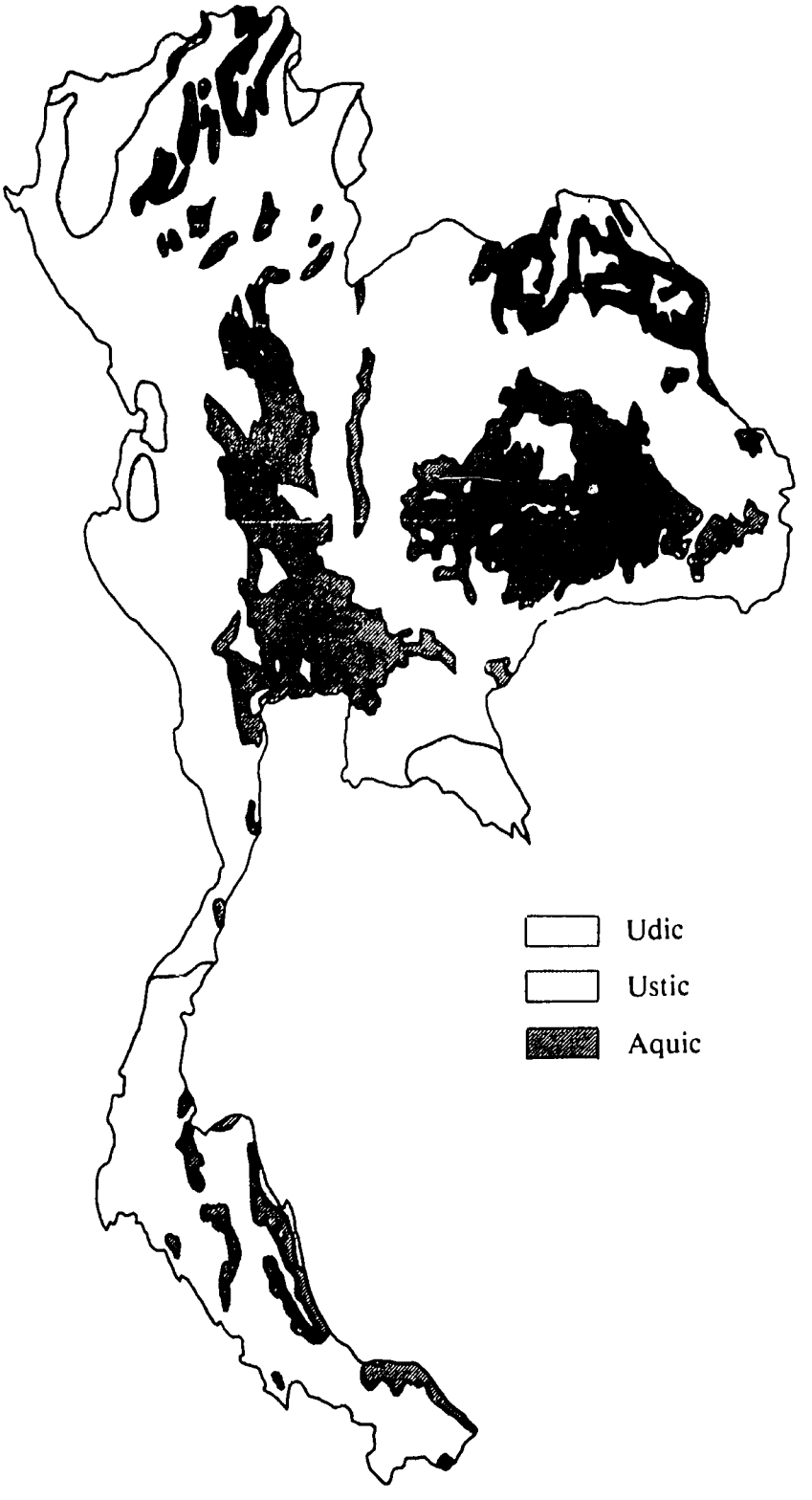


Figure 6. Soil moisture regimes of Thailand.

Source : Changprai (1987b).

Soil moisture and the length of growing period :

From some pertinent climatic data, obtained for 30 years from 53 meteorological stations throughout the country, the length of the plant growing period has been assessed by Akratanakul and Sankasila (1987). The length of plant growing periods was determined based on soil moisture content calculated from monthly precipitation, potential evapotranspiration (ETp) at 0.5 ETp and the water balance principle, assuming the capacity of the root zone soil to retain 100 mm water. Subsequently, the results were drawn onto the country map to obtain the isolines of mean length of growing period (LGP) and the probable LGP patterns in each region (Figure 7).

As shown in Figure 7, six LGP patterns comprise the probable occurrence of one LGP pattern (1, 1 Ha), two LGP patterns (1-2a, 1-2b and 1-2-H) and more than two LGP patterns (1-2-3, 1-2-3-H, 1-2-3-4) during the entire year under study. The corresponding probability criteria for each LGP pattern are also presented in the same figure. As seen, most of the areas in the country are classified into the 1-2a, 1-2b and 1-2-H LGP patterns. These three patterns account for 76% of the country (Akratanakul and Sankasila, 1987). In other words, about three-fourth of the country fall under the 1-2 classes with the probability of having 2 lengths of growing periods during the year. For the 1-2-3 and 1-2-3 H patterns (2 LGP), which are mainly found in the Peninsula, this accounted for 22% of the country. Note that most of the areas under cassava in the Northeast and Eastern regions are classified into the 1-2a and 1-2b LGP patterns with the total LGP varying from 180 days in the western part of the Southeast to 225 days in the lower Northeastern regions. This 1-2 LGP pattern comprise one normal LGP preceded by a shorter LGP with a relatively dry period in between the two. More details about procedures and results are reported by Akratanakul and Sankasila (1987).

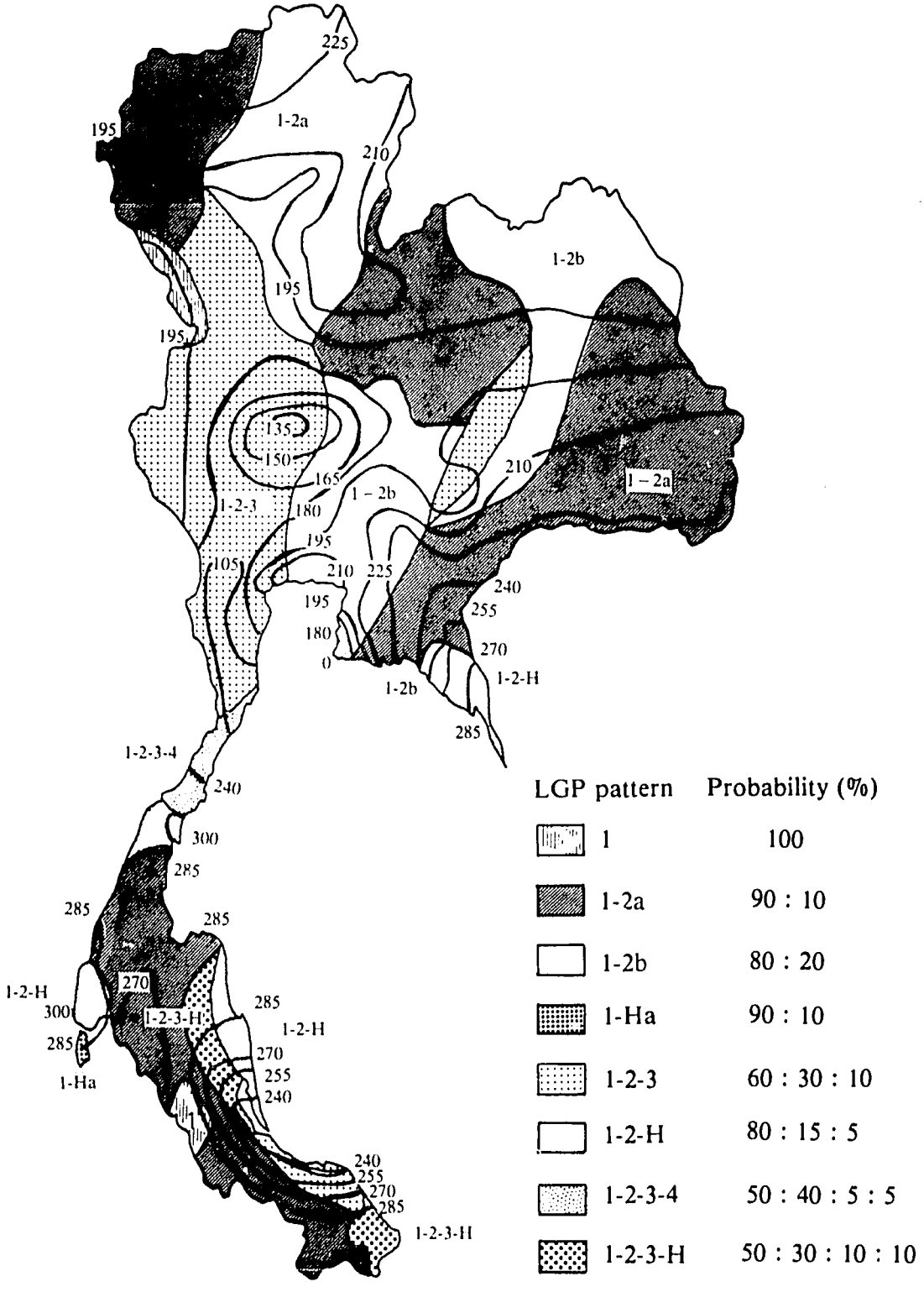


Figure 7. Mean length of the growing period (LGP) isolines (days) and LGP patterns with their corresponding probability criteria in Thailand.

Source : Akratanakul and Sankasila, 1987.

Soils of the Cassava Region

Classification and distribution :

Figure 8 shows the general distribution of soil orders in Thailand, according to the USDA system of "Soil Taxonomy". It is clear that the predominant upland soils are classified as Ultisols, especially in the east and north-east. Owing to the fact that almost 90 percent of the total cassava planted areas in the country are located in the Northeast and Eastern regions the characterizations of cassava soils will emphasize mainly these two regions.

By overlaying the land use map onto a soil classification map of the same 1 : 500,000 scale, it was possible to estimate the cassava acreage belonging to each great soil group in the Northeast and Eastern regions. These data are shown in Tables 3, 4, and 5. Table 3 shows that 75.3% of cassava soils in Thailand are classified as Ultisols, 14.5% as Entisols, 4.1% as Oxisols, 3.8% as Alfisols and the remaining 2.3% as Inceptisols and Vertisols. Among the Ultisols, by far the predominant great group are the Paleustults with only small areas of Plinthustults, Paleaquults, Paleudults and Haplustults. Among the Entisols the predominant great group are the Quartzipsamments. The Paleustults are found in three phases, i.e., loamy, clayey and skeletal phase of which the loamy phase is by far the most common among the

Table 3. Area by soil order and great group of cassava growing regions in Thailand[1/]

Order	Great group	Northeast		East		Total	
		ha	%	ha	%	ha	%
Entisol	Quartzipsamment	98,420	13.0	53,190	16.0	151,610	13.9
	Ustipsamment	2,400	0.3	-	-	2,400	0.2
	Ustifluvent	4,012	0.5	-	-	4,012	0.4
	Total	104,832	13.8	53,190	16.0	158,022	14.5
Ultisol	Paleustult	487,419	64.3	239,799	72.0	727,218	66.6
	Plinthustult	38,196	5.1	-	-	38,196	3.5
	Haplustult	-	-	13,650	4.1	13,650	1.3
	Paleudult	-	-	17,634	5.3	17,634	1.6
	Paleaquult	20,720	2.7	3,750	1.1	24,470	2.2
	Total	546,335	72.8	274,833	82.5	821,168	75.3
Alfisol	Haplustalf	36,600	4.8	-	-	36,600	3.3
	Paleustalf	5,143	0.7	-	-	5,143	0.5
	Total	41,743	5.5	-	-	41,743	3.8
Inceptisol	Dystropept	20,097	2.7	2,500	0.8	22,597	2.1
Vertisol	Usterthert	-	-	2,478	0.7	2,478	0.2
Oxisol	Haplustox	45,000	5.9	-	-	45,000	4.1
	Total	758,007	100	333,001	100	1,091,008	100

1/ Estimated from data obtained from Department of Land Development, MOAC.

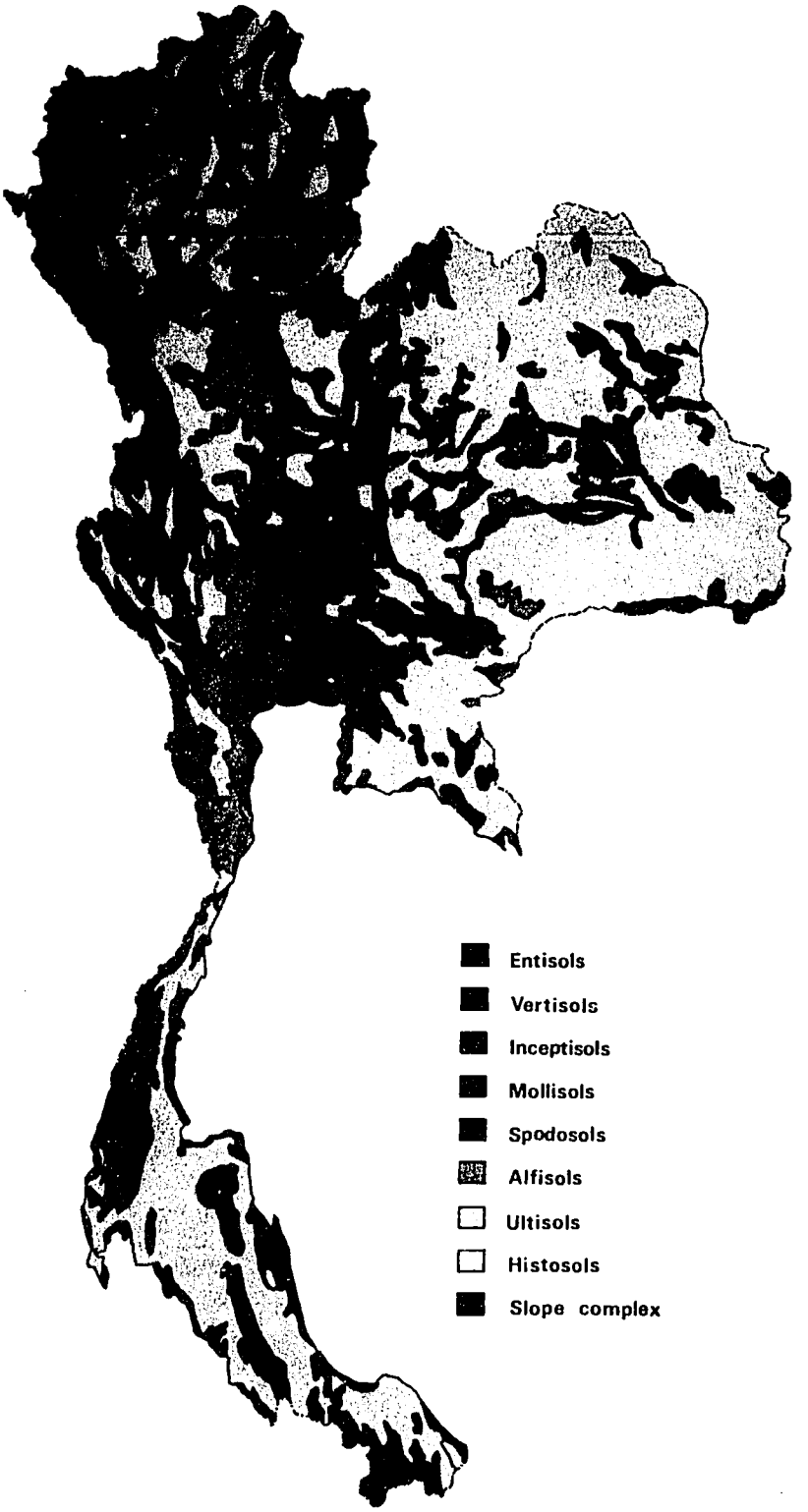


Figure 8. Distribution of soil orders in Thailand.

Source : Adapted from General Soil Map of Thailand, Soil Survey Div. Dept. Land Development, Thailand, by Piya and Howeler.

Table 4. Cassava growing area by phase of great group of soils in the Northeast and East.[1/]

Phase of great group	Northeast		East		Total	
	ha	%	ha	%	ha	%
Sandy Quartzipsamment	88,380	11.6	53,190	16.0	141,570	13.0
sandy Ustipsamment	2,400	0.4	–	–	2,400	0.2
sandy Quartzipsamment /loamy Dystropept	10,040	1.3	–	–	10,040	0.9
Loamy Paleustult	310,569	41.2	135,666	40.7	446,235	40.9
loamy Paleaquult	20,720	2.7	3,750	1.2	24,470	2.2
loamy Dystropept	20,097	2.6	2,500	0.8	22,597	2.0
loamy Haplustalf	6,600	0.8	–	–	6,600	0.6
loamy Paleustalfs	5,143	0.7	–	–	5,143	0.5
loamy Ustifluvent	4,012	0.5	–	–	4,012	0.4
loamy Plinthustult	3,483	0.4	–	–	3,483	0.3
loamy Paleudult	–		2,500	0.8	2,500	0.2
loamy Haplustult /skeletal Haplustult	–		11,250	3.4	11,250	1.0
Loamy Paleustult /loamy Paleaquult	142,018	18.8	–	–	142,018	13.0
loamy Paleustult /loamy Dystropept	10,000	1.3	–	–	10,000	0.9
clayey Haplustox	45,000	6.0	–	–	45,000	4.2
clayey Haplustalf	30,000	4.0	–	–	30,000	2.7
Clayey Paleustult	16,250	2.2	35,008	10.5	51,258	4.8
clayey Haplustult	–		2,400	0.7	2,400	0.2
clayey Paleudult	–		1,250	0.4	1,250	0.1
skeletal Plinthustult	32,609	4.1		–	32,609	3.0
Skeletal Paleustult	8,582	1.1	69,125	20.7	77,707	7.2
skeletal Usterthert	–		2,478	0.7	2,478	0.2
skeletal Paleudult	–		13,884	4.1	13,884	1.3
skeletal Plinthustult /loamy Dystropept	2,140	0.3	–	–	2,104	0.2
Total	758,007	100	333,001	100	1,091,008	100

1/ Estimated from data obtained from Department of Land Development, MOAC.

cassava soils (Table 4). By regions, the majority of cassava soils in the Northeast comprise three phases of great groups, i.e., sandy Quartzipsamment, loamy Paleustult, and loamy Paleustult/loamy Paleaquult association. This is also true in the East, except that large areas of clayey and skeletal Paleustults are also found in this region.

Table 5 shows the area of the principal cassava soils in each province. It is clear that in the majority of provinces in the two regions cassava is mainly grown on Paleustults and Quartzipsamments. Of these, the loamy Paleustult soil is the most widespread and can be found in almost every province. Note that large areas of clayey soils under cassava are found only in Nakhon Ratchasima province in the Northeast and Rayong province in the East. The most important soil series found within these groups of clayey-red and yellow soils are Chok Chai (Haplustox), Chatturat (Haplustalf) and Pak Chong (Paleustult), which occupy the largest acreage of clayey cassava soils found in Nakhon Ratchasima province.

Table 5. Cassava growing area by phase of great group of soils in the Northeast and Eastern provinces (ha)[1/]

Northeast	Phase of Great Group								
	Sandy Quartzipsamment	Loamy Paleustult	Loamy Paleustult Loamy Paleaquult	Loamy Paleaquult	Clayey Haplustox	Clayey Haplustalf	Clayey Paleustult	Others	Total
Nakhon Phanom	-	11,200	-	720	-	-	-	1,512	13,432
Sakhon Nakhon	3,750	7,479	10,000	-	-	-	-	-	21,229
Nong Khai	2,880	25,000	-	-	-	-	-	34,209	62,089
Udon Thani	2,500	38,467	5,000	-	-	-	3,750	1,920	51,637
Loei	-	7,500	-	-	-	-	2,500	4,163	14,163
Mukdahan	-	2,500	628	-	-	-	-	-	3,128
Yasothon	-	2,400	1,042	-	-	-	-	1,920	5,362
Ubon Ratchathani	-	5,000	7,449	-	-	-	-	5,000	17,449
Kalasin	11,200	25,000	9,836	-	-	-	-	-	46,036
Khon Kaen	10,000	10,000	35,000	-	-	-	2,500	2,104	59,604
Maha Sarakham	12,500	-	15,774	-	-	-	-	-	28,274
Roi Et	-	7,500	2,500	-	-	-	-	31,517	41,517
Buri Ram	5,000	25,000	14,054	-	-	-	-	2,500	46,554
Si Sa Ket	1,250	5,000	-	-	-	-	-	2,539	8,789
Surin	2,400	-	3,453	-	-	-	-	-	5,853
Chaiyaphum	2,500	27,500	37,283	-	-	-	-	-	67,283
Nakhon Ratchasima	34,400	111,023	-	20,000	45,000	30,000	7,500	12,686	260,609
Total	88,380	310,569	142,019	20,720	45,000	30,000	16,250	100,070	753,008
Percentage	11.6	41.2	18.8	2.7	6.0	4.0	2.2	13.5	100

Table 5. (cont.)

East	Sandy Quartzipsamment	Loamy Paleustult	Loamy Paleudult	Loamy Paleaquult	Clayey Paleustult	Skeletal Paleustult	Skeletal Paleudult	Loamy Haplustult/Skeletal Haplustult	Others	Total
Chachoengsao	6,368	22,500	–	–	–	31,625	–	–	–	60,493
Prachin Buri	6,822	20,000	–	–	–	12,500	–	–	2,400	41,722
Chon Buri	25,000	53,891	–	–	–	7,500	–	–	–	86,391
Rayong	15,000	39,275	–	3,750	35,008	17,500	–	–	2,500	113,033
Chantaburi	–	–	–	–	–	–	7,500	11,250	3,728	22,478
Trat	–	–	2,500	–	–	–	6,384	–	–	8,884
Total	53,190	135,666	2,500	3,750	35,008	69,125	13,884	11,250	8,628	333,001
Percentage	16.0	40.7	0.8	1.2	10.5	20.7	4.1	3.4	2.6	100

1/ Estimated from data obtained from Department of Land Development, MOAC.

The Paleustults are terrace soils characteristically having a sandy loam surface with more clay in the lower horizons. Typically, these soils are well drained, have low base saturation (< 35%), low water holding capacity (5-10%), and have been classified under an Ustic soil moisture regime (drying more than 90 consecutive days in the year). The Paleustults are usually found occupying the middle and high terraces in the Northeast (Figure 9) and are widespread in the undulating to rolling areas in the East. Usually, they are classified as being moderately well suited for upland crops including cassava. The main constraints are insufficient soil moisture during the dry season, low inherent soil fertility and great susceptibility to erosion, particularly in those areas with rolling and hilly topography. The most common and important soil series in this Paleustult great group are Korat, Warin, Satuk and Yasothon in the Northeast and Map Bon in the East (Table 6).

Second only to the Paleustult soils in term of acreage under cassava, the Quartzipsamments are found scattered throughout the Northeast, particularly in the low to middle terraces (Keerati-Kasikorn, 1984). Substantial areas of Quartzipsamments also exist in the East, where they are located around the old beach areas in Chonburi and Rayong provinces (Changprai, 1987a). Typically, these soils are very sandy throughout the profile and 95% or more of the sand fraction is in the form of quartz sands. Other distinct characteristics are that they are well to excessively well-drained and of relatively low fertility. They are poorly suited for many upland crops due to their severe limitations that restrict their use. Important soil series in this great group include Sattahip and Pattaya in the East and Nam Phong series in the Northeast (Table 6).

Inherent Characteristics of the Representative Soils

Besides some of the general features of soils classified within the two great groups of Paleustults and Quartzipsamments, described above, the physical and chemical characteristics as well as the native fertility status of some representative soils at soil series level demonstrate some distinct properties. As shown in Table 6, the soil series fairly well representing the Northeast cassava fields comprise Korat, Yasothon, Warin and Satuk, all of which belong to the Paleustult great group. The main soil series from the East include Sattahip (Quartzipsamment), Pattaya (Quartzipsamment), Huai Pong (Paleudults) and Map Bon (Paleustults) (Table 6). From among all these soil series, Korat and Sattahip soil series are the most predominant in the Northeast and East, respectively.

The generalized physical and chemical characteristics of these eight soil series are shown in Table 7. All soils are acidic, ranging in pH between 4.5 to 6.5. Based on the soil fertility categories determined from soil test values (Table 8), all soil series except Huai Pong are characteristically low in organic matter (O.M.), available phosphorus and potassium, and also low in the capacity to retain cationic nutrients as indicated by low CEC values. Most of the soils are light, having a sandy loam texture in the soil surface. Moreover, most of the soils are moderately well-drained to well-drained indicating low to moderate capacity of the soils to retain water. As shown in Figures 10 and 11 all the soil test values of the surface soils (30 cm depth) obtained are within the same range as those show in Table 7, except for the Pakchong and Chok Chai series, which in general are more fertile and thus used for crops other than cassava.

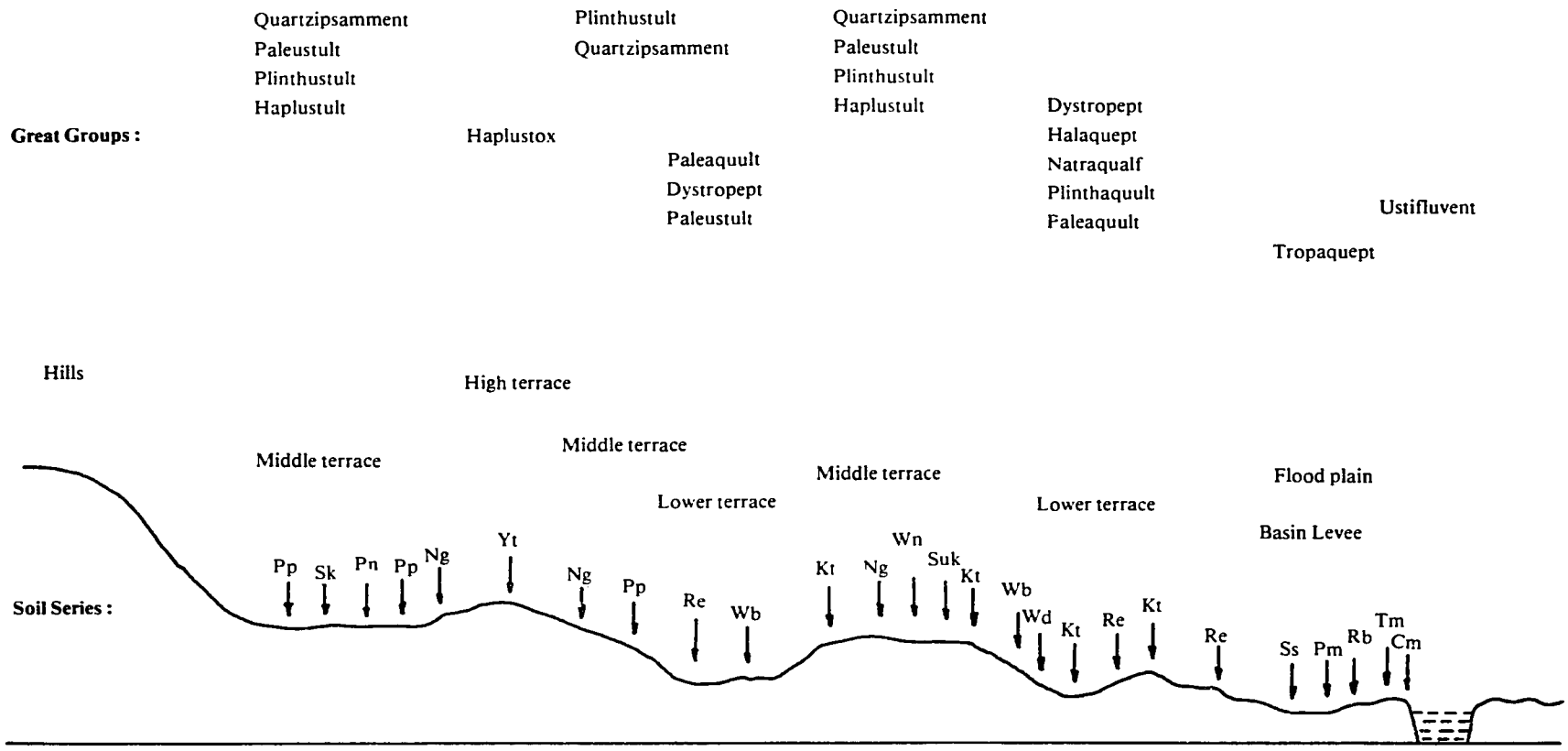


Figure 9. Physiographic position of soil series and great groups in the Northeast region of Thailand.

Source : Modified from Keerati-Kasikorn, 1984.

Table 6. Acreage of the major soil series in the cassava growing areas in the Northeast and Eastern provinces (ha).

Northeast	Soil series				Total
	Korat	Warin	Satuk	Yasothon	
Kalasin	43,452	3,266	998	2,745	50,461
Khon Kaen	34,926	622	8,072	5,591	49,211
Chaiyaphum	13,569	17,831	773	1,558	33,731
Nakhon Phanom	37,935	340	–	–	38,275
Nakhon Ratchasima	22,167	24,256	17,520	11,206	75,149
Buri Ram	45,959	2,035	13,457	3,460	64,911
Maha Sarakham	19,057	491	1,539	685	21,772
Roi Et	36,159	–	–	466	36,625
Loei	599	–	147	–	746
Si Sa Ket	31,900	7	643	131	32,681
Sakon Nakhon	45,068	–	–	80	45,148
Surin	30,911	3,264	2,505	2,064	38,744
Nong Khai	5,963	906	2,733	–	9,602
Udon Thani	69,165	1,098	1,548	3,433	75,244
Ubon Ratchathani	106,792	70	–	801	107,663
Total	543,622	54,186	49,935	32,220	679,963
Percentage	80.0	8.0	7.3	4.7	

East	Soil series				Total
	Sattahip	Mapbon	Pattaya	Huaipong	
Chantaburi	248	–	–	25,442	25,690
Chonburi	46,733	16,745	2,649	–	66,127
Chachoengsao	9,147	1,658	–	–	10,805
Rayong	14,695	15,824	2,389	17,931	50,839
Trat	–	–	117	146	263
Total	70,823	34,227	5,155	43,519	153,724
Percentage	46.1	22.3	3.3	28.3	

Source : Duangpatra (1983).

Table 7. Physical and chemical characteristics of some major cassava surface soils (10-30 cm.) collected from the majority of provinces in the Northeast and Southeastern regions of Thailand.

Region	Soil series	pH	O.M (%)	P (ppm.)	K (ppm.)	B.S (%)	CEC (me./100 g.)	Texture	Drainage*
Northeast	Korat	5.6-6.0	0.5-1.0	2-6	20-60	35-75	3-5	sandy loam	MW
	Yasothon	5.0-6.0	0.5-1.0	2-6	30-60	35-75	2-5	sandy loam	W
	Warin	4.5-6.5	0.5-1.5	3-10	20-60	35-75	3-5	sandy loam or loamy sand	W
	Satuk	4.5-6.5	0.5-1.5	2.5-6	30-90	35-75	2-6	sandy loam	MW to W
	Range mean	4.8-6.3	0.5-1.3	2.3-7	25-68	35-75	2.5-5.0		
Southeast	Sattahip	5.5-6.5	0.5-1.0	4-7	20-60	35-75	2-4	sand or sandy clay loam	W
	Mapbon	5.5-6.5	1.0-2.0	4-10	60-80	60-75	2-5	sandy loam	W
	Huaipong	4.5-6.0	1.5-3.0	10-20	60-80	25-30	3-10	sandy clay or sandy clay loam	W
	Pattaya	4.5-5.5	0.3-1.0	3-6	10-40	50-70	2-5	sand	E
	Range mean	5.0-6.2	0.8-1.8	5.3-10.8	38-65	43 – 63	2-6		

* MW = moderately well-drained, W = well-drained, E = excessively drained

Source : Duangpatra (1983).

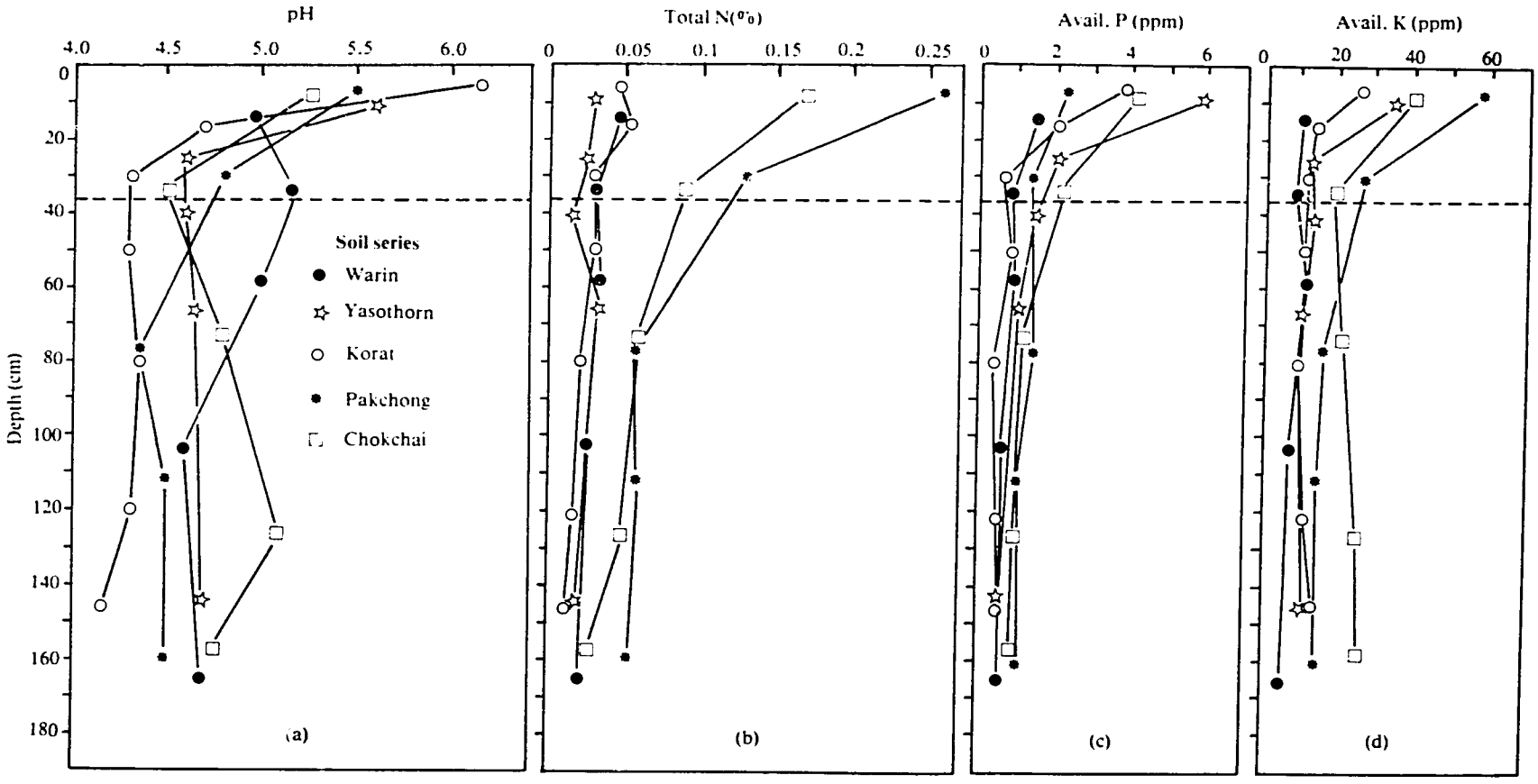


Figure 10. Change of soil pH, total N, and available P and K with depth in several typical upland soil series in the Northeast (Suddhiprakarn and Kheoruenromne, 1982).

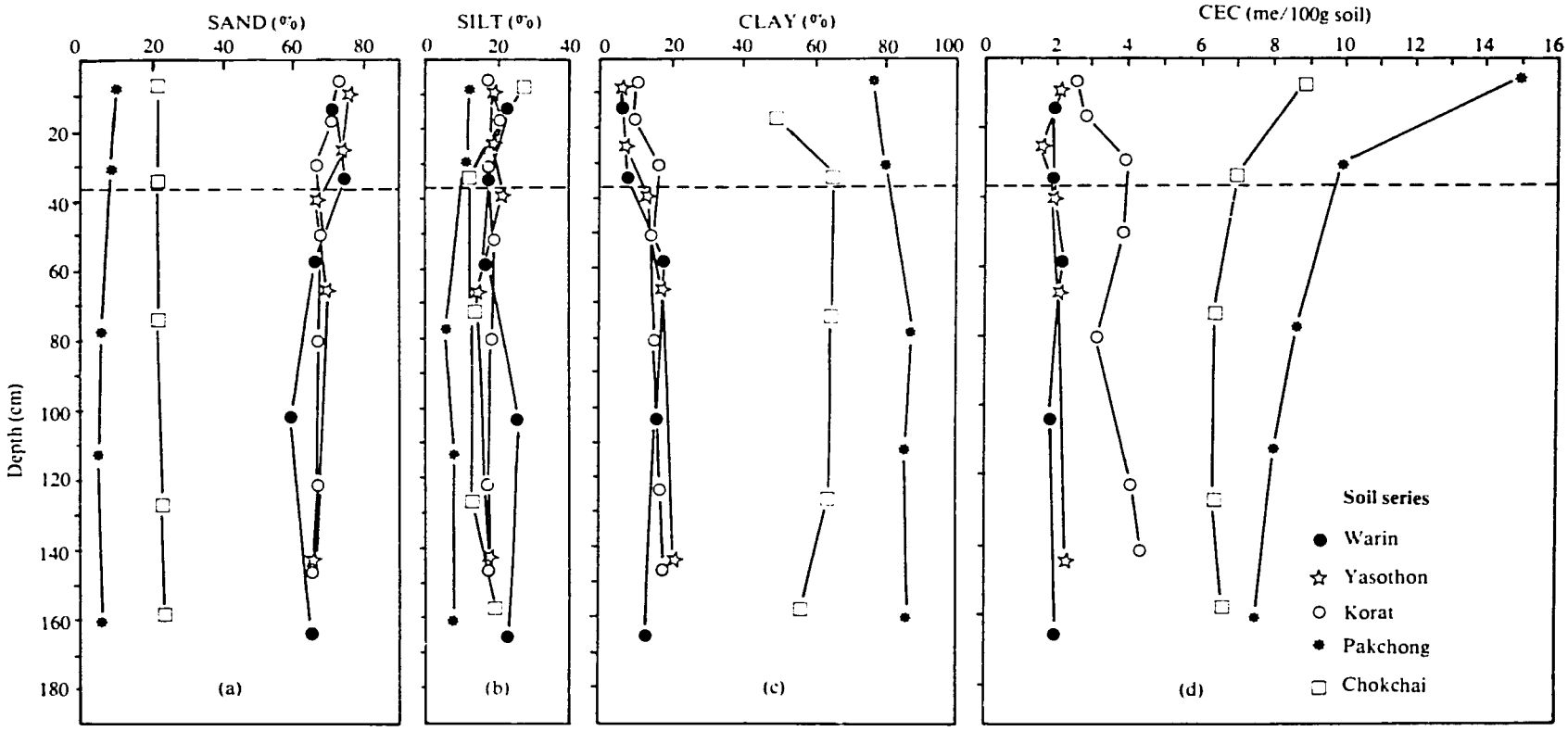


Figure 11. Change of sand, silt and clay content as well as cation exchange capacity with depth in several typical upland soil series in the Northeast (Suddhiprakarn and Kheoruenromne, 1982).

Table 8. Soil fertility categories according to soil test values.

Soil fertility status	CEC (me/100 gm)	Base sat. (%)	O.M. (%)	Avail. P (ppm)	Avail. K (ppm)	Exchangeable bases (me/100 gm)	
						Ca	Mg
Very low	< 3.0	< 20	< 0.5	< 3	< 30	< 2	< 0.3
Low	3-5	20-40	0.5-1.0	3-6	30-60	2-5	0.3-1
Moderately low	5-10	–	1.0-1.5	6-10	–	–	–
Moderate	10-15	40-60	1.5-2.5	10-15	60-90	5-10	1-3
Moderately high	15-20	–	2.5-3.5	15-25	–	–	–
High	20-30	60-80	3.5-4.5	25-45	90-120	10-20	3-8
Very high	> 30	> 80	> 4.5	> 45	> 120	> 20	> 8

Source : Lek Monchareon (1982).

By evaluating the fertility status based on soil test values shown in Table 8, it is concluded that the majority of cassava soils in most provinces of the two regions are inherently low in their indigeneous fertility, as reflected by their low organic matter contents as well as insufficient contents of P and K. Apparently, the cause of the existence of many low fertility soils in the cassava areas in the Northeast and East are partially due to soil loss by water erosion. It is evident from Tables 9 and 10 that enormous losses of soil by water erosion occur, mainly in the Northeastern and Eastern regions and particularly in areas used for field crops.

Table 9. Extent of different degrees of soil erosion calculated for various land uses in Thailand.

Degree of erosion	Soil loss (t/ha/year)	Area (million ha)	Main land use
Very slight	0.06-6.25	19.00	forest, paddy
Slight	6.25-31.25	14.44	forest, rubber, orchards, paddy
Moderate	31.25-125.0	4.15	rubber, orchards, field crop, forest + field crops
Severe	125.0-625.0	6.82	rubber, orchards, field crop, forest + field crops, shifting cultivation
Very severe	> 625.0	6.27	field crop, forest + shifting cultivation field crops
Others	–	0.73	coastal area, mangrove forest, shrimp farm etc.
Total	–	51.41	–

Source : Krishnamara and Srikhajon (1987)

Table 10. Extent of different degrees of erosion in the six regions of Thailand.

Region	Degree of soil erosion			
	Moderate	Severe	Very severe	Total
	million ha			
1. North	0.82	2.88	0.98	4.68
2. Northeast	1.17	2.04	3.66	6.87
3. Central	0.06	0.42	0.14	0.62
4. East	0.35	0.43	1.06	1.84
5. West	0.03	1.16	0.18	1.42
6. South	1.77	0.08	0.06	1.91
Total	4.25	7.01	6.08	17.34

Source : Krisnamara and Srikhajon (1987).

Conclusions

Cassava growing areas in Thailand are predominantly in the Northeast and Eastern regions. The climate of the Northeast is classified as Tropical Savannah, whereas that of the Eastern region comprise two types, i.e., Tropical Savannah and Tropical Monsoon climates. The rainy season in these regions extends from May to October with a mean annual rainfall of about 1,200 to 1,600 mm. The rainfall pattern is of bimodal shape with the first peak generally occurring in May to June and the second in September or October. This rainfall distribution is dominated to a large extent by the Southwest monsoon and by tropical cyclones originating in the Indian Ocean and South China sea, respectively.

Atmospheric temperatures found in all cassava areas are classified as Isohyperthermic with the annual average temperature of 26-28°C. The mean annual relative humidity range from 70-75% in most areas of the Northeast and also in some parts of the southeast coast. Mean potential evapotranspiration in the Northeast and East vary from about 1,400 to 2,000 mm annually. In terms of soil moisture content, most soils in the cassava regions are classified under the Ustic soil moisture regime. Based on the annual variations in soil moisture content, most cassava growing regions have two lengths of growing period during the year, with an annual total length of about 180 to 225 days.

The majority of cassava soils in the country fall into two phases of great groups, i.e., the loamy Paleustults and sandy Quartzipsamments. The Paleustults occupy about 75% of the cassava growing regions of Thailand and are widespread both in the Northeast and the East, whereas the Quartzipsamments are relatively more dominant in the Eastern region. The most common soil series, belonging to the Paleustult great soil groups, comprise Korat, Warin, Yasothon and Satuk in the Northeast and Map Bon in the East; those classified as Quartzipsamment are the soil series Sattahip, and Pattaya, in the East. From among all these, the Korat and Sattahip are the most important soil series of the cassava regions.

Characteristically, most cassava soils are poor in terms of their indigeneous soil fertility. They have rather unfavourable physical and chemical properties, such as having very sandy textures in the surface soil, containing very low levels of organic matter, having relatively

low nutrient and water retention capacity and also fairly low contents of available P and K. Moreover, due to their rather poor aggregate stability and their frequent occurrence in areas of undulating or rolling topography, soil losses due to erosion can be very severe, particularly in the Northeast. This is one of the main causes of an apparent soil fertility decline in most of the cassava growing areas in the country.

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AGRONOMIC PRACTICES IN MAJOR CASSAVA GROWING AREAS OF INDONESIA

J. Wargiono[1/]

Introduction

Cassava (*Manihot esculenta* Crantz) is the third most important crop in Indonesia and the fourth in the tropics. This crop is more adapted than other food crops to marginal soils and to semiarid climates.

The low average yield obtained in Indonesia during the last ten years (Direktarat Bina Program Deptan, 1985), indicate that agricultural technology for increasing yield is still not effective. On the other hand, cassava is a crop that is highly efficient in nutrient extraction and for that reason it is commonly grown on marginal soils. Therefore, it should be backed up by comprehensive research in order to increase yield, and farmer's income, while maintaining the soil fertility (Wargiono, 1979).

In Indonesia the main goal for agricultural researchers is to develop technologies that not only increase production but also prevent erosion and soil degradation in the marginal soils of the principal production areas. Inspite of the interdisciplinary and integrated approach among Research Institutes and Universities, progress in technology development has been slow due to budget constraints. Collaborative research with CIAT and other cassava programs can help to improve the experiments and enable more comprehensive research.

Distribution of Cassava Growing Areas

Table 1 shows that over the last 17 years the average cassava area in Indonesia decreased approximately 0.7% per year. In Java, the principal cassava production zone, the area decreased at a rate of 1.9% per year (Dir. Bina Program Deptan, 1985). This is caused by the expansion of irrigation facilities for other crops. However, cassava yields in Java increased significantly, resulting in a 11% increase in total production, between 1969 and 1985. In the production areas outside of Java the cassava area, as well as the average yields increased. Thus, total cassava production in Indonesia increased from 10.7 to 14.1 million tons fresh roots between 1969 and 1985.

The increase in production inspite of a decrease in harvested area indicates that farmers have increased yields mainly through the implementation of improved technology. Sumatra produces the highest yields, reflecting the introduction of new technology. The development

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Table 1. Harvested area and average yield of fresh cassava roots in Indonesia from 1969 to 1985.

Location	Harvested area (1000 ha)				Average yield (t/ha)			
	1969-74	74-79	79-84	84-85	1969-74	74-79	79-84	84-85
Java	1,106	1,046	941	869	7.68	8.86	9.97	10.83
Sumatra	102	130	143	174	9.73	10.46	10.57	11.27
Kalimantan	35	32	31	41	8.62	10.17	9.82	10.20
Sulawesi	82	76	79	79	7.58	8.75	8.51	9.97
East Indonesia	111	120	155	159	3.07	8.42	12.92	9.65
Indonesia	1,434	1,404	1,350	1,321	7.48	9.00	9.76	10.67

Source : Direktorat Bina Program Deptan (1985).

of technologies for specific target areas permits more specific recommendations. The technology then becomes more acceptable to farmers and allows for transfer of technology to similar agroclimatic regions.

Rainfall Pattern

Growth and production of cassava will be decreased whenever water stress occurs during the first five months of the growth stage (Hozyo *et. al.*, 1984). Oldeman (1975-1980) made a stratification of the agroclimatic zones in Indonesia on the basis of number of consecutive wet months (>200 mm rainfall) and dry months (<100 mm rainfall). This classification system is shown at the bottom of Table 2 and the distribution of rainfall categories in Indonesia is shown in Figure 1 and Table 2. Cassava production zones in E-Java are located principally in agroclimatic zones C_2, C_3 and D_3, which are characterized by 2-6 dry months, while production zones in W-Java and Sumatra are located in zones and B and C_2, characterized by only 2-3 dry months (Figure 2).

The main target area of cassava in Java is located in agroclimatic zones D and C, where cassava is generally intercropped with upland rice and/or palawija (non-rice food) crops, and planting at the beginning of the wet season is most common. In areas of zones A, B and C that are near a starch factory or big city cassava is planted year-round.

Table 2. Distribution (%) of the agroclimatic zones on Java, Sumatra, Kalimantan and Sulawesi.

Location	Agroclimatic zone*											
	A_1	B_1	B_2	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2	E_3
Java	4	16	7	0	25	14	0	5	20	0	0	9
Sumatra	24	46	1	6	9	0	10	2	0	1	2	0
Kalimantan	40	30	1	8	7	0	3	1	0	5	1	0
Sulawesi	1	21	4	10	11	4	10	8	4	12	11	4
• Climatic zone :	A_1	B_1	B_2	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2	E_3
No. months : Wet :	> 9	7-9	7-9	5-6	5-6	5-6	3-4	3-4	3-4	< 3	< 3	< 3
Dry :	< 2	< 2	2-3	< 2	2-3	4-6	< 2	2-3	4-6	< 2	2-3	4-6

Source : Oldeman *et.al.*, 1975-1980.

Figure 1. Distribution of agroclimatic zones in Indonesia. A wet month has>200 mm and a dry month<100 mm rainfall.

Source : Oldeman *et.al.*, 1975-1980.

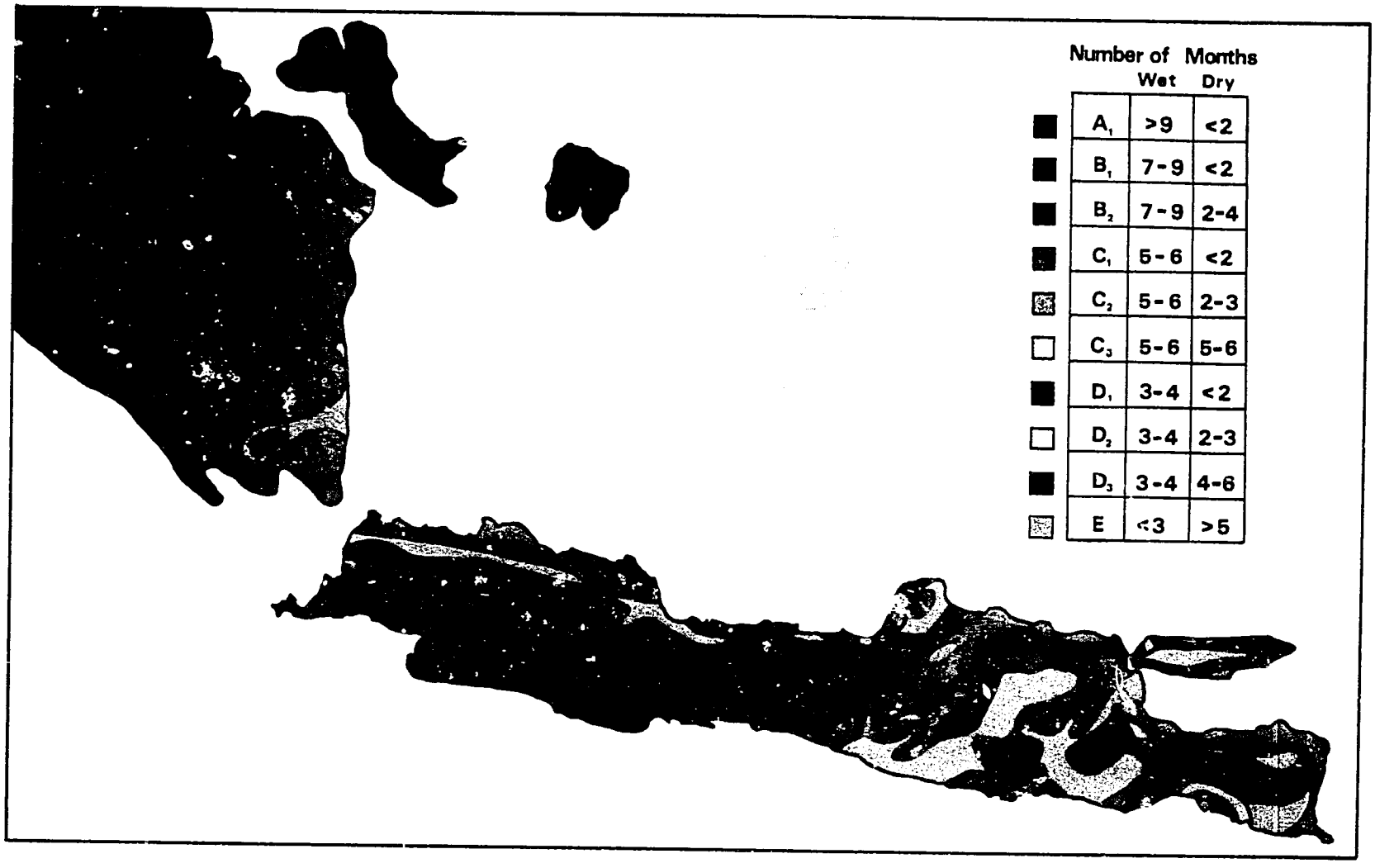

Figure 2. Distribution of agroclimatic zones in the main cassava growing areas of Indonesia. A wet month has >200 mm and a dry month <100 mm rainfall.

Source : Oldeman *et.al.*, 1975 and 1979.

In Sumatra and Kalimantan, cassava is planted during the wet season in areas of C and B rainfall patterns for intercropped systems, and year-round for areas near starch factories. Different intercrop and monocropping patterns dominate in Zone D during the wet season. Based on the distribution of rainfall and the possibility of area expansion, these areas would be suitable for agro-industrial development.

In Sulawesi and the eastern islands of Indonesia, cassava is planted in the beginning of the wet season with D and E type of rainfall patterns.

Cassava Soils and Soil Conservation

Soil erosion, as the main factor affecting soil degradation, is influenced by climate, topography, vegetation, soil type and human endeavors, and must be considered as an important factor in considering the expansion of cassava areas (Suwardjo and Sinukaban, 1986; Suwardjo *et. al.*, 1986). Table 3 shows that soil losses due to erosion are greatest during the wet season months from October to May, especially in crops like upland rice or cassava, but that these losses can be greatly reduced by the construction of terraces and adequate soil and crop management practices.

Table 3. Average soil losses due to erosion with different terrace and cropping patterns on Mediteran soil of West Java.

Terrace and cropping pattern	Erosion (t dry soil/ha)		
	Feb-May	Jun-Sept	Oct-Feb
Bench, planted with upland rice + secondary food crops and brachiaria grasses on terrace risers	0.76	0.28	0.42
Contour, planted with secondary food crops and brachiaria grasses with leucaena and brachiaria planted on the contour	3.78	0.75	1.21
Individual, planted with upland rice + secondary food crops with strips of glyricidia	4.12	1.31	4.21
Farmer's bench, planted with upland rice + cassava + corn	7.21	1.77	3.61

Source : Suwardjo *et. al.*, 1986.

Cassava is often grown on very marginal soils and in mountainous areas, where it is generally planted at the beginning of the wet season. Due to its slow initial growth, cassava may cause a high rate of erosion during the first few months of establishment; moreover, the crop is very efficient in nutrient uptake. Thus, continuous planting of cassava without rotation with other crops may increase the rate of soil degradation if soil conservation is not effective. (Howeler, 1980; Hozyo *et. al.*, 1984; Wargiono, 1986; Wargiono *et al.*, 1987).

The major cassava growing areas of Java are located on Mediteran (Alfisol), Podzolic (Ultisol), Alluvial (Entisol), Latosol (Inceptisol) and Regosol (Entisol) soils. On the other

hand, cassava growing areas outside of Java are predominantly on Red Yellow Podzolic (Ultisol) soils (Figure 3).

Red Yellow Podzolic soils are found principally under high rainfall conditions (2,000-5,000 mm/year) and are characterised by high porosity of top soil, slow permeability of sub soil and undulating or mountainous topography. They cover approximately 27 million hectares, mostly under C or B type rainfall patterns, and are considered a major area for expansion of cassava production as long as soil conservation practices are used. Conventional tillage in this area should be avoided because it can promote soil erosion. Minimum tillage in combination with application of herbicides was able to reduce soil erosion in an area planted with upland rice (Bangun *et. al.*, 1986). Intercropping systems of cassava with upland rice, corn and legumes in these areas are intensive. Consequently, soil conservation should be done properly in order to reduce water erosion. Table 4 shows that mulching and/or incorporation of straw into the soil improved both the physical and chemical characteristics of the soil. So, efforts to improve the present farming systems must focus on overcoming constraints, e.g. the low level of soil organic matter in podzolic soils. The incorporation of crop residues into the soil is a way to maintain adequate levels of organic matter.

Table 4. Effect of corn and rice straw management on soil organic matter content, soil erosion and soil aggregate index stability.

Soil treatment	Organic matter content (%)	Aggregate index stability	Soil erosion (t/ha/year)
Unplanted soil (check)	2.31	43	93.9
Upland rice + corn (straw removed)	2.63	97	32.5
Upland rice + corn (straw incorporated)	3.12	143	15.8
Upland rice + corn (straw as mulch)	3.54	148	0.1

Source : Suwardjo and Sinukaban, 1986.

Cultural Practices

The ultimate objective of applied research is to develop and introduce to farmers new technologies that may be adopted, thereby improving their welfare. But, in some cases, the existing large differences in cassava yields between those of farmers and those obtained at research stations indicate that farmers have not yet adopted the recommended technology packages.

Cassava, as the main crop in marginal land, can be developed whenever the production technology is capable of raising the crop's productivity and farmers income. However, the existing technologies need to be improved.

1. Land preparation : Farmers with less than 1-2 hectares of arable land prepare their land either in the dry season, or after the first crop is harvested if the cassava is planted during

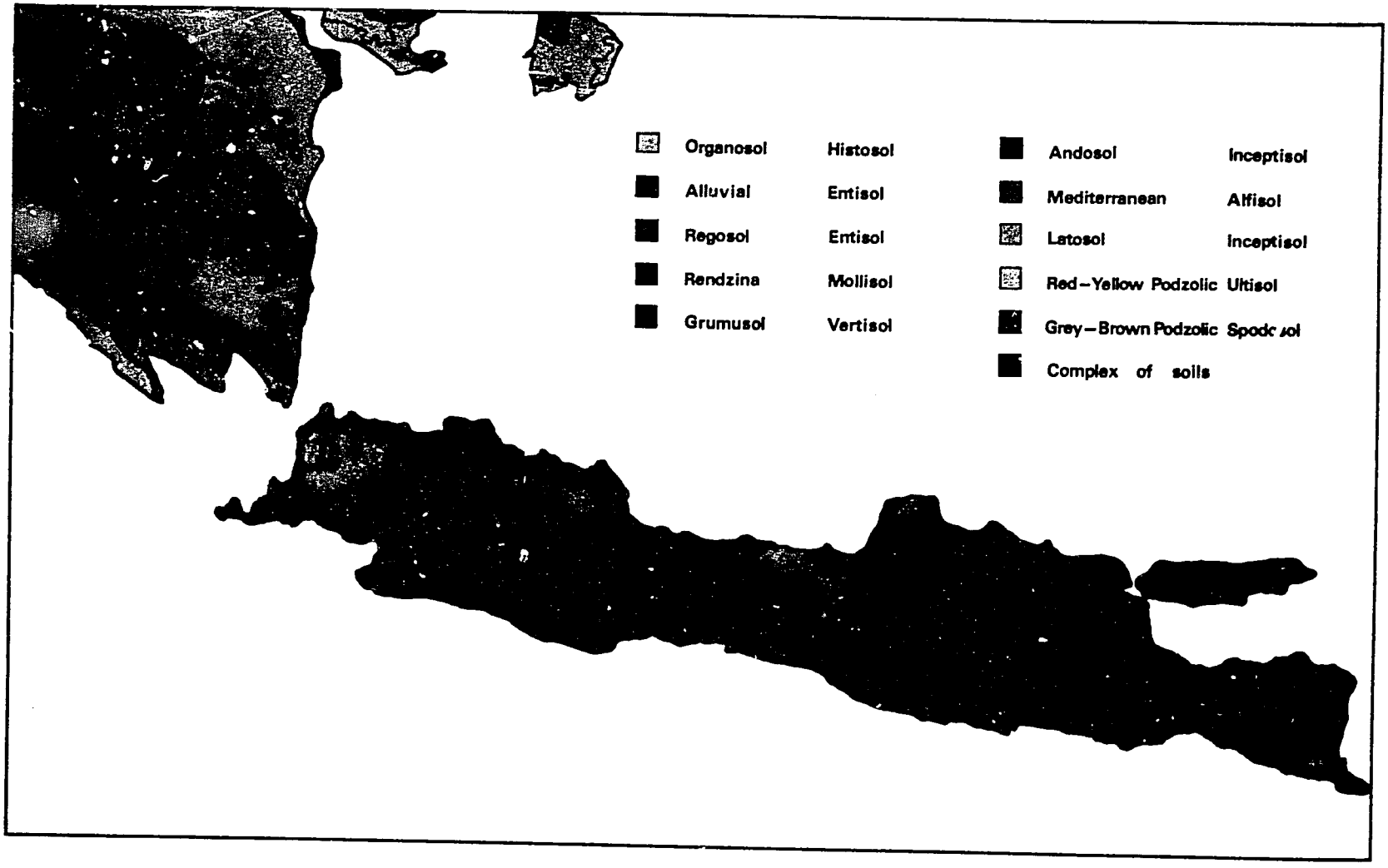

Figure 3. Distribution of soils in the main cassava growing areas of Indonesia.

Source : Adapted from "Generalized Soil Map of Indonesia". Soil Research Institute, 1976, by R. Howeler.

the whole year (Wargiono, 1979). They generally use conventional tillage, either by hand or with bullocks. Land cultivation with tractor is recommended for large areas or plantations, since it can reduce costs around 50% compared to traditional tillage (Wargiono, 1984). Minimum tillage is better in terms of reduced operational cost and better soil conservation. It was found (Wargiono and Pane, 1984) that this method, combined with herbicide application, increased cassava yields. At the same time, it reduced soil losses due to erosion by 16 t/ha/year, compared with complete or conventional tillage (Bangun *et. al.*, 1986). Soil tillage should be done at a depth of around 15 to 25 cm, since deeper cultivation resulted in no increase in yield of cassava (Wargiono, 1984).

2. Cropping systems : Some factors that influence the choice of cropping systems of cassava are the size of land holdings, soil and climatic conditions, marketing constraints, prices, and farmers' traditions.

Monocropping is commonly used in plantation areas on the outer islands and near starch factories. One thing that need more research attention is the problem of soil erosion during the initial period of plant growth, when the leaf canopy has not yet completely covered the soil surface. Mulching, minimum tillage and chemical weed control may be used to overcome this proble.... Selection of fast growing cassava cultivars, adequate fertilizer application, and increased plant populations are considered as alternatives for solving this problem (Wargiono and Bangun, 1986).

Intercropping of cassava with upland rice and/or corn and legumes is commonly done by farmers with small areas of less than 2 ha, because it provides a higher income than monocropping (Basa *et. al.*, 1984; Hidayat *et. al.*, 1984, Pandang *et. al.*, 1986). The ratio between the maincrop and the intercrop depends on the soil conditions and the value of each crop. If cassava is treated as the main crop, it will be planted at high population (8,000-10,000 plants/ha), while the others are additional crops. The cassava population will be increased if the cassava price is higher and *vice versa.*

In an intercropping trial the cassava spacing in the cropping system varied from 1.5 to 4.0 m between rows and 0.5 to 1.0 m within the row, while the plant spacing of the companion crop was maintained near optimum. It was found that the earlier the intercropped plants matured, the lower the intercrop competition. Thus, cassava yields were reduced less when cassava was intercropped with mungbean as compared with either soybean or peanut (Wargiono, 1987). Intercropping cassava with mungbean yielded 1.23 t/ha of mungbean in 70 days, and decreased cassava yields only 36%. This means that farmers' income can be increased, because after the mungbean crop is harvested there is the posibility of growing 1 to 2 other crops. Intercropping of cassava with corn and upland rice followed by soybean and/or peanut, followed by cowpea and/or rice bean resulted in a relatively high net return (Table 5). It should be noted that the intercrops produce large amounts of residues, which, when returned to the soil as mulch, will improve crop production and soil productivity (Wargiono and Tuherkih, 1987). Approximately 60% of the total area of cassava is planted in various intercropping systems, so that cropping systems research is necessary and of vital importance for increasing farmers' income and maintaining soil productivity.

Table 5. Production cost, product value, and net return (000 RP/ha/year) of various cassava intercropping systems in different parts of Indonesia.

Cropping pattern	Java			Sumatra			Kalimantan			Sulawesi		
	Pc	Gr	Nr	Pc	Gr	Nr	Pc	Gr	Nr	Pc	Gr	Nr
Farmers	296	1,016	721	205	259	53	156	254	78	154	270	116
Cassava + corn + soybean	333	1,150	817	420	850	441	–	–	–	441	804	363
Cassava + corn + upland rice – soybean/ peanut + cowpea	444	840	396	393	713	321	265	553	293	425	794	369

Pc = production cost; Gr = gross return; Nr = net return.

Source : Hidayat *et.al.*, 1984; Pandang *et.al.*, 1986; and Pasaribu *et.al.*, 1986.

3. Planting time : If rainfall is distributed uniformly during the year, the planting time of cassava does not depend on the season, and the growth of cassava will not be affected by water stress. However, planting of cassava is generally done either at the beginning or at the end of the wet season, in order to obtain better crop growing conditions and avoid water stress. But there appears to be potential for planting cassava also during the dry season of May, June and July, as long as there is sufficient water during the growing period of the crop or the crop is planted in areas of A, B and C agroclimatic zones (Table 6). However, there are some cassava cultivars that are not suitable for harvesting in the wet season, because of their susceptibility to root rots (Wargiono, 1987c). Consequently, management of market price should be improved to allow for planting of cassava year-round.

Table 6. Effect of time of planting and harvest on yield of cassava in Bandaraya, Lampung, Sumatra.

Planting date	Harvest age (months)						
	6	7	8	9	10	11	12
	t/ha						
February	4.8	20.8	35.2	38.4	43.2	25.6	41.6
March	16.0	24.0	24.0	43.2	27.2	28.8	36.8
April	25.6	27.2	40.0	38.4	33.6	40.0	46.4
May	16.0	27.2	27.2	33.6	30.4	30.4	–
June	24.0	22.4	22.4	36.8	30.4	–	–
July	17.6	20.8	25.6	35.2	–	–	–
August	14.4	22.4	20.8	–		–	–

Note : Data are average of three varieties.

Source : Wargiono, 1984.

4. Plant spacing : Some factors that affect optimum plant spacing are variety, soil fertility, cropping systems and farmers traditions (Wargiono, 1983). Farmers are more interested in non-branching cultivars, because they can be more easily managed, both for monocrop

and intercropping. A square plant pattern is commonly used by farmers growing cassava in monoculture, in which plant populations are between 10,000 and 12,000 plants/ha. Figure 4 shows that on fertile soil, populations of more than 10,000 plants/ha decreased yields for both branching and non-branching cultivars. In an unfertile soil, however, yields of the non-branching cultivars increased by increasing plant population to 15,000 to 20,000 plants/ha. Table 7 shows the effect of planting arrangement on cassava yield. Varying the space between

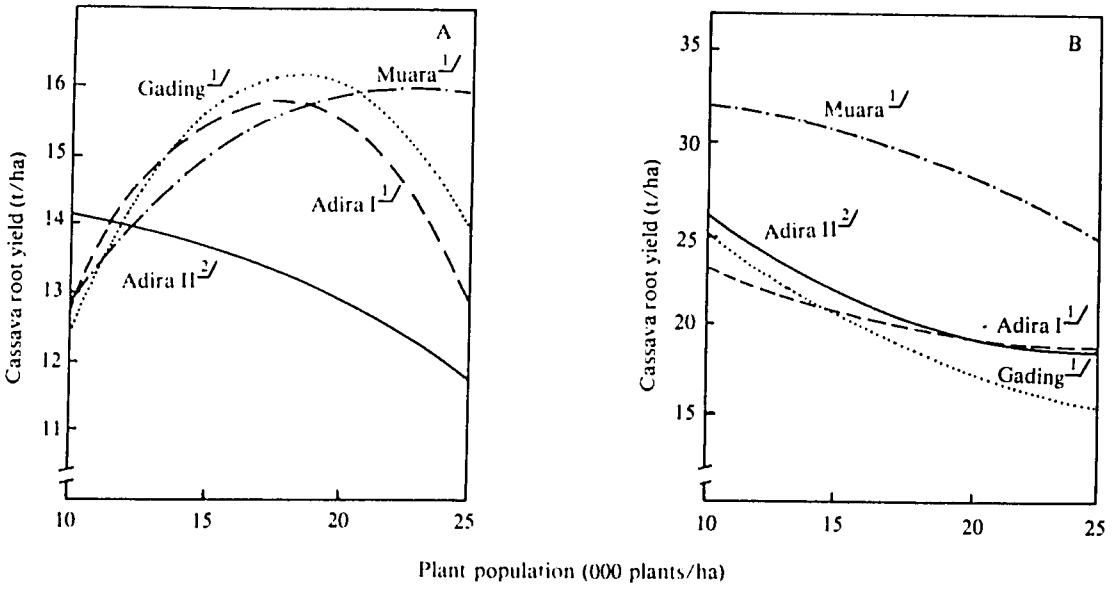

Figure 4. Effect of plant population on the yield of four cassava cultivars grown in (A) low fertility soils of Playen and Jakenan substations, or (B) high fertility soils of Muara and Tamanbogo substations. 1/ non-branching, and 2 branching variety.

Source : Wargiono, 1983.

Table 7. Yield of cassava at different plant spacing, at Bandar jaya, Lampung, Sumatra. Data are average of 3 cultivars (Adira 1, M-30 and M-31).

Plant spacing (cm)	Plant population (000 plants/ha)	Fresh root yield (t/ha)
400 × 50	5.0	15.7
300 × 50	6.7	16.3
200 × 50	10.0	26.0
400 × 75	3.3	11.9
300 × 75	4.5	15.7
200 × 75	6.7	20.4
400 × 100	2.5	8.9
300 × 100	3.3	11.5
200 × 100	5.0	14.6
100 × 100	10.0	16.2

Source : Wargiono, 1984.

rows had a greater affect on yield than the spacing within the row or plant population. The spacing of 50 cm in the row resulted in higher yields as well as in better root shape and size. The spacing of plants in a particular cropping system is an important yield-determining factor and depends on the varietal response to light intensity. The east-west direction of rows minimizes shading during the growth period.

5. Weed control : Cassava plants, growing slowly for the first 3-months, are generally not very competitive with fast growing weeds. Weeding 2-3 times (until the cassava canopy is completely closed) is the only way to minimize the competition between cassava and weeds. Weed control can be done either chemically, by cultivation, or by hand weeding, or their combinations (Wargiono and Pane, 1984; Wargiono, 1986). There are some herbicides, which, by their selectivity, can change the composition of the weed population. Application of the herbicides glyphosate and Gesapax were effective in an area dominated by cogon grass *(Imperata cylindrica)* (Wargiono and Pane, 1984, Wargiono and Bangun, 1986) and slightly increased the production of cassava (Table 8). It was shown that either lodging or residues of cogon grass are capable of stimulating the production of seeds which germinate and invade the area. Chemical weed control may be effective if it is backed up by specific information on both the herbicides and the weeds.

Fast growing cassava cultivars such as M-31 or W 1435/1166, planted in optimum spacing, are able to suppress the growth of weeds that are susceptible to shading (Table 9).

Table 8. Effect of weed control on the yield of cassava at Tamanbogo, Lampung, Sumatra.

Treatment	Fresh root yield (t/ha)
No weeding	6.0
Hand weeding : 30, 60, 90 DAP*	25.3
Gesapax 80 WP : 1.5 kg/ha, 1 DAP	9.3
Laso 4 l/ha : 4 DAP	6.4

*DAP = days after planting.

Source : Wargiono and Bangun, 1986.

Table 9. Effect of the growth of various cassava cultivars on weeds at Tamanbogo, Lampung, Sumatra.

Species of weeds	Cassava clones					
	Adira 1	M-30	M-31	W 1435/1166	W 1745	Local
	g/m^2 dry weight of weeds					
I. cylindrica	137	146	87	79	121	105
Cyperus sp	2	2	7	8	8	13
B. latifolia	4	3	8	6	4	6
C. hirtus	1	1	1	10	4	2
S. nodiflora	7	10	8	10	12	18
S. anthelmia	8	11	17	10	10	10

Source : Wargiono and Bangun, 1986.

Improvement of these clones through a breeding program can help farmers with low income to develop cassava in these areas.

6. Fertilization : As indicated earlier, cassava is very efficient in the uptake of soil nutrients. If there is no additional fertilizer applied to the soil, the continuous production of food crops will lead to a decrease in soil fertility after land clearing (Table 10).

Table 10. Effect of continuous cropping of food crops without fertilizer application on soil chemical characteristics in Bandarjaya, Lampung, Sumatra.

	Years after land clearing			
	Newly opened	1	3	4
pH (KCl)	4.4	4.6	4.2	4.1
Exch. Ca (me/100 g)	3.1	1.6	1.5	1.3
Exch. Mg (me/100 g)	1.1	0.8	0.9	0.4
Exch. K (me/100 g)	0.5	0.5	0.5	0.3
CEC (me/100 g)	10.1	12.2	9.2	10.8
Base sat. (%)	25	25	26	19
Org. C (%)	4.37	2.92	2.23	2.80
Org. N (%)	0.31	0.10	0.18	0.21
C/N ratio	14	15	12	13
P (Bray I) (ppm)	32.1	11.5	8.9	13.3

Source : Suryatna, *et al.*, 1986.

Fertilization at a level at least equal to the amounts of nutrients extracted by the cassava crop should be applied regularly to permit a sustainable production of the crop (Wargiono, 1986; Wargiono, 1987). Fertilizer experiments in Gunung Kidul and Wonogiri in low fertility soils in Central Java, and in Lampung, S. Sumatra, increased the yield from 60 to 260% compared to the control treatments (Wargiono, 1987a, 1987e; Wargiono *et. al.*, 1987). Figure 5 shows that in Java the yield of cassava tended to decrease with each successive crop, but stayed nearly constant in the newly opened area of Lampung after 5 continuous cassava crops. In both Latosol soils in Java there was a significant response mainly to N; in Gunung Kidul there was also a marked response to K, while in the Red Yellow Podzolic soil of Sumatra there was a response only to P.

The total uptake of N, P and K by the cassava crop, with and without fertilization, is shown in Table 11. The average nutrient uptake by the unfertilized crop was about 37 kg N, 11 kg P, and 72 kg K, while for the fertilized crop it was 72 kg N, 28 kg P and 139 kg K/ha. Thus, in both cases the crop extracted large amounts of K from the soil. Figure 6 shows that the annual application of 120 kg N, 60 kg P_2O_5 and 100 kg K_2O/ha could prevent a yield decline in the second crop in Gunung Kidul and Wonogiri, but was probably insufficient to sustain high yields in the third crop.

The efficiency of fertilizer application can be improved by using the right time of application, i.e., P + 1/3 NK as a basal fertilizer application and 2/3 NK at 2-3 months

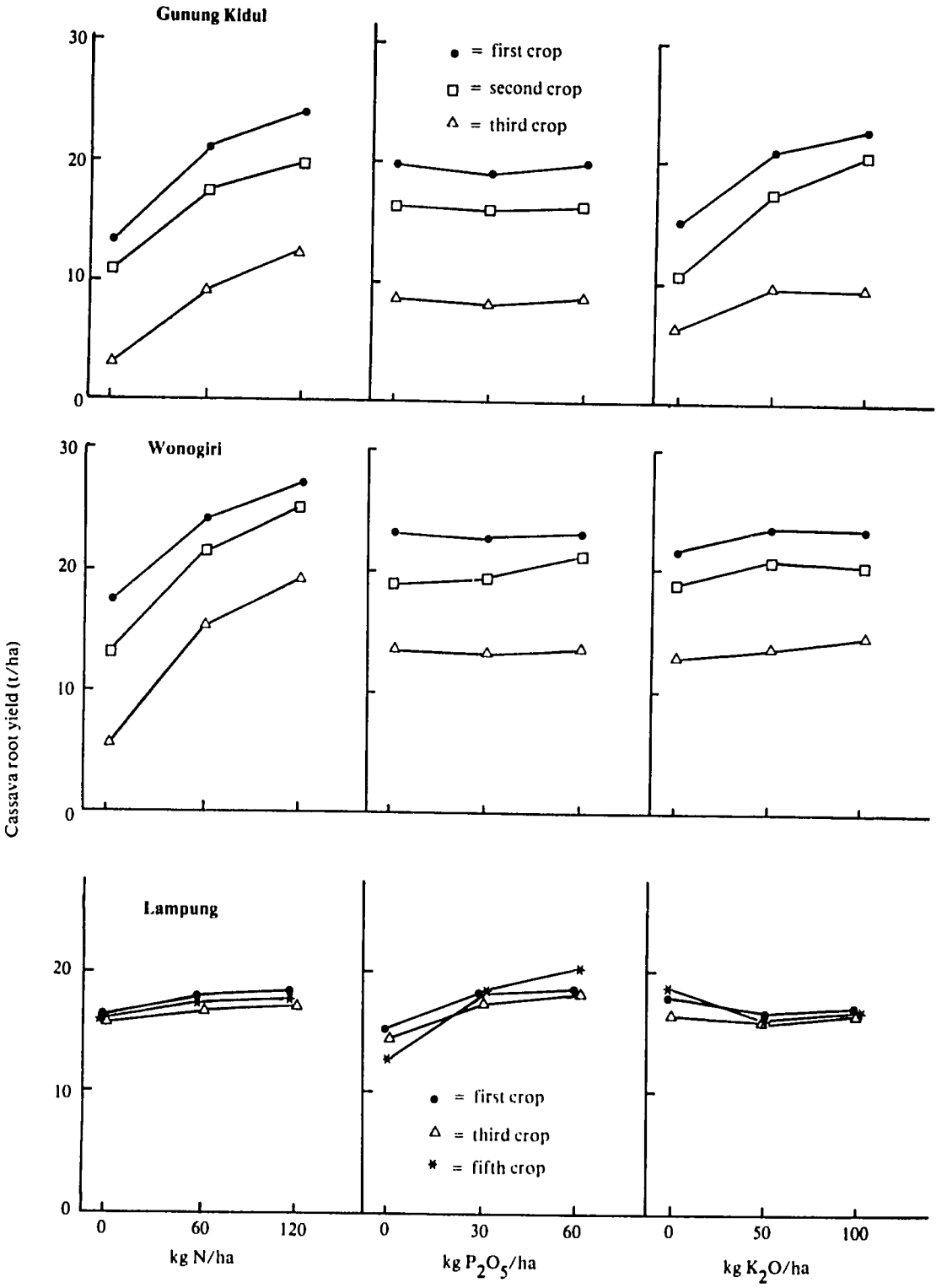

Figure 5. Response of several consecutive cassava crops to annual applications of various levels of N, P, and K in Latosol soils of Gunung Kidul and Wonogiri in Central Java and in Red Yellow Podzolic soils in Lampung, Sumatra.

Source : Wargiono, 1986 and Wargiono, *et.al.*, 1987.

Table 11. Total amount of N, P, and K extracted by unfertilized and fertilized cassava grown in Latosol soils of Gunung Kidul and Wonogiri in Central Java and in Red Yellow Podzolic soil in Lampung, Sumatra.

		kg/ha			kg/t fresh roots		
		N	P	K	N	P	K
Gunung Kidul	- unfertilized	25.3	9.3	32.8	3.15	1.16	4.09
	fertilized*	78.5	30.7	101.1	4.68	1.77	6.25
Wonogiri	- unfertilized	31.0	9.9	91.7	2.91	0.93	8.62
	fertilized*	81.6	27.4	200.8	3.98	1.34	9.76
Lampung	- unfertilized	41.8	13.6	92.3	2.96	0.69	6.54
	- fertilized*	55.0	25.7	114.0	3.00	1.44	6.49

* Average of 26 fertilizer treatments.

Source : Wargiono *et.al.*, 1987; Wargiono, 1987e.

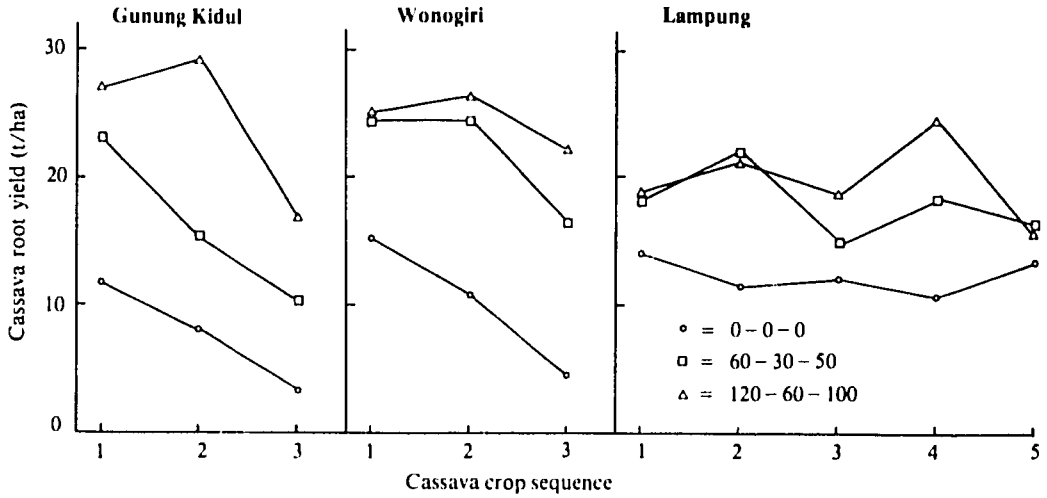

Figure 6. Root yield response of three consecutive cassava crops grown on Latosol soil in Gunung Kidul and Wonogiri in Central Java, and of five consecutive crops grown on Red Yellow Podzolic soil in Lampung, Sumatra, to annual application of three levels of $N-P_2O_5-K_2O$ in kg/ha.

after planting (Table 12). Organic fertilizer can improve both the physical and chemical properties of the soil and should be included in the program of intensification combined with inorganic fertilizer.

Table 12. Effect of time of N and K application on cassava yield in various locations in Java.

Location	Time of second NK application[1]			
	1	2	3	4
	months after planting			
	t/ha fresh root			
Citayam (W. Java)	23.89**	23.98**	26.71[2]	22.10**
Wonogiri (C. Java)	22.93**	24.67[2]	22.59**	22.88**
Muneng (E. Java)	22.95*	23.43	23.73[2]	20.83**
Genteng (E. Java)	37.39**	39.70[2]	35.44**	34.86**
Average	26.79	27.94	27.12	25.17

1/ 1/3 of N and K as well as all P applied at planting.

2/ Highest yield

* Significantly different from highest yield at LSD = 0.05

** Significantly different from highest yield at LSD = 0.01

Source : Wargiono, 1987a.

Summary

1. The harvested area of cassava in Indonesia decreased at the rate of about 0.7% per year; on the other hand, the production increased at 2.2% yearly due to a steady increase in yield.

2. Cassava growing areas are generally located in agroclimatic zones B, C, D, and E and the soils are classified as Mediteran, Alluvial, Podzolic, Latosol or Regosol in Java, and outside of Java mostly as Red Yellow Podzolic soils.

3. Soil erosion is an important cause of soil degradation for cassava growing areas. Soil losses can be reduced by using soil conservation practices such as minimum tillage, terraces, mulching, multiple cropping and application of herbicides. These soil conservation practices should be studied in more detail to make them applicable to farmers.

4. Planting time is affected by rainfall patterns as well as the cropping and marketing system. Planting cassava at the beginning of the wet season is most common, but is also possible at the end of the wet season in agroclimatic zones B and C without affecting yields.

5. Plant spacing is affected by plant type, soil fertility and cropping system. A planting arrangement in rows tend to be better than a square pattern both for mono and intercropping.

6. Hand weeding is generally used to control weeds, but for soils susceptable to erosion a combination with minimum tillage is recommended. Chemical control is still expensive for the farmer, but it is able to control weeds and reduces erosion rather effectively.

7. Inorganic fertilizer application increased the cassava yield and nutrient status in the plant. A combination of chemical fertilizer with organic manures is necessary to stabilize the yield of continuously grown cassava and maintain the soil fertility. To increase fertilizer

efficiency all P and 1/3 of NK dosage should be applied at planting time, with a second application of 2/3 NK fertilizer at 2 to 3 months after planting.

8. A cropping system that is capable of increasing production and profit for the farmer while maintaining soil productivity should be developed.

9. The research priorities are: 1) onfarm testing of integrated management practices; 2) component technologies, i.e., variety, fertilization, intercropping, plant spacing; and 3) soil conservation.

10. The areas of highest priority are the Red Yellow Podzolic soils, mountainous areas and other marginal regions that need specific technologies.

11. A cooperative research network is needed to develop the integrated technology packages, including financial assistance to enable the execution of the research.

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CASSAVA AGRONOMIC PRACTICES AND RESEARCH IN EAST JAVA, INDONESIA

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Introduction

Cassava in Indonesia is used principally as human food (58%), but also as industrial raw material (28%), as export commodity in the form of dried cassava chips (8%), and for animal feed (2%), while 4% is lost or wasted (CGPRT, 1984).

Cassava is grown in 26 provinces in Indonesia with much variation in area and production (Figure 1, Table 1). Figure 2 shows the distribution of cassava growing areas in Indonesia. The total area under cassava in Indonesia during 1984 was 1.35 million ha with a production of 14.2 million tons. Most of the cassava production in Indonesia is concentrated on the island of Java (including Madura), which account for 67% of the cassava acreage as well as production. Figure 3 shows that cassava is produced throughout Java, but that it is an especially important crop in south central Java as well as in central and eastern Madura. The province of East Java produces 3.7 million tons in an area of 0.36 million ha. In other words, East Java produces 39% of the cassava produced in Java and 26% of that produced in Indonesia. The average cassava yield in Indonesia, however, is relatively low, i.e. about 10.5 t/ha, whereas experimental yields at Bogor Agricultural Research Institute for Food Crops (BORIF) and Brawijaya University in Malang, Indonesia, range from 20 to 40 t/ha.

Soil and Climatic Characteristics in East Java

Soils :

The total land area of East Java is about 4.8 million ha, of which 3.0 million ha are used for food crop production. From this area, about 2.0 million ha is fully rainfed agricultural land consisting of about 0.8 million ha rainfed sawah (lowland) and 1.2 million ha rainfed tegalan (upland). Cassava is mostly grown on rainfed tegalan, although in some districts such as Kediri a very limited amount of cassava is also found in rainfed sawah.

Soils of East Java are dominated by an east-west running chain of volcanoes. The relief varies from flat coastal alluviums via undulating hills to steep mountains. The distribution of soils in East java is presented in Figure 4 and the schematic geographical distribution is in Figure 5 (adapted from Stroosnijder *et.al.*, 1986).

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Table 1. Cassava production, yield and area harvested in 26 provinces of Indonesia, during 1984.

Province	Production 000 t	Yield t/ha	Area 000 ha
1. Aceh	70	10.8	6.5
2. North Sumatra	256	11.7	21.9
3. West Sumatra	83	12.4	6.7
4. Riau	79	11.5	6.8
5. Jambi	27	11.3	2.4
6. South Sumatra	312	11.0	28.4
7. Bengula	33	10.2	3.3
8. Lampung	1,298	11.0	118.0
SUMATRA	2,160	11.1	194.1
9. DKI Jakarta	2	10.1	0.2
10. West Java	2,082	10.8	192.8
11. Central Java	3,134	10.5	299.8
12. DI Yogyakarta	604	10.5	57.5
13. East Java	3,715	10.4	358.4
JAVA	9,538	10.5	908.3
14. Bali	233	11.6	20.1
15. West Nusa Tenggara	138	9.9	14.0
16. East Nusa Tenggara	870	9.8	88.7
BALI and NUSA TENGGARA	1,241	10.1	122.8
17. West Kalimantan	135	10.3	13.1
18. Central Kalimantan	71	9.8	7.2
19. South Kalimantan	89	9.4	9.5
20. East Kalimantan	63	9.8	6.4
KALIMANTAN	358	9.9	36.2
21. North Sulawesi	98	9.0	10.8
22. Central Sulawesi	65	9.4	6.9
23. South Sulawesi	302	10.6	28.5
24. South-east Sulawesi	286	9.8	29.2
SULAWESI	751	10.0	75.5
25. Maluku	47	9.0	5.2
26. Irian Jaya	71	8.7	8.2
MALUKU and IRJA	118	8.8	13.4
INDONESIA	14,167	10.5	1,350.4

Source : Biro Pusat Statistik - Jakarta. 1985.

1. Aceh
2. North Sumatra
3. West Sumatra
4. Riau
5. Jambi
6. South Sumatra
7. Bengula
8. Lampung
9. DKI Jakarta
10. West Java
11. Central Java
12. KI Yogyakarta
13. East Java
14. Bali
15. West Nusa Tenggara
16. East Nusa Tenggara
17. West Kalimantan
18. Central Kalimantan
19. South Kalimantan
20. East Kalimantan
21. North Sulawesi
22. Central Sulawesi
23. South Sulawesi
24. South-east Sulawesi
25. Maluku
26. Irian Jaya

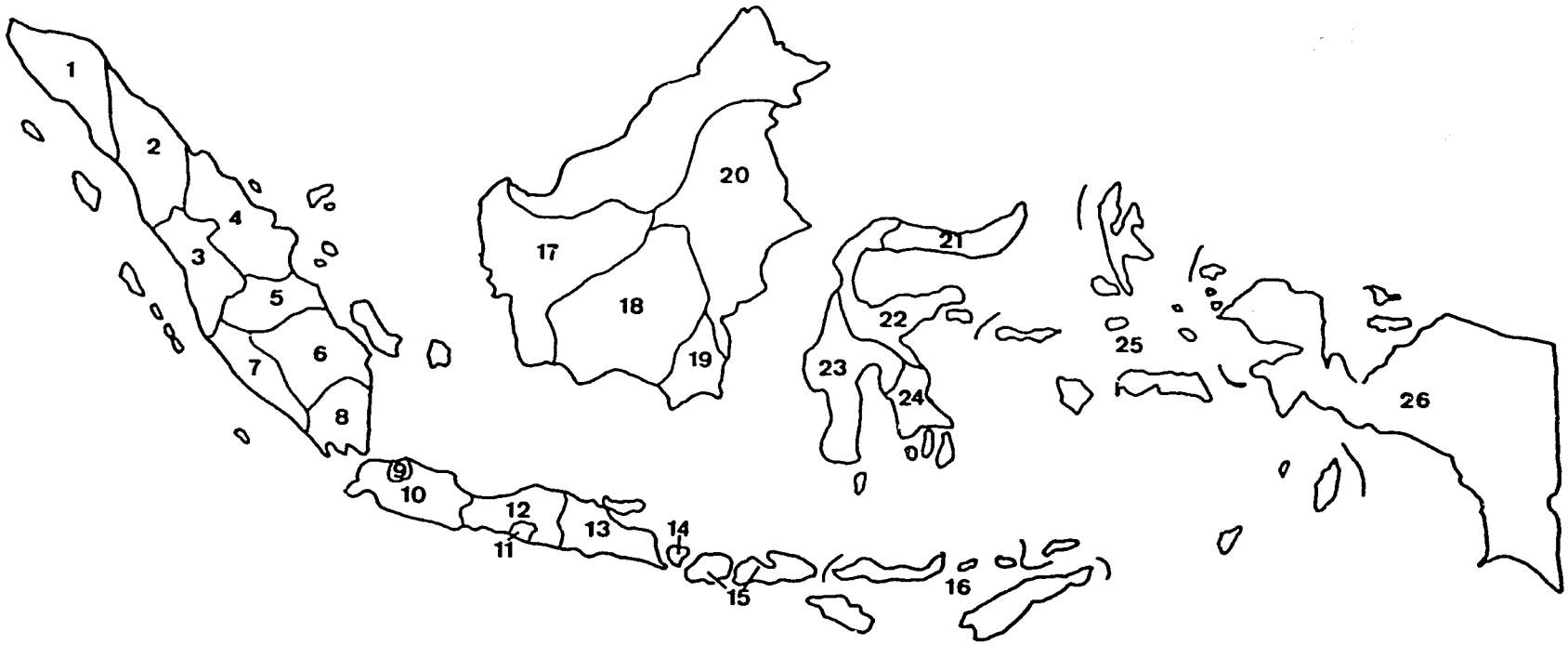


Figure 1. Provinces of Indonesia.

Figure 2. Cassava production zones of Indonesia. Each dot represent 10.000 ha of cassava harvested in 1984.

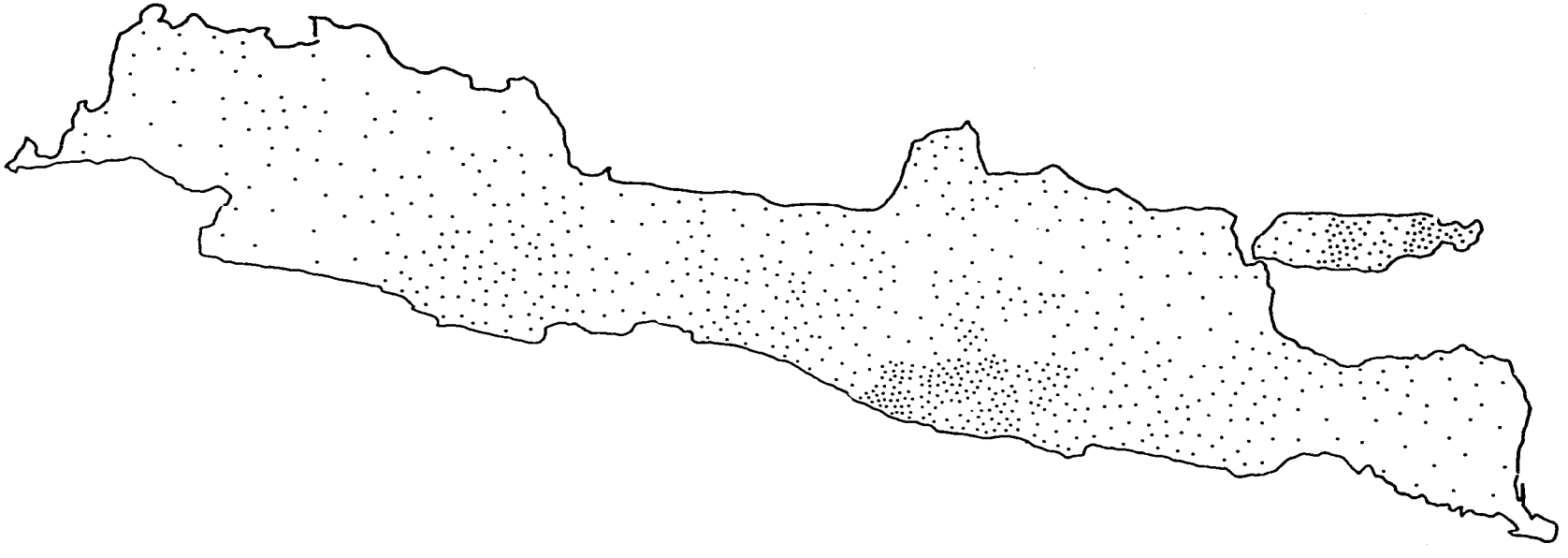


Figure 3. Cassava production zones in Java. Each dot represent 1000 ha of cassava harvested in 1985.

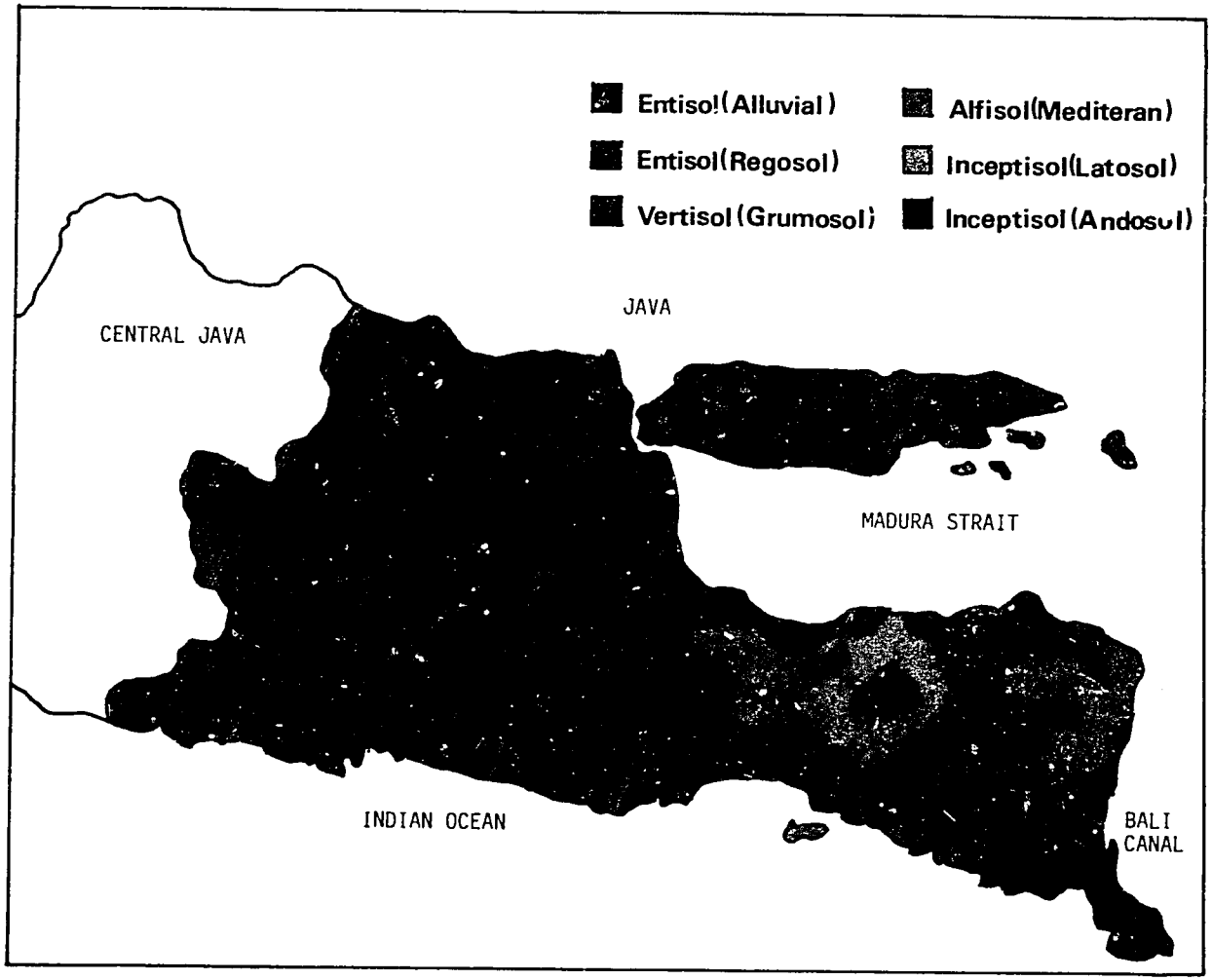
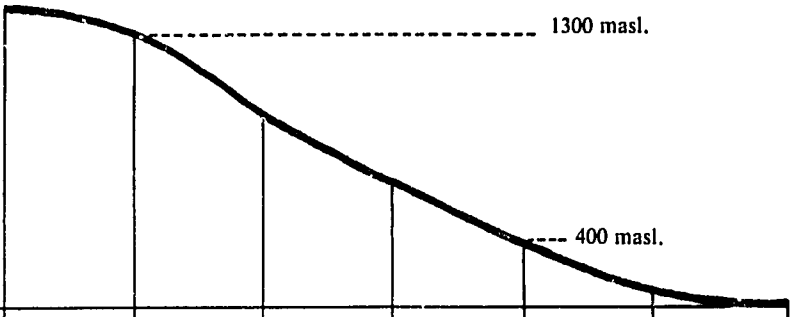


Figure 4. Distribution of principal soils in E. Java.

Source : Adapted from CRS, 1978.



Soil type : (US Taxonomy) (Other names) % of land Domiant land use	Inceptisol Andosol 7 forest, horticulture	Inceptisol Latosol 13 palawija-based cropping horticulture	Entisol Regosol 20 forest and palawija-based cropping	Alfisol Mediteran 29 palawija-based cropping systems	Vertisol Grumosol 10 rice-based cropping systems	Entisol Alluvial 21 rice based cropping systems

Figure 5. Schematic geographical distribution of major soils and land use in East Java. Soil types according to FAO/UNESCO (1977) Soil Research Institute (1978) and USAID/SCS (1975).

Six main soil types exist in East Java, i.e. Alfisols (Mediteran), Entisols (Alluvial), Vertisols (Grumusol), Inceptisols (Latosol) and Inceptisols (Andosol). Alluvial and Grumusol soils are mostly used for rice-based cropping systems and Andosols are used for forestry and horticulture. The three remaining soil types, which make up over 60% of East Java, are used for upland agriculture. About 30% of this land (mainly the Alfisols) is too shallow (lithic contact) or too coarse (Regosol) for agricultural production.

The general characteristics of the main upland soil types in Java are as follows :

Inceptisol (Latosol) :

These soils are often called "laterite" soils and are geographically situated between Andosols and Mediteran soils. Latosols have good physical properties, are deep and tolerant to erosion. The soil fertility, however, is low, and their response to N and P fertilization is good. Sometimes they are deficient in K and in micro-nutrients such as B, Zn, and Cu. They are suitable for the cultivation of upland rice and palawija crops, and also for industrial (a.o. tobacco) and fruit crops. Under conditions of limited water availability forestry dominates.

Entisol (Regosol) :

The Regosols are found in undulating hilly areas and middle slopy areas of mountains. They commonly have a light soil texture (sandy) and high permeability. Due to their low water holding capacity, these soils oftentimes are affected by severe drought during the dry season. Moreover, they have a low agricultural potential due to a low organic matter content and low availability of P and K; they are also susceptible to erosion. Regosols are not suitable for lowland rice cropping and are only marginally suitable for upland rice and palawija crops,

except those developed from volcanic ash. Often the post-rainy season crop can be risky and these soils are therefore often used for forestry or left unused as waste land.

Alfisol (Mediteran) :

These soils on the foot of the mountains and in the rolling hilly areas are geographically situated between the alluvial Entisols and the Latosols and are derived from limestone material. They are medium in texture (sandy loam), susceptible to erosion, have a medium soil fertility and are used for dry land farming. Under supplementary irrigation, one rice crop followed by one or two palawija crops can be grown; without irrigation, rice-palawija or palawija-rice cropping patterns are possible. Due to the low water storage capacity these soils are also used for forestry or left unused as waste land.

Shallow soils with lithic contact :

These soil complexes occur in hilly areas generally below 1,300 meters. The agricultural potential is very low due to a shallow effective soil depth of sometimes only 0.2 m and to topographical limitations. The water storage capacity is low. Consequently these soils are mainly used as forest land or left uncultivated. Some of these soils are developed *in situ* on limestone and have a fine texture (loamy) and heavy subsoils. Chemically these soils are dominated by calcium and magnesium. Year-round cassava cropping, often in a mixture with other palawija crops, may cause severe erosion. Major constraints are drainage, surface run-off and erosion, nutrient deficiency, limited root zone, and drought during the dry season. Agriculture is only possible when proper soil-water conservation measures are applied.

Climate :

On the basis of the rainfall data, there are four types of agroclimate in East Java, i.e. B, C, D and E (Oldeman system) as shown in Figure 6. In the major food crop producing areas in East Java, the dominant agroclimatic types are C and D, which cover an area of 2.3 million ha and 1.0 million ha, respectively. They are characterized by 3-6 wet months (>200 mm rainfall) and 2-6 consecutive dry months (< 100 mm rainfall).

The lowland in East Java is characterized by its small range of temperatures, both diurnally and annually. The range of temperature is not limiting for growing suitable food crops. The mean monthly maximum and minimum temperatures, collected from three meteorological stations: one in D (Surabaya, 1973-1977 means), one in C (Jember, 1974-1979 means) and one in C (Tulungagung, 1971-1979 means), ranged from 29.5° to 33.5°C and 19° to 28°C, respectively.

Cassava Growing Areas in East Java

About 95% of cassava is grown in rainfed areas (tegalan). On densely populated Java, cassava is generally intercropped with maize and legume crops, rather than planted in pure stands. In East Java, where rainfall is less abundant, cassava is commonly intercropped only with one maize or legume crop. Where market channels are well developed and micro climate permits, cassava is often interplanted with high-value vegetable crops. Almost 75 percent of Java's cassava is planted during the early wet-season months of October to January, and about 70 percent is harvested during the five months from June to October (Figure 7).

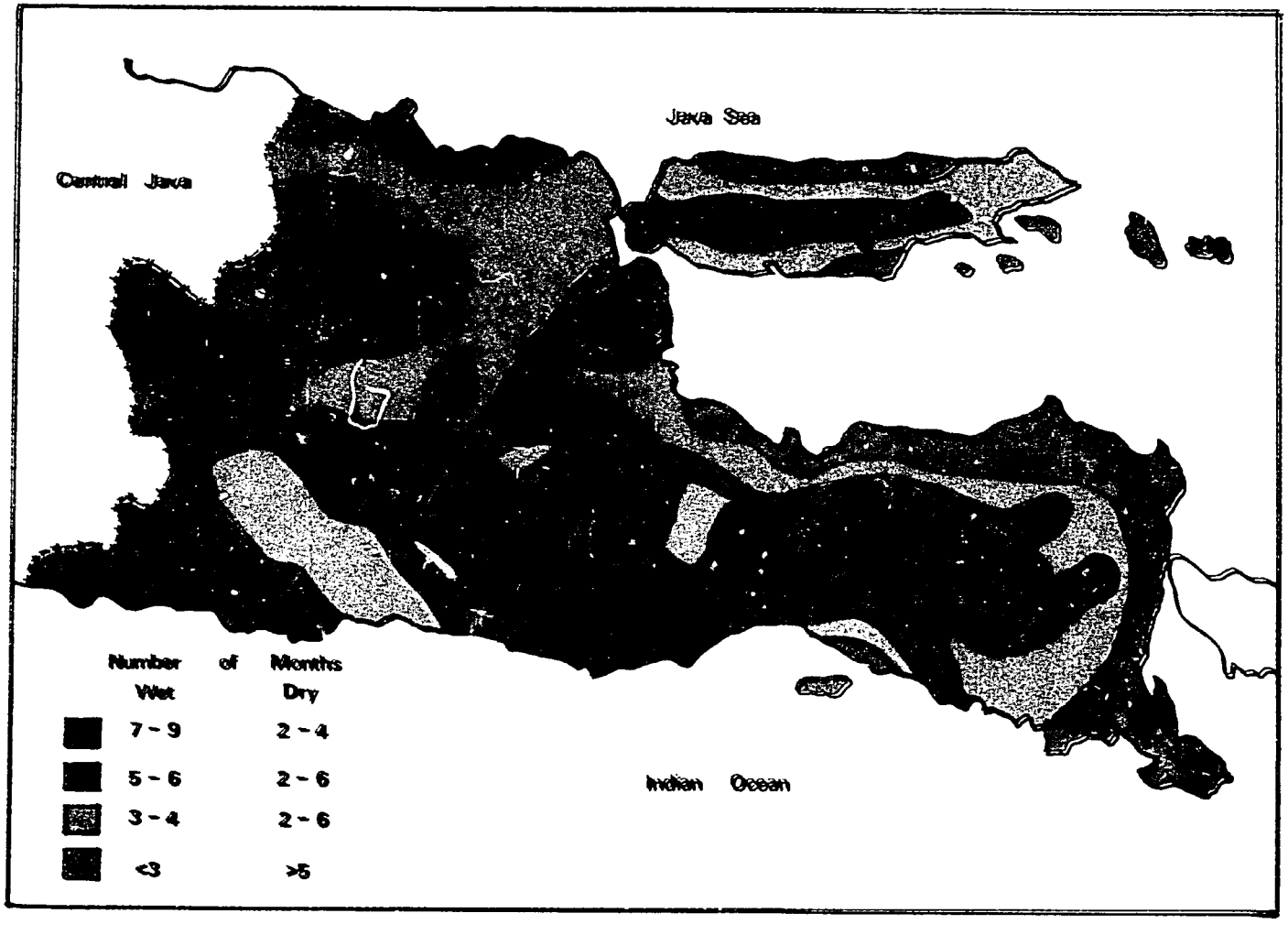


Figure 6. Agroclimatic map of East Java, based on the number of "wet" and "dry" months.
Source : Adapted from Oldeman, 1975.

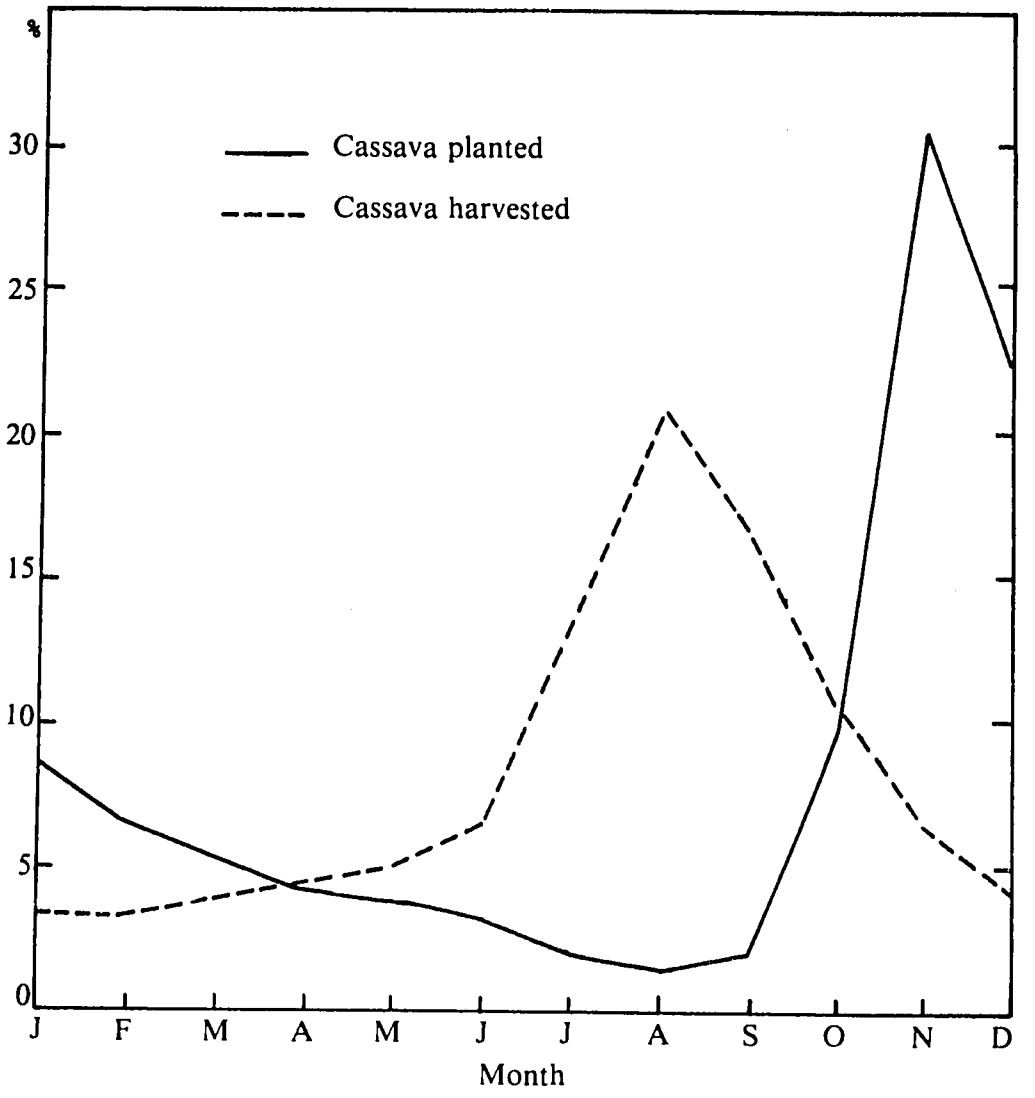


Figure 7. Percent of cassava planted and harvested by month for an average year, Java and Madura (Roche, 1984)

Figure 8 shows the distribution of cassava growing areas in East Java. Total production, yield and area harvested in 1985 are shown in Figure 9 and Table 2. The overall mean yield was about 11.1 t/ha. Differences between the areas of higher and lower yield are caused by size and location of the planting, the cropping system and the cultivar chosen and by varied cultural practices, such as land preparation, fertilization, weeding, and pest management.

Cassava can be cultivated under various climatic and soil conditions. However, both factors have a great effect on yield. The contributions of climate and soil type in determining yield of cassava are shown in Table 3. Usually cassava is cultivated on rainfed land, planted at the start of the wet season; total precipitation and rainfall distribution between the wet and dry season are very important. A higher yield is obtained in an area with higher precipitation. Effects of soil type are uncertain, but Alluvial and Regosol soils are more productive than Grumusol and Mediteran/Lithosol soils. Different agricultural practices are thought to be the determining factor in cassava yield variation.

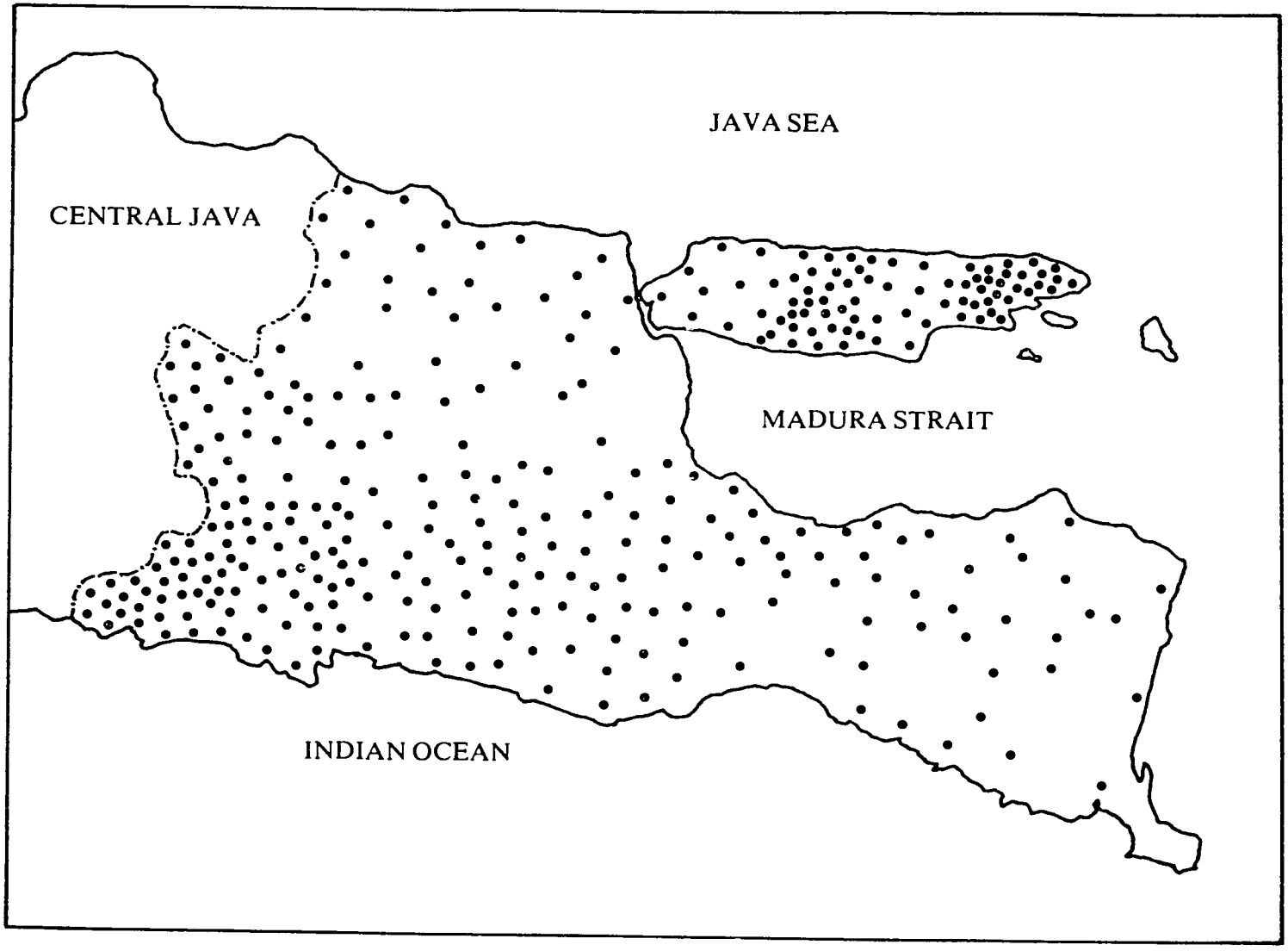


Figure 8. Cassava production in East Java. Each dot represent 1000 ha of cassava harvested in 1985.

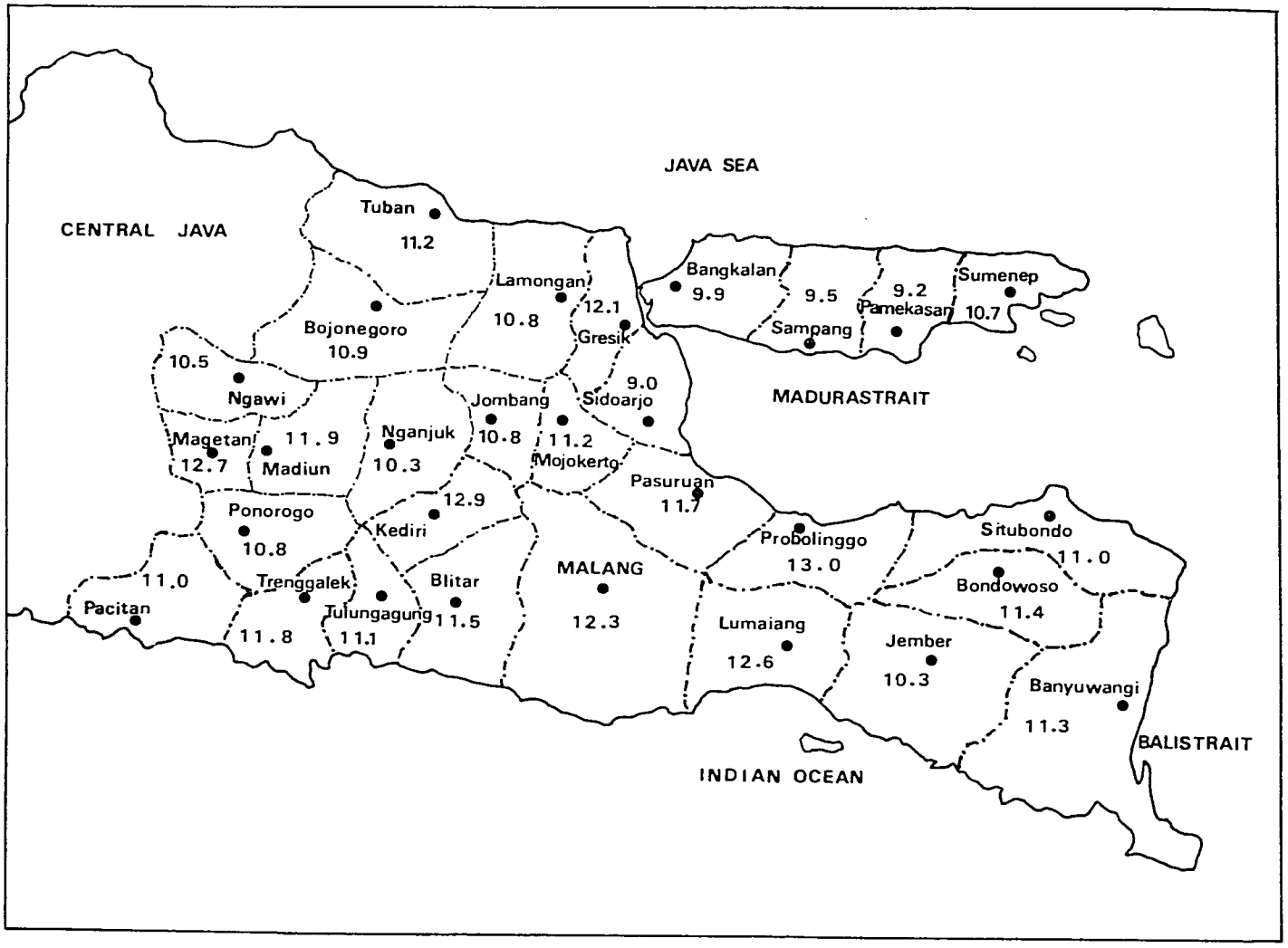


Figure 9. Average cassava yields (t/ha) in each district of East Java - 1985.

Table 2. Cassava production, yield and area harvested in East Java during 1985.

District	Production 000 t	Yield t/ha	Area 000 ha
Pacitan	365	11.0	33.1
Ponorogo	270	10.8	24.9
Trenggalek	165	11.8	14.1
Tulungagung	84	11.1	7.5
Blitar	188	11.5	16.4
Kediri	129	12.9	10.0
Malang	326	12.3	26.4
Lumajang	47	12.6	3.7
Jember	94	10.3	9.1
Banyuwangi	59	11.3	5.2
Bondowoso	96	11.4	8.4
Situbondo	45	11.0	4.1
Probolinggo	153	13.0	11.7
Pasuruan	137	11.7	11.7
Sidoarjo	3	9.0	0.3
Mojokerto	35	11.2	3.1
Jombang	21	10.8	2.0
Nganjuk	62	10.3	6.0
Madiun	90	11.9	7.6
Magetan	106	12.7	8.4
Ngawi	142	10.5	13.6
Bojonegoro	72	10.9	6.6
Tuban	121	11.2	10.9
Lamongan	61	10.8	5.6
Gresik	65	12.1	5.4
Bangkalan	98	9.9	9.9
Sampang	307	9.5	32.1
Pamekasan	105	9.2	11.4
Sumenep	302	10.7	28.2
	3,753	11.1	337.6

Source : Biro Pusat Statistik - Jakarta.

The methods of land preparation and follow-up cultivation are important factors for growing cassava in rainfed non-irrigated upland areas. For this the ridging system is favourable. The intensity of land preparation depends on the texture and compactness of the soil, and the following cultivation depends on weed conditions.

Time of cassava planting depends on the existing cropping system (Figure 10). In rainfed soils, cassava is planted early in the wet season, either in monoculture or intercropped with maize. In that case cassava extends over most of the year. Or it is planted mid-way through the wet season (Jan/Feb), as a second crop after maize or groundnut. The first pattern is usually used by farmers in the drier areas, whereas the second pattern is sometimes used by farmers in wetter areas where the rainfall in the wet season is adequate.

Table 3. Yield of cassava, climatic type, precipitation, and soil type in a number of regencies.

Regency	Cassava yield (t/ha)	Climatic type	Precipitation (mm)			Soil type
			Wet season	Dry season	Total	
Kediri	18.8	C	1580	477	2057	Re
Malang	15.5	C	1600	452	2052	Me, Al
Probolinggo	13.8	E	1578	378	1956	Al, Re
Mojokerto	10.5	D	1858	425	2283	Re, Al
Banyuwangi	11.8	D, E	1068	714	1782	Re, La
Jombang	12.8	D	1703	397	2100	Re, Al
Tulungagung	9.0	D, C	1241	471	1712	Me, Li
Bojonegoro	6.9	C	1514	522	1986	G
Bangkalan	6.8	D, C	1275	458	1733	Me

Re = Regosol
Me = Mediteran
Al = Alluvial
G = Grumusol
Li = Lithosol
La = Latosol

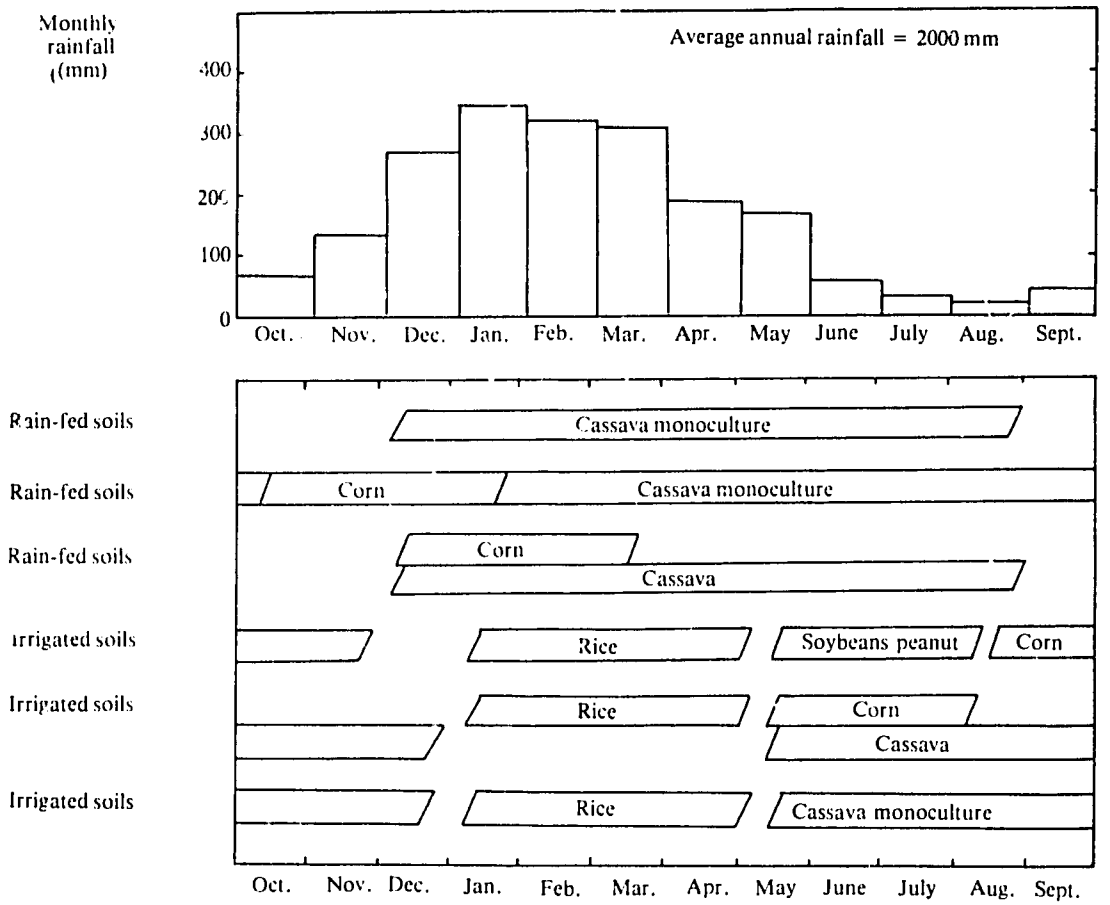


Figure 10. Rainfall distribution and cropping patterns in Kediri (Roche, 1984).

Apparently, a lower productivity of cassava is related to the local cultivar used and its planting at low density. Information is not yet available on the effect of variations in fertilizer application and land preparation at the farm level.

Improvements in existing cultural practices will increase cassava yields to levels approaching those of potential productivity (Table 4). The results of several trials in farmers' fields show such higher yields. The increase of production ranged from 80 to 150%. The production potential of cassava in East Java is far higher than current yields. It is evident that cassava cultivation can be improved by using the following recommended practices :

Table 4. Farmers and experimental yields of cassava in several locations of E. Java.

Regency	Actual yield t/ha	Exp. yield t/ha	Cultivar
Probolinggo	13.8	26.2 [1)] 35.0 [2)]	Gading
Malang	15.5	27.6 [1)] 31.3 [2)]	Adira 1
Tulungagung	9.0	21.6 [1)]	Faroka

1) Ordinary system

2) Mukibat system (grafting of a scion of **Manihot glaziovii** onto a stock of ordinary cassava (**M. esculenta**)).

(1) Cultivar : Faroka, Ndoro

(2) Planting system : ordinary method : at a spacing of 1.0 × 0.75 m
Mukibat : at a spacing of 1.0 × 1.0 m.

(3) Soil tiliage : ridging system

(4) Fertilization : ordinary method : 100 kg N + 50 kg P_2O_5 + 100 kg K_2O/ha
Mukibat : 200 kg N + 50 kg P_2O_5 + 150 kg K_2O/ha

(5) Harvest time : 10-12 months for ordinary cassava
12-15 months for Mukibat

(6) Time of planting : according to the cropping pattern

(7) Cropping system : monocropping or intercropping with peanut, maize, or soybean

In certain areas the problem of weed control needs to be given priority. In fact, weed competition can seriously reduce root yield.

Present Agronomy Research

Cassava research has relatively low priority compared to other secondary crops or rice. However, research activities on root crops have been increasing at BORIF, Malang Research Institute for Food Crops (MARIF) and Centre for the Root Crops Research, Brawijaya University with financial support from IDRC. Some of the results obtained by Brawijaya University during the last ten years are :

1. Mukibat cassava :

Mukibat cassava, i.e. the grafting of a shoot of ordinary cassava (*Manihot esculenta* Crantz) of 30-35 cm length with a scion shoot of *M. glaziovii* of 15-20 cm length, increased

cassava production by up to 50 to 200%, depending on the clones used and the location of the planting. The preparation of the graft combination is time-consuming, but such grafted stakes can be planted up to four times. Also, the usual planting practice by farmers of planting Mukibat cassava into planting holes of about 0.75 × 0.75 × 0.75 m, filled with organic matter, is not necessary. Such stakes can be planted on ridges just as ungrafted stakes.

Experiments have shown that for monoculture a plant density of 8,000 plants/ha is optimal. N fertilization up to a level of 100 kg N/ha increased the yield significantly. No significant response to P and K was obtained. High root yields were obtained after a growth period of 12 to 15 months. Mukibat cassava had a somewhat higher HCN content than ordinary cassava.

2. Stake quality :

The best stakes are those cut from the basal part of the stem, about 25 cm long, and with a diameter of 2.25-2.50 cm. However, in general, any stakes cut from the lower half of the stem give satisfactory results (Guritno, 1984).

3. Storage of planting material :

Stems to be used as planting material can be stored in the open field for up to 20 days without any significant effect on production. There is a tendency, however, for production to increase if the stems are stored for up to 5 days, while longer storage resulted in a yield decrease (Guritno *et.al.*, 1982).

4. Cassava-based cropping systems :

In the 1982-1986 period, Brawijaya University, with funds from the Canadian International Development Research Centre (IDRC) has conducted research on cassava-based cropping systems. Results of the studies indicated that the success of a cassava-based cropping systsm was dependent on plant population, planting arrangement, fertilizer application, kind and planting pattern of intercrops. With sufficient water available a second intercrop could be planted, increasing farmers net income (Tables 5 and 6) (Guritno and Utomo, 1987). As shown in Table 5, the net income of the farmers planting two successive intercrops was 92-110% higher than those planting only one intercrop. Usually the increase of income depends on the kind of crops to be planted as intercrops; for example, the price of peanut in Indonesia is higher than that of maize. The use of different fertilizer, land tillage and mulch could also produce different yields (Tables 7 and 8) (Utomo and Guritno, 1984; Guritno and Utomo, 1985).

Table 5. Yield of cassava, maize and peanut and farmer's income in various cropping systems.

Treatment	Yield(t/ha)					Gross income (000 Rp/ha)	Cost (000 Rp/ha)	Net income (000 Rp/ha)
	Cassava (fresh root)	Maize (grain seed)		Peanut (pods)				
		I	II	I	II			
C + M	32.0	2.56	–	–	–	850.4	496	354.4
C + P	32.0	–	–	1.33	–	941.4	524	417.4
C + M – M	28.1	3.23	0.86	–	–	1032.4	530	502.4
C + M – P	28.4	2.80	–	–	0.86	1100.7	545	555.7
C + P – P	36.8	–	–	1.30	1.07	1317.0	572	745.0
C + P – M	31.0	–	0.98	1.28	–	1046.3	536	510.3
LSD 5%	3.3							

Notes :

C + M = cassava planted at the same time as maize
C + P = cassava planted at the same time as peanut
C + M – M = cassava planted at the same time as maize, the second intercrop being maize
C + P – P = cassava planted at the same time as maize, the second intercop being peanut
C + P – P = cassava planted at the same time as peanut, the second intercrop being peanut
C + P – M = cassava planted at the same time as peanut, the second intercrop being maize

Cassava spacing : 1.25 × 1.00 m
Maize spacing : 0.75 × 0.25 m
Peanut spacing : 0.25 × 0.25 m

Exchange rate : 1US$ = Rp 1,635.00

Table 6. Effect of row spacing and varying intercropping systems on crop yields.

Treatment	Yield (ton/ha)			
	Cassava	1st maize	2nd maize	Peanut
C(S)0 + M – M	34.4	3.06	2.26	
C(S)0 + M – P	35.6	2.74		1.30
C(D)0 + M – M	33.5	3.10	2.62	
C(D)0 + M – P	34.1	3.26		
C(S)1 + M – M	30.7	3.18	2.17	
C(S)1 + M – P	32.3	2.87		
C(D)1 + M – M	32.6	3.28	2.85	
C(D)1 + M – P	32.8	3.48		
LSD 5%	1.9		0.15	0.30

Note :

C(S)0 + M – M = cassava (single row) planted at the same time as maize, the second intercrop being maize
C(S)0 + M – P = cassava (single row) planted at the same time as maize, the second intercrop being peanut
C(D)0 + M – M = cassava (double row) planted at the same time as maize, the second intercrop being maize
C(D)0 + M – P = cassava (double row) planted at the same time as maize, the second intercrop being peanut
C(S)1 + M – M = cassava (single row) planted one month after maize, the second intercrop being maize
C(S)1 + M – P = cassava (single row) planted one month after maize, the second intercrop being peanut
C(D)1 + M – M = cassava (double row) planted one month after maize, the second intercrop being maize
C(D)1 + M – P = cassava (double row) planted one month after maize, the second intercrop being peanut

Cassava spacing, single row : 2.50 × 0.5 m, double row 5.0/1.0 × 0.5 m Maize and peanut planted in between the cassava rows at spacings of 0.75 × 0.25 m and 0.25 × 0.25 m, respectively.

Cultivars of cassava, maize and peanut : Faroka, Arjuno, and Gajah, respectively.

Fertilizers applied : 135 kg N/ha for cassava, 90 kg N/ha for maize and 22.5 kg N/ha for peanut.

Table 7. Effect of tillage and mulching on cassava root yield (kg/plant).

Treatment	Exp. 1	Exp. 2
1. Traditional plowing of the whole field followed by ridging	0.51 b	3.07 bc
2. Plowing the whole field without ridging	0.42 a	2.78 ab
3. Plowing the plant rows only (without furrows)	0.39 a	2.53 a
4. Single furrow followed by ridging	0.42 a	3.35 c
1. Without mulch	0.36 a	
2. Groundnut stems as mulch	0.40 a	
3. Rice straw as mulch	0.56 b	
4. Maize stems as mulch	0.50 ab	

Exp. 1 was carried out in the dry season of 1982 (March to November 1982).
Exp. 2 was carried out in the wet season of 1982/1983 (December 1982 to October 1983).

The mulch materials (equal to about 6 tons of dry mulch/ha) were applied on the soil surface.

Table 8. Fresh root and total plant dry matter yield of cassava.

Treatment	Fresh Root yield (t/ha)	Total plant (t/ha)
1. Cassava monocrop + AS	47.45 c	32.20 d
2. Cassava monocrop + Urea	36.45 a	20.43 a
3. Cassava monocrop + (Urea + S)	39.35 b	28.87 a
4. Cassava intercropped with maize + AS	44.85 c	32.45 d
5. Cassava intercropped with maize + Urea	34.42 a	22.24 b
6. Cassava intercropped with majze + (Urea + S)	44.07 c	29.67 c

Values with the same letter in each column are not significantly different at P = 0.05

AS = Ammonium sulphate

S = Sulphur as elemental S

Doses of fertilizer : 180 kg N/ha, half applied at 2 weeks and half at 8 months after planting
50 kg P_2O_5 and 100 kg K_2O given at 2 weeks after planting
20 kg Sulphur

5. Variety selection

In cooperation with CIAT, cassava clones obtained from introduced seeds are being tested. It is expected that from these a high yielding cultivar will be found.

Future Directions and Priority Areas

Cultivar selection

To obtain high yielding cultivars cross-breeding and yield testing of local and introduced cassava germplasm are necessary. In considering the objectives of this program, the following factors must be taken into account: For Java there is a need for high yielding cultivars with little branching and narrow leaves for intercropping, along with good eating quality (i.e. low levels of hydrocyanic acid). In outer Java, there is a need for high yielding cultivars with a high starch content and, particularly for dry areas, a cultivar that has a high drought tolerance.

Cropping system :

Improving soil fertility by better soil management for stable, long-term production is a major goal. Aspects of this objective include tillage practices, mulching, fertilizer use, and maintenance of soil fertility with a suitable cropping system. With the use of a suitable cassava cultivar, compatible intercrops, and a suitable cropping sequence, the productivity of intercropping might be increased.

Need of Network Research and Cooperative Project

Asian Coordinator for Research Activities :

To avoid duplication of research on cassave and to distribute well-adapted germplasm over Asia, an Asian Coordinator for research activities is needed. Besides coordinating cassava research in Asian countries he would also be responsible for helping to find funds for cassava research.

Centre for Cassava Information :

A Centre for Cassava Information could be established to collect research results on cassava. These results could be gathered and published in a journal to be published by the Centra and or in its Annual Reports. Periodically, scientific meetings could be conducted, attended by researchers from Asian countries to present their research results on cassava. These meetings could rotate among the Asian countries.

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CASSAVA AGRONOMY AND SOIL RESEARCH IN INDIA

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Introduction

Cassava was introduced to Kerala (India) by the Portuguese in the 17th Century. As a food crop it was popularized by Shri Vishakam Tirunal, the then Maharaja of the erstwhile Travancore – who ruled the State during 1880 to 1885. From that time onwards the crop has gained importance as a cheap source of carbohydrate, mostly for human consumption. Recently, both area and production have decreased from 0.37 million ha and 6.3 million tons during 1973 – 74, to 0.31 million ha and 5.7 million tons, respectively, during 1984 – 85. Though the total area and production have reduced slightly, cassava yields have increased from 17.3 to 18.4 t/ha during this period, which is considered to be one of the highest average yields in the world (Table 1).

Table 1. Area and production of cassava in India.

States	Area (ha)		Production (t)	
	1973 – 74	1984 – 85	1973 – 74	1984 – 85
Kerala	306,400	232,753	5,630,000	3,952,514
Tamil Nadu	57,700	47,820	654,300	1,477,010
Andhra Pradesh	5,700	13,800	49,900	65,900
Karnataka	900	1,400	11,000	14,291
Orissa	100	–	200	–
Assam	600	2,153	2,200	9,580
Meghalaya	1,960	3,836	9,200	21,482
Tripura	100	338	600	1,609
Nagaland	–	420	–	–
Rajasthan	–	322	–	615
Andaman & Nicobar Islands	–	192	–	1,482
Arunachal Pradesh	–	4,252	–	14,882
Mizoram	–	10	–	65
Pondicherry	–	695	–	12,156
All India	367,460	307,991	6,358,300	5,673,486

Source : 1. Scientific Cassava Cultivation (Malayalam), CTCRI, 1977.
2. Agricultural Situation in India, 1986, 41(9) pp. 515 – 516.

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Presently, about 70 – 75% of the cassava area and production in India is confined to the State of Kerala while 15 – 20% is produced in the State of Tamil Nadu (Figures 1 and 2).

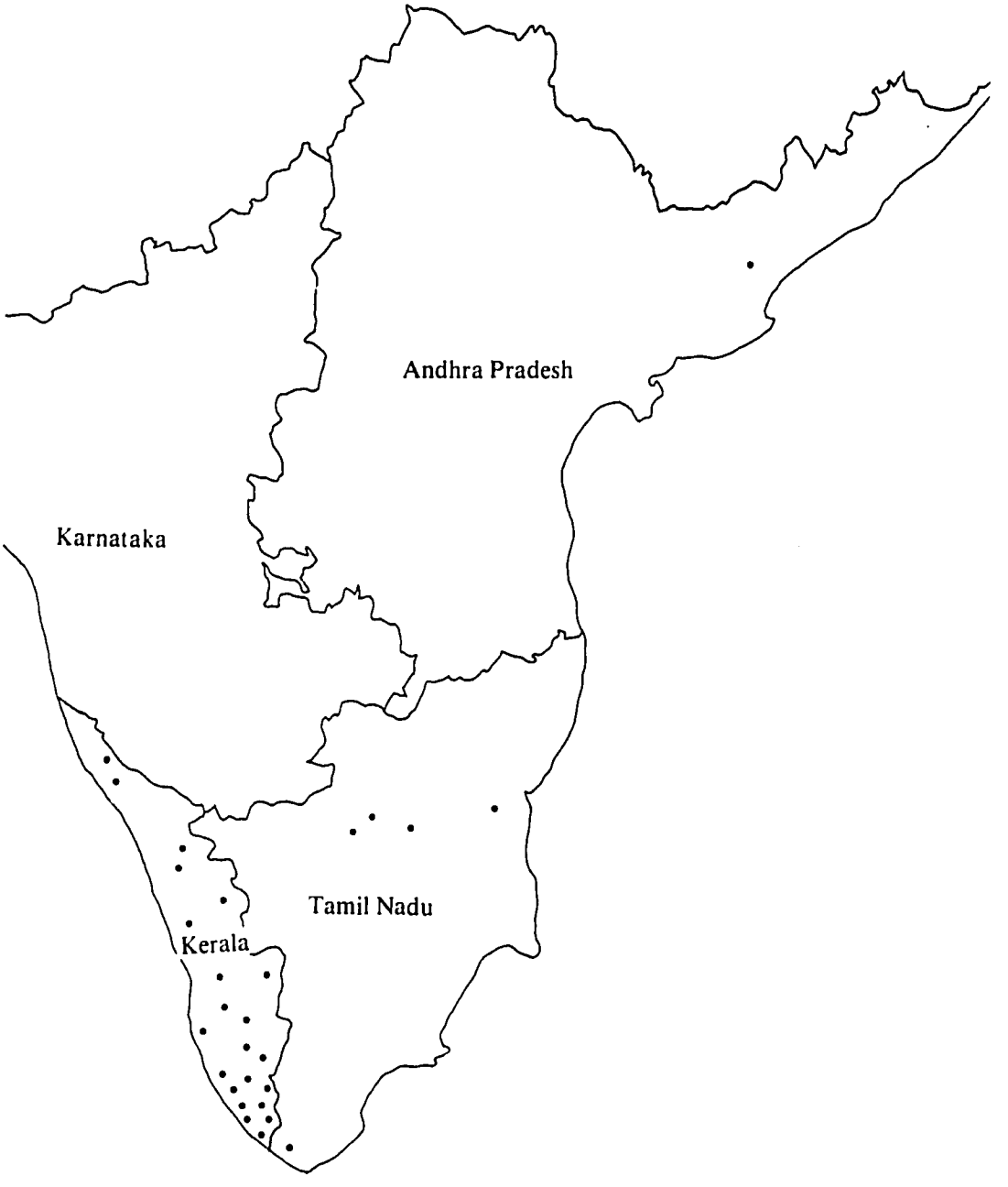

Figure 1. Cassava production zones in India. Each dot represents 10,000 ha of cassava in 1985.

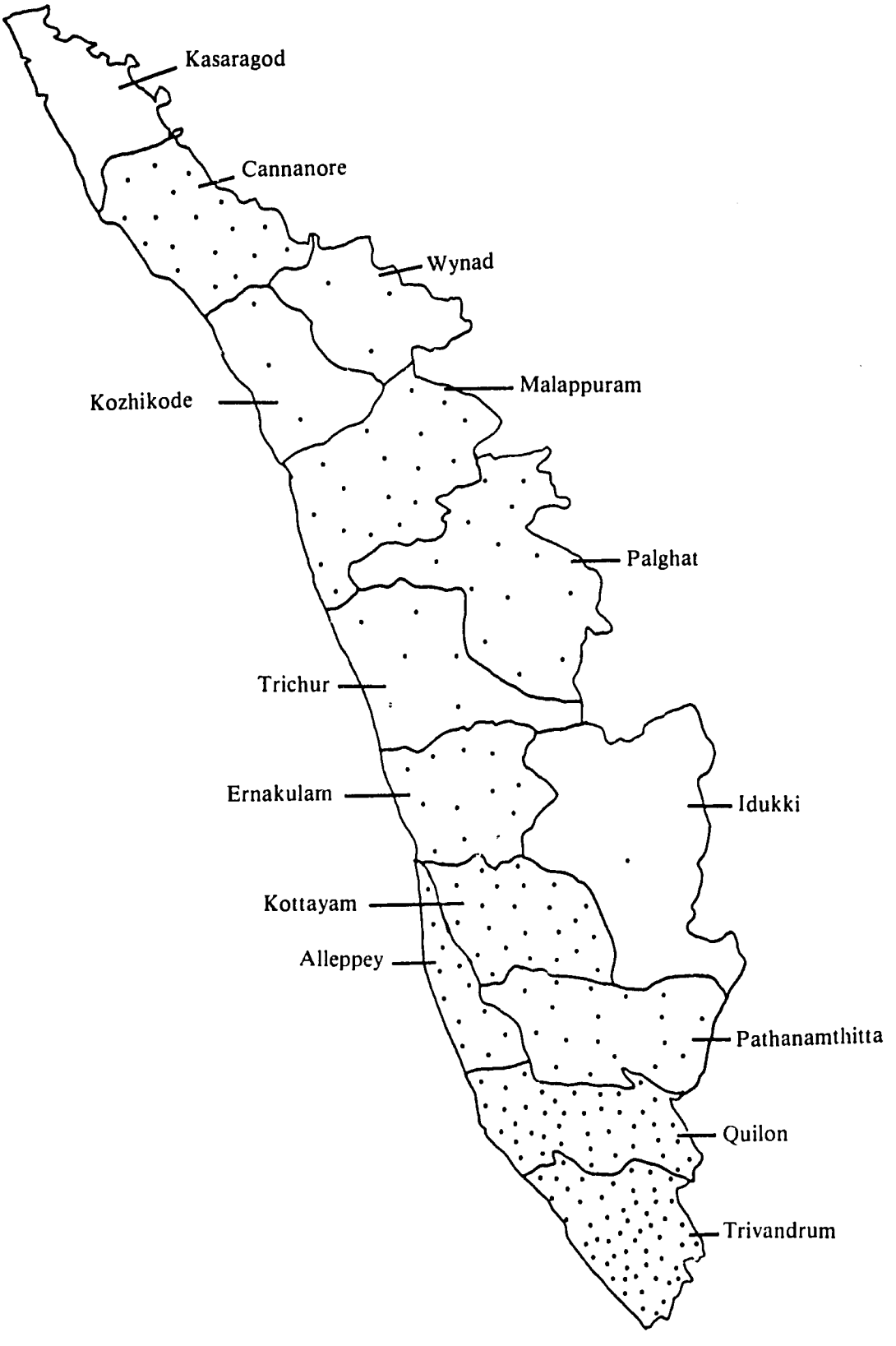

Figure 2. Cassava production zones in Kerala State of India. Each dot represent 1000 ha of cassava in 1985.

Soil and Climatic Characterization of Major Cassava Growing Areas

Soil :

In Kerala and Tamil Nadu the predominant soil groups in which cassava is grown are laterite (Oxisols), red soils (Alfisols) and black soils (Vertisols). In Kerala under conditions of heavy leaching, due to excessive rainfall and high summer temperatures, laterite (Oxisol) is the predominant soil group (Figure 3). These soils have a loamy texture and are acidic in reaction (pH 5.0 – 6.5); they can also contain appreciable amounts of gravel. Lateritic soils contain fair amounts of organic matter and N, but are very deficient in P, K and bases. Though they are of low natural fertility, they are well drained and respond to good management practices.

In Tamil Nadu, the major cassava growing soils are black (Vertisols) and red soils (Alfisols) with pH ranging from 6.5 to 8.0. Black soils originate from basic material containing 45 to 55% silica. These soils are black at the surface and brownish in the subsoil. They are high in clay and produce deep cracks in summer, exhibiting their characteristic property of swelling on wetting and shrinkage on drying. The CEC is high (30 - 70 me/100 g soil) and they contain high amounts of Fe, Ca and Mg. Free calcium carbonate is present in the soil in the form of kankar (limestone). These soils are poor in organic matter, N and P, but fairly well supplied in K and rich in lime.

Red soils of ferruginous nature are mainly associated with granites and are rich in Fe bearing minerals such as limonite and magnetite. They are loamy in texture and the pH ranges from 6.8 to 8.0. These soils show an absence of horizon differentiation and there is no accumulation of salt or calcium carbonate. The soils contain low amounts of organic matter, N and P, but have generally adequate amounts of K and lime.

Climate:

Kerala lies in the south-western part of India, where the agro-climatic conditions are suited for the cultivation of cassava. The state extends from 8° 18′ to 12° 48′ N latitude and 74° 52′ E to 77° 22′ E longitude, along the coast in the south-western part of India.

The State of Kerala has a high annual rainfall amounting to about 3000 mm. The rainfall increases from the southern to the northern part of the state. The state receives both south-west and north-east monsoons. Nearly 60% of the annual precipitation is received during the SW monsoon season. The NE monsoon is from September – November and the distribution pattern is quite different from that of the SW monsoon. In general the northern parts of Kerala receive less rainfall during the NE monsoon compared to the south-eastern parts of the state. Though the northern parts of the state receive more total rainfall, the distribution is more uniform in the southern part. Further climatic details of the major cassava growing states are provided in Table 2.

In Salem district of Tamil Nadu the total annual rainfall is only 800 – 900 mm, about 10% of which is received during April – May as summer showers, 30% during the SW monsoon (June – August) and the remaining 60% during the NE monsoon (September – November).

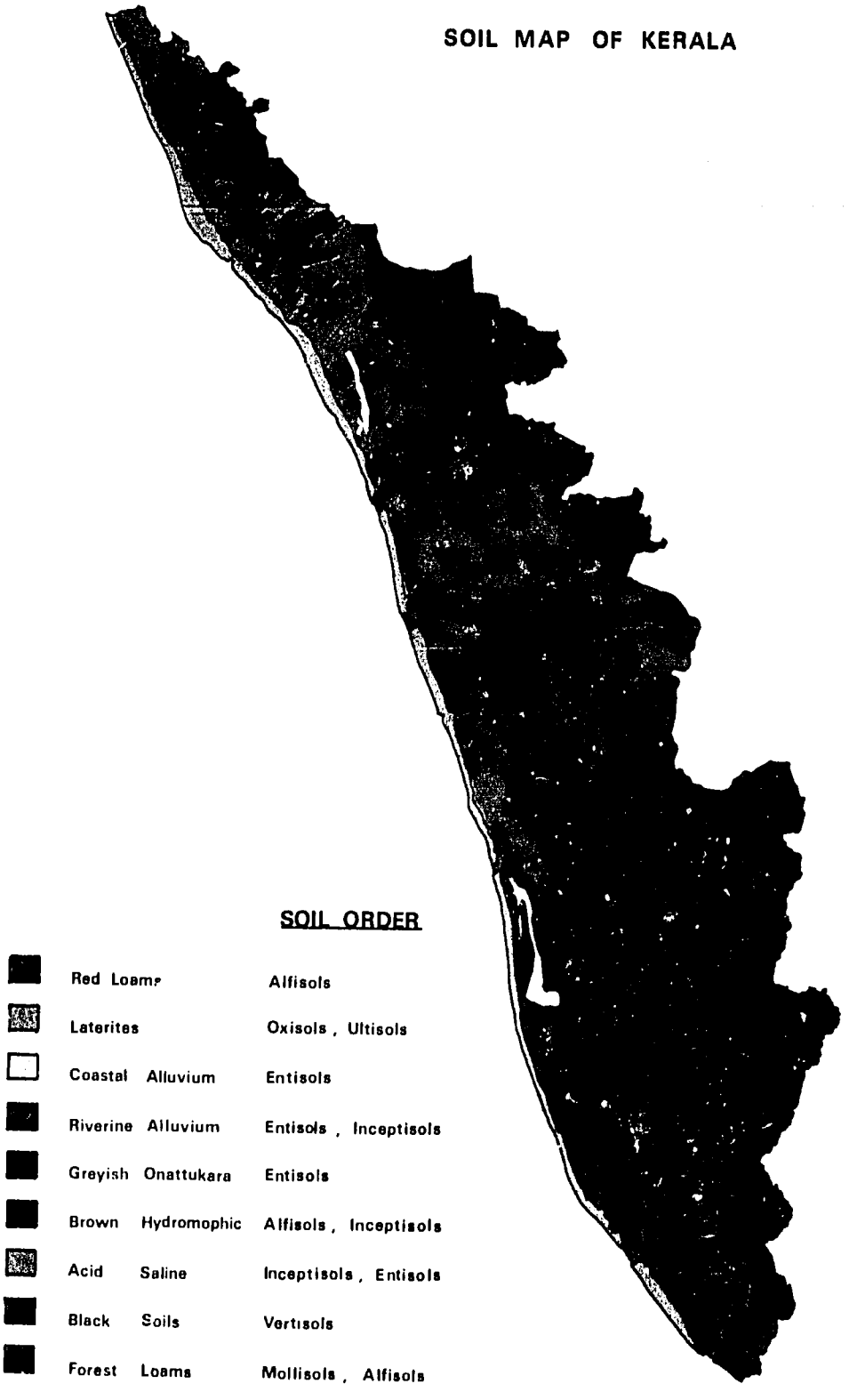

Figure 3. Distribution of soils in Kerala State of India.
Source : Soil Survey Branch, Dept. Agric. Kerala, 1978.

Table 2. Climatic characteristics of the major cassava growing states in India.

State (city)	Weather factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov.	Dec.	Annual total or average
	Rainfall (mm)	17	17	41	109	236	676	703	426	238	302	185	49	3000
Kerala														
(Trivandrum)	Max. temp. (°C)	30.6	30.7	31.3	31.4	30.9	29.0	28.1	28.1	28.3	29.2	29.8	30.3	29.8
	Min. temp. (°C)	23.2	24.3	25.8	26.0	25.7	24.1	23.7	24.0	24.2	24.2	24.1	23.5	24.4
	Rainfall (mm)	35	14	22	41	75	57	64	90	93	186	174	76	927
Tami Nadu														
(Salem)	Max. Temp. (°C)	31.1	33.7	36.1	36.9	36.8	34.9	33.4	33.2	33.1	31.9	30.5	30.1	33.5
	Min. Temp. (°C)	19.2	20.2	22.5	25.1	24.5	24.4	23.6	23.4	23.3	22.8	21.2	19.6	22.6
	Rainfall (mm)	30	70	60	40	38	150	200	220	100	120	60	20	1092
Andhra														
Pradesh	Max. Temp. (°C)	24.6	26.5	29.0	31.7	33.7	32.0	29.0	28.6	28.0	27.9	25.9	24.1	28.6
(Godavari)	Min. Temp. (°C)	19.1	20.0	22.3	25.6	27.7	27.3	25.3	25.1	25.2	24.2	21.1	19.1	23.5

Methods of Cassava Cultivation

In Kerala cassava is grown under rainfed conditions with the onset of the monsoon. The two main planting seasons are April – June and September – October, coinciding with the onset of the SW and NE monsoons, respectively. The cultivation of cassava is mostly confined to marginal and submarginal lands of undulating topography. With the onset of the monsoon, the land is plowed or dug to a fine tilth and mounds are formed at a spacing of 75 to 90 cm. Local cassava cultivars are used for planting while high yielding new cultivars are used in less than 10% of the total area under this crop. Stem cuttings of 20 to 30 cm length, obtained from the previous crop, are used as planting material. Shallow vertical method of planting is adopted. At the time of land preparation farm yard manure/compost and ash are applied as a basal dressing. Recommended levels of chemical fertilizers are rarely applied by farmers. Two intercultural operations (hand weedings) are carried out at the second and third month of the crop. Fertilizers are sometimes applied during this time. As the crop is almost free from serious pests and diseases, plant protection practices are seldom used. The crop is harvested at 10 to 11 months after planting. The yields for local and new cultivars under farmers' conditions range from 15 to 20 and 25 to 30 t/ha, respectively.

Though cassava is not a shade-loving crop, because of the population density and scarcity of land in Kerala, it is widely grown as an intercrop in coconut plantations. As an intercrop it can accommodate about 70% of the sole crop population, and the yield ranges from 5 to 7 t/ha.

In Tamil Nadu cassava is grown mainly in Kanyakumari and Salem districts. In Kanyakumari district (southern tip of Tamil Nadu) it is grown under rainfed conditions, whereas in Salem it is grown mainly (70%) under irrigation. The rainfall in Kanyakumari ranges from 900 to 1200 mm per year, while in Salem it ranges from 700 to 950 mm. The predominant cultivar in Salem is the hybrid H-226, released from the Central Tuber Crops Research Institute (CTCRI), Trivandrum, India. The area under this variety is rapidly expanding (now about 75% of total) due to its high yielding ability and drought tolerance, as well as its resistance to root cracking, which is a serious problem in the local cultivar "Burma".

In Salem the land is either ridged or furrowed before planting. The present fertilizer recommendation for irrigated cassava by the State Department of Agriculture is 60:60:150 kg N, P_2O_5 and K_2O per ha. But many farmers are actually applying higher levels. The fertilizers are applied in two splits, a full dose of P and a half dose of N and K three months after planting, and the remaining half dose of N and K six to seven months after planting, at the time of interculture operation and weeding.

The crop is harvested at about ten months. The entire produce is used for the production of starch and sago. The yield ranges from 30 to 35 t/ha.

Accomplishments and Present Status of Cassava Research

Various studies have been carried out to determine the best cropping systems and agronomic practices, as well as the nutrient requirements of cassava under rainfed conditions. The results are briefly summarized below.

Time of planting:

Under irrigated conditions planting of cassava can be done throughout the year. As a rainfed crop the best time of planting of cassava in Kerala is April - May with the onset of pre-monsoon showers. The next best season is August-September, with the onset of the NE monsoon. The effect of time of planting on root yield is presented in Figure 4 (CTCRI, 1980).

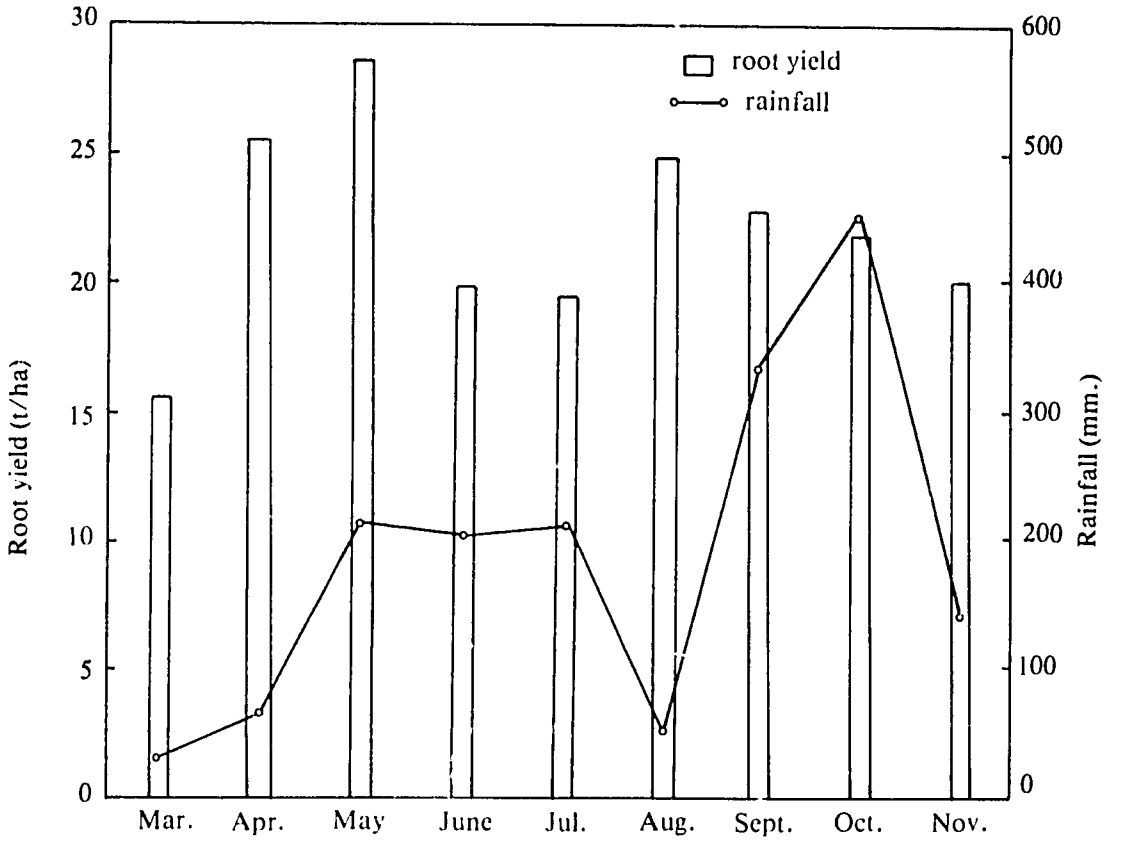

Figure 4. Effect of time of planting and rainfall on cassava root yield.

Land preparation and planting:

Soil physical conditions influence the plant growth and hence proper tillage is required for the successful cultivation of cassava. 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. Earthing up during weeding at monthly intervals, starting from 30 days after planting, increased yields significantly compared with no-earthing up (Table 3). Maximum root yield was obtained with three earthings up, but taking into consideration the cost involved in this type of work, two earthings up at 2nd and 3rd month stage of the crop was found to be the most economical (Mandal and Mohankumar, 1973).

Table 3. Effect of tillage on cassava root yield (t/ha).

Plowing/digging	Number of earthings up*				
	0	1	2	3	Mean
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	
C.D. (5%) Plowing : N S	Earthing up : 2.51				

*This includes weeding.

Source : Mandal and Mohankumar, 1973.

Method of planting:

Different methods of land preparation, such as pit followed by mound, flat method, mound method and ridge method did not show any significant difference in yield, even though pit followed by mound recorded the maximum root yield (Figure 5) (CTCRI, 1971).

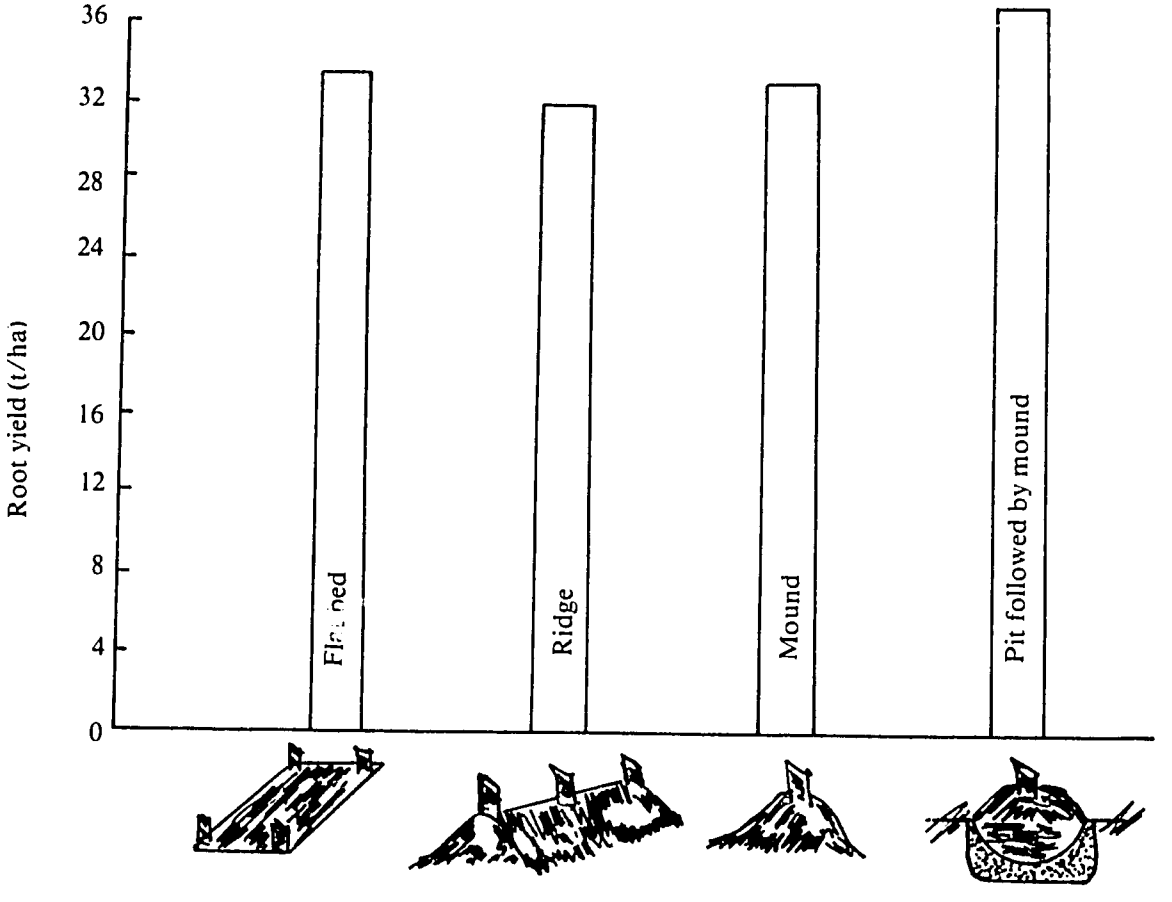

Figure 5. Effect of method of planting on cassava root yield.

Selection of planting material:

Preparation of planting material is done by means of cutting stems from disease free plants of 8 – 12 months maturity, having a stem diameter of 2 – 3 cm. It was found that survival of stakes was significantly superior when the lower part of the stem was used as planting material as compared to the immature upper part. The use of the bottom part of the stem resulted in the highest root yield, while the upper part gave the lowest yield (CTCRI, 1968).

Preparation of planting stakes:

Stakes are prepared by discarding 1/3 of the total length of the stem from the top and about 5 cm from the bottom. It was observed that the plant establishment was better when stakes obtained from this part of the stem were used as planting material (CTCRI, 1968). While preparing the stakes, it is better to have a smooth circular cut rather than an irregular cut for uniform callus formation and root initiation.

Stake size and depth of planting:

A stake length of 25 to 30 cm was found to be advantageous for higher yield. Significant reduction in root yield was observed when stakes of 10 cm were used. Shallow planting facilitates production of a greater number of roots. When the soil is sufficiently loose and friable stakes can be planted to a depth of 5 to 10 cm. Planting the stakes deeper results in swelling of the mother stem with consequent reduction in root size and yield. This is especially true when the soil becomes compacted.

Method of planting of stakes:

Different methods of planting stakes, such as vertical, slanted (at 45° angle) and horizontal, showed that vertical planting resulted in a more uniform distribution of callus tissue around the cut surface, which helped in the uniform bulking of roots all round the base of the plant (CTCRI, 1969, 1971).

Storage of planting material:

Storing the stems for a period of 15 days resulted in the highest percentage sprouting (96%) as compared to planting of fresh stakes (90%). Storage beyond 60 days resulted in the loss of viability of the planting material, and sprouting was less than 75%. Stems stored in vertical or in inverted position gave better sprouting when compared to horizontal storage (CTCRI, 1983).

Production of quality planting material:

The normal rate of multiplication of planting material is about ten times at harvest. When an improved cultivar is released there is a great demand for the planting material. In order to increase the rate of multiplication a field trial was conducted with closer spacing and planting single and double stakes per hill. The results suggested that the spacing of 60 × 60 cm and 90 × 45 cm with one stake/hill were significantly superior to other spacings tried. Planting of two stakes per hill considerably reduced the number of high quality planting material under different spacings (Mohankumar *et al.*, 1980).

Another approach to increase the planting material is to use split stakes. It was observed that planting of whole stakes yielded 32 t/ha as against 20 t/ha for split stakes (Sasidhar *et al.*, 1977).

By adopting the method of rapid propagation technique of single node planting with the help of a mist chamber, 647 stakes could be produced from a single cassava plant in one year as against ten plants in the conventional method of planting (Kamalam *et al.*, 1977).

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 90 × 90 cm for branched and a closer spacing of 75 × 75 cm for non-branched cultivars gave maximum production (Table 4).

Table 4. Effect of plant population on root yield.

Plant type	Plant spacing (cm)			
	60 × 60	75 × 75	90 × 90	120 × 90
	Root yield (t/ha)			
Non-branched	32.9	34.9	31.7	29.1
Semi branched	23.3	25.6	28.9	25.1

Planting two stakes/hill for non-branched types had shown encouraging results, as compared to normal practice of one plant per hill. Even though the total yield increased by this method, the root size was reduced considerably, probably due to the competition for light, nutrients and moisture.

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 per plant at opposite sides was found to be better than retaining only one shoot. This practice helped the production of a greater number of uniform sized roots all round the base of the plant (Mandal *et al.*, 1973). Thus, 10 to 15 days after sprouting excess sprouts have to be removed, leaving only two sprouts per plant.

Gap filling:

Under field conditions all the planted stakes may not establish due to the use of poor quality planting material and adverse weather conditions, which necessitate gap filling within a reasonable time. 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 15th day after planting could produce 50% higher yield as compared to normal stakes (20 cm) used for gap filling (CTCRI, 1983).

Topping and defoliation:

Cassava has a built-in mechanism to shed leaves when environmental conditions are adverse. The physiological activities during this period will be minimum and new leaves are

produced only when environmental conditions are favourable. To determine the effect of topping or defoliation at various stages of the crop, an experiment was conducted with two methods of leaf removal (topping or defoliation) during three growth stages of cassava, viz. 2, 4 and 6 months after planting. Either in topping or defoliation, 50% of the foliage was removed. The results (Table 5) indicate that either topping or defoliation at any stage of the crop decreased the root yield. Topping at the initial stage of the crop (2 months after planting) was found to affect most seriously crop growth and yield. When there was no leaf removal, either by topping or defoliation the maximum root yield was obtained (Mohankumar and Mandal, 1975).

Table 5. Effect of topping/defoliation on cassava root yield (t/ha).

Treatment	Time of topping or defoliation (months)			
	2nd	4th	6th	Control
No defoliation or topping	–	–	–	25.3
Topping	18.1	20.7	22.3	–
Defoliation	21.2	21.6	23.3	–
C.D. (5%) : Control vs. treatments : 1.29				
Between treatments : 1.69				
Between stages : 1.19				
Topping vs. defoliation : 0.95				

Source : Mohankumar and Mandal, 1975.

Stage of harvest:

Studies on the response of cassava (hybrid H-165) to varying levels of soil fertility and stage of harvest showed that there was a significant increase in yield with increase in the level of fertilizer application. The root yield also increased progressively with delay of the harvest from the 6th to the 10th month (the last harvest of the experiment) of the crop. Maximum root yields were observed at the 10th month as seen from Table 6 (Mohankumar *et al.*, 1975).

Table 6. Cassava root yield (t/ha) as affected by level of fertilization and stages of harvest.

Stage of harvest after planting	Fertilization level*			
	Low	Medium	High	Mean
6 th month	13.3	18.7	21.6	17.9
7 th month	18.9	21.1	24.8	21.6
8 th month	20.6	21.2	25.3	22.4
9 th month	21.3	23.6	25.6	23.5
10 th month	21.2	24.5	28.2	24.6
Mean	19.1	21.8	25.1	
C.D. Fert. levels : 3.40; Stage of harvest : 1.85.				

*low : 12.5 t FYM/ha
medium : 12.5 t FYM + 50 kg N + 50 kg P_2O_5 + 50 Kg K_2O/ha
high : 12.5 t FYM + 100 kg N + 100 kg P_2O_5 + 100 kg K_2O/ha

Source : Mohankumar *et al.*, 1975.

Cassava-based cropping systems:

In Kerala state about 42% of farmers have less than 0.2 ha of land. These small and marginal farmers, out of necessity, have to adopt intercropping systems to realize maximum returns per unit area per unit time. Usually cassava is planted during May – June at a spacing of 90 × 90 cm. The initial growth rate of the crop is slow and it takes 3 – 4 months to produce enough canopy to cover the entire field. The solar radiation available in between cassava rows during its early growth stage can be well exploited by raising short duration seasonal crops.

Studies conducted by using green gram *(Phaseolus aureus)*, groundnut *(Arachis hypogea)*, maize *(Zea mays)*, soybean *(Glycine max)*, as intercrops with cassava under two methods of cassava planting (normal and double row) with and without fertilizers to the intercrops have shown that groundnut was the most profitable combination with cassava. The details are provided in Table 7 (Mohankumar and Hrishi, 1979).

Table 7. Yield and economic benefits of intercropping with cassava.

Crop combination	Cassava root yield (t/ha)	Intercrops yield (kg/ha)	Net income (Rs/ha)*
Cassava + Green gram	18.7	222	6051
Cassava + Soybean	18.6	204	6072
Cassava + Groundnut	17.2	1347	8093
Cassava + Sunflower	18.0	400	6466
Cassava + Maize (dry maize)	18.4	1135	7140
Cassava alone	31.3	-	6397

*Exchange rate : US$ = Rs 10.

Source : Mohankumar and Hrishi, 1979.

Table 8. Influence of planting arrangement and fertilizers on cassava root yield.

Treatments	Yield (t/ha)
Single rows; no fertilizer to intercrop	18.2
Single rows; fertilizers to intercrop	19.0
Paired rows; no fertilizer to intercrop	18.4
Paired rows; fertilizer to intercrop	19.2

Table 9. Yield and yield components of cassava as influenced by spatial arrangement.

Treatment	Root yield (t/ha)	No. of roots per plant	Mean root size (g)
Square method : 1 × 1 m	22.6	8.1	289
Paired row method : 1.35 × 0.65 m	24.6	8.4	298
Wide row method : 2 × 0.5 m	23.9	9.3	287

Source : Prabhakar *et al.*, 1982

Table 8 shows that different planting arrangements did not have much influence on the root yield of cassava, but an additional dose of fertilizer to the intercrop was found to be beneficial. Table 9 shows that cassava is highly flexible to spatial adjustment and the root yield remained unaffected as long as the optimum plant population was maintained (Prabhakar *et al.* 1982).

In a comparative study to evaluate the performance of some vegetables as intercrop with cassava, French bean *(Phaseolus vulgaris)*, variety "Contender", was shown to be a successful intercrop with cassava (Thomas *et al.*, 1982). Similar results were reported by Prabhakar *et al.*, (1983).

Experiments conducted to explore the feasibility of raising a second intercrop after the harvest of the first intercrop with cassava were not successful. This is due to the fact that at the time of harvest of the 1st intercrop, cassava has developed enough canopy to cover the entire field and as such the sun light penetration to the ground was less than 10% of the total radiation. (CTCRI, 1978 – 79).

Canopy spread and light penetration studies conducted in cassava fields in which the stakes were planted at a spacing of 90 × 90 cm, showed that the cassava canopies meet between the 45th and 75th days, and with advancing age there was substantial canopy overlapping. Hundred percent light penetration through the canopy at the interspace of 45 cm between two rows of cassava was observed upto the 45th day after planting, and thereafter the percentage of light penetration reduced to 50%, 36% and 26% at 75, 90 and 120 days after planting, respectively (Ashokan *et al.*, 1986).

In a cassava-legume intercropping study, it was observed that cowpea *(Vigna unguiculata)* may be the most remunerative intercrop in high rainfall Oxisols of Central Kerala. The cost of weeding could be reduced by 50% by growing cowpea as an intercrop with cassava (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 state and the results showed 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).

Cassava as an intercrop in coconut plantations:

A study on the growth and development of twelve genotypes under coconut shade indicate 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 unproportionally small resources for root development. The details are given in Table 10 (Ramanujam *et al.*, 1984).

Table 10. Crop growth rate and yield of cassava genotypes under shade and open conditions.

Clone	Crop growth rate ($g/m^2/day$)		Root yield (g/plant)		Yield reduction (%)
	Unshaded	Shaded	Unshaded	Shaded	
M4	5.06	1.11	2000	160	92
M-2304	6.40	2.61	2500	506	79
H-1687	5.62	2.17	2410	483	80
H-1423	4.81	1.83	2000	206	90
H-2253	5.30	1.49	1930	366	81
H-648	5.29	1.12	2300	283	88
H-226	5.17	1.58	2450	393	84
H-165	6.02	2.38	2500	800	68
H-97	6.49	1.07	2000	170	94
H-97/2	4.73	2.79	2170	500	77
C.590	3.44	2.92	2000	700	65
C.167	5.00	1.04	1840	184	90

Source : Ramanujam *et al.*, 1984

Root crop-based farming systems for livestock feed production:

Studies conducted to identify a suitable cropping system for the production of both green forage and raw materials for cattle feed concentrates under rainfed conditions showed that the treatment consisting of two short duration cassava and sweet potato crops in sequence for a period of 24 months mixed with *Leucaena* + guinea grass and seasonal crops like groundnut, maize and cowpea recorded the maximum forage and protein yield. The details are summarised in Table 11 (Ghosh *et al.*, 1987).

Table 11. Fresh forage yield and protein of cassava leaves harvested in several cassava-based cropping systems.

Cassava crops	Perennial crops	Seasonal crops	Yield	
			Forage (t/ha)	Protein (kg/ha)
1. Two cassava crops (16 and 8 months duration)	*Leucaena* + Guinea grass	Groundnut, Horsegram, Cowpea, Sweet potato	38.4	89o
2. Two cassava crops (16 and 8 months duration)	*Leucaena* + Guinea grass + Stylosanthes	Groundnut, Horsegram, Cowpea, Sweet potato	43.9	859
3. Two cassava crops (12 months each)	*Leucaena* + Guinea grass	Groundnut, Cowpea	43.7	907
4. Two cassava crops (12 months each)	*Leucaena* + Guinea grass + Stylosanthes	Groundnut, Horsegram	42.5	773
5. Two cassava crops (8 months each)	*Leucaena* + Guinea grass	Groundnut, Maize, Sweet potato	52.7	1222

Source : Ghosh *et al.*, 1987

Cassava-based multiple cropping systems :

In a cassava based multiple cropping experiment involving pure stands of perennials (banana, *Leucaena*, eucalyptus, and coconut), cassava, and seasonal intercrops (groundnut or cowpea), it was observed that inclusion of cassava and intercrops improved wood recovery of eucalyptus, as is seen in Table 12. However, cassava intercropping adversely affected the yield of banana and the forage yield of *Leucaena*. The perennials, especially eucalyptus, were also found to cause reduction in the root yield of cassava. Intercropping with banana, however, increased cassava yields, due to absorption by cassava of nutrients applied to the banana.

Table 12. Wood yield of eucalyptus (t/ha) in several cassava-eucalyptus cropping systems.

Months after planting	Eucalyptus	Eucalyptus + Cassava	Eucalyptus + Cassava + Groundnut	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

The cost/return analysis showed that the highest net return was obtained for the crop combination cassava + French bean or cowpea. The next best combination was banana + cassava + French bean or cowpea (Ghosh *et al.*, 1987).

Root crop-based cropping systems for paddy fields:

Single crop rainfed paddy fields: In Kerala the usual practice in single crop rainfed paddy fields is to grow one crop of dry-sown rice during the Kharif season (April – May to August – September); this is followed by fallow, because of lack of water for growing a second crop of rice. A study was therefore undertaken with cassava and other short duration crops in comparison with the traditional system of rice followed by fallow.

The results suggest that though cassava alone recorded the maximum benefit/cost ratio and net return per ha, there was a significant reduction in root yield of cassava from the 1st year (70.0 t/ha) to the second year (58 t/ha). However, in the rice-cassava sequence there was an increase in cassava root yield from the first year (39 t/ha) to the second year (44 t/ha). Therefore, from the long term fertility point of view, rice followed by cassava might be a better crop sequence from such type of rice fields. Yields and economic benefits of each crop sequence are provided in Table 13. (Mohankumar *et al.*, 1985).

Table 13. Yield and economic-returns of several alternative crop sequences (average of two years).

Crop sequence	Mean yield (t/ha)	Total net income* (Rs/ha)
Rice-fallow		
rice grain	2.6	
rice straw	5.2	1016
Rice-sweet potato-fallow		
rice grain	2.3	
rice straw	4.9	
sweet potato fresh tuber	11.9	3450
Rice-cowpea-fallow		
rice grain	2.5	
rice straw	5.1	
cowpea fresh pods	3.0	3214
Rice-cassava		
rice grain	2.4	
rice straw	4.8	
cassava fresh roots	41.7	6621
Cassava-fallow		
cassava fresh roots	64.3	11088
C.D. 5%		879

Source : Mohankumar *et al.*, 1985.
*Exchang rate : US$ = Rs 12.

Double cropped irrigated paddy fields: In Kerala the usual cropping system in irrigated paddy fields is to grow two consecutive crops of rice followed by a crop of cowpea. Rice is a labor intensive crop, but due to high wages in the State of Kerala the cultivation of rice is becoming less profitable and farmers are searching for an alternative cropping system. Therefore, to develop an alternative cropping system for low lands a study was undertaken with cassava and other short duration crops. The results suggest that vegetable cowpea followed by cassava (H-1687) would be the most profitable combination (CTCRI, 1986).

Agronomic investigations to reduce erosion on slopy land under cassava:

An experiment conducted at Central Kerala to determine the effect of various agronomic practices on erosion in a sandy clay loam soil with 15% slope, showed that soil and run-off losses were significantly higher in bare fallow compared with cassava intercropped with groundnut (Viswambharan and Sasidhar, 1985).

Similar studies in a cassava-based multiple cropping system in south Kerala on a sandy clay loam soil with 8 to 9% slope, indicate that maximum soil loss again occured under bare fallow. By planting cassava alone on staggered mounds the soil loss could be reduced by 45% compared with bare fallow. Intercropping cassava with perennial trees (banana and eucalyptus) reduced the soil loss to only 22% as is shown in Table 14 (Ghosh *et al.*, 1985 and 1987).

Table 14. Surface run-off and soil loss in a cassava-based multiple cropping system on 9% slope at CTCRI, Trivandrum, Kerala.

Treatments	Run off		Soil loss	
	% of rainfall	% reduction over fallow	t/ha	% reduction over fallow
Bare fallow	23.0	-	8.8	-
Cassava	15.4	33.0	4.8	45.5
Banana	9.6	58.3	3.3	62.5
Banana + Cassava	6.7	70.9	1.9	78.4
Leucaena	10.4	54.8	3.7	57.9
Leucaena + Cassva	5.8	74.8	2.1	76.1
Eucalyptus	10.0	56.5	4.4	50.0
Eucalyptus + Cassava	6.2	73.0	1.9	78.4

Source : Ghosh *et al.*, 1985 and 1987.

Soil Fertility Management

In order to increase crop production per unit area, soil fertility management is one of the important factors. Though cassava is well adapted to low fertility conditions it can respond very well to fertilization as evidenced by research conducted all over the world.

Nutrient removal:

The nutrient requirement of cassava is fairly high because of its high biological yield. Under favorable growing conditions cassava produces about 30 – 40 tons of fresh roots per ha, for which considerable amounts of nutrients are removed from the soil. It was observed that monocropped cassava removed 180 – 200 kg N, 15 – 22 kg P and 140 – 160 kg K per ha for different cultivars grown in an Oxisol (CTCRI, 1983). However, when grown in association with other crops the uptake pattern may differ. The nutrient uptake of cassava grown under different crop combinations, viz. banana, *Leucaena*, eucalytus and coconut, was studied in an upland laterite soil (Oxisol) of medium fertility (Table 15). From three years results it was observed that the nutrient uptake of cassava in association with banana was more or equal to that of

Table 15. Nutrient uptake by cassava under different cassava-based multiple cropping systems.

Crop combinations	Nutrient uptake of Cassava (kg/ha)*				
	N	P	K	Ca	Mg
Banana + Cassava	213.4	14.6	126.9	50.7	21.8
Leucaena + Cassava	125.3	8.8	67.5	21.7	13.1
Eucalyptus + Cassava	101.3	6.5	44.6	20.4	12.3
Coconut + Cassava	140.8	8.3	66.6	25.8	14.7
Cassava alone	196.3	13.2	106.5	40.8	21.8

*tops + roots

Source : Ghosh *et al.*, 1987.

monocropped cassava, while cassava in association with eucalyptus recorded the lowest nutrient uptake (Ghosh *et al.*, 1987). Under lowland conditions the nutrients removed by cassava (H-1687) grown in sequence with other crops like rice, groundnut and cowpea did not exhibit much variation in the quantities of nutrients removed (Table 16). The maximum total removal of nutrients was 324 kg N, 46 kg P, and 304 kg K/ha for the crop sequence cassava-groundnut (CTCRI, 1986).

Table 16. Nutrient removal by cassava under different crop sequences.

Crop sequence	Nutrient removal by cassava (kg/ha)*		
	N	P	K
Rice-Cassava	204.9	35.0	308.5
Cassava-groundnut	233.8	38.5	264.6
Veg. Cowpea-cassava	201.1	30.6	210.3

*tops + roots + fallen leaves.

Source : CTCRI Annual Report, 1986

Fertilizer requirement:

In order to formulate fertilizer recommendations for cassava in 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 farm yard manure (FYM) and 100 kg/ha of N, P_2O_5 and K_2O each, produced the highest yield (Mandal *et al.*, 1973). Of the different combinations of N, P, and K tried, either alone or in combination with FYM, maximum root yields were recorded for the treatment FYM + NPK (Mohankumar *et al.*, 1976). Pillai *et al.*, (1985) reported that for continuous cultivation of cassava in laterite soil, a combined application of 12.5 t/ha FYM and 100 kg/ha each of N, P_2O_5 and K_2O was highly beneficial in increasing the yield and quality of cassava roots and also for maintaining the fertility of the soil.

Response to nutrients:

I) Nitrogen: In lateritic soils of India the rate of decomposition of organic matter and loss of N are high. Hence the crop's response to applied N can be high under this type of tropical climate. Among different sources of N (calcium ammonium nitrate (CAN), ammonium phosphate, ammonium sulfate, urea, and sodium nitrate) CAN was found to be the best for cassava in laterite soil, followed by urea. Among the different levels of N applied (0, 50, 100, 150 and 200 kg N/ha) 100 kg N/ha was found to be optimum, beyond which the yield either tended to decrease or remained constant. Application of this dose as two splits, viz. half as basal and the other half after one or two months after planting, was found to be superior to other split applications (Mandal *et al.*, 1971). Application of urea, half to the soil and half as a foliar spray was found to be most effective and economic and it was found to reduce the HCN content of roots.

Vijayan and Aiyer (1969) reported that the mean number of roots per plant increased with an increase in N levels from 0 to 75 kg N/ha in cassava cultivars M4 and H-165 grown on a red loam soil. Ashokan and Sreedharan (1977) observed that the length, girth and number of

tuberous roots in cassava were not significantly affected by different levels of N. The plant height, number of nodes and number of functional leaves of cassava, however, were found to increase with an increase in N level whereas the leaf N content increased only upto 125 kg N/ha (CTCRI, 1983).

Many workers such as Mandal *et al.* (1971), Natarajan (1975), Pillai and George (1978) reported the beneficial effect of N in increasing the starch content of cassava roots. However, Vijayan and Aiyer (1969) observed a decrease in starch content with increasing N levels.

2) Phosphorus: As compared to other nutrients the requirement and removal of P by cassava is very low. However, a high response to P application can be obtained in virgin Oxisols due to their low available P content and high P fixing capacity. The citrate soluble forms of P fertilizers, viz. basic slag and ultra phosphate, were compared with common water-soluble superphosphate in acid laterite soil. Basic slag was found to be the most economical P source. Citrate soluble forms were found to increase the available P content of the soil. The P uptake by the plant was also greater (about 15%) in the case of citrate soluble P (CTCRI, 1969 – 70).

In acid laterite soil of Kerala with low available P content (5 – 7 ppm P) cassava responded to P application upto 100 kg P_2O_5/ha. However, continuous application of P at 100 kg P_2O_5/ha resulted in a build up of P in the soil to a level of 50 ppm P, and there was no response to further P application (CTCRI, 1983 – 85). It was observed that in this case during five years of no further P application (control plots) the available P level decreased again from 50 to 8 ppm.

Vijayan and Aiyer (1969) also reported highest yields with 100 – 150 kg P_2O_5/ha in combination with 100 kg N and 100 kg K_2O/ha. Among the different times of P application it was observed that full dose of P applied at planting was superior to other applications. Three depths of P application, viz. surface, 7 cm depth, and 14 cm depth, were tried and it was observed that the depth of P application did not significantly influence the yield of cassava roots.

Vijayan and Aiyer (1969) reported that application of P up to 100 kg P_2O_5/ha enhanced the starch content and reduced the HCN content. However, Muthuswamy *et al.* (1974) reported that application of P had no significant influence on the quality parameters like dry matter, starch and crude protein content with higher levels of P application, especially in combination with N. Thomas Kurian *et al.* (1976) found that there was a significant reduction in HCN content of cassava roots due to P application.

3) Potassium: Since K is involved in the synthesis and translocation of carbohydrates this element is very important for the growth of cassava. Two indigenous sources of K, viz. Schoenite and Syngenite, were compared with KCl and wood ash at different levels of K_2O (0, 50, 100 and 150 kg/ha) in acid laterite soil of Kerala. The two indigenous sources, containing 24% K_2O, were equal to KCl in increasing the root yield of cassava. Increasing levels of K application resulted in an increase in starch content and a decrease in HCN content of roots (Table 17). Among different levels tried, 100 kg K_2O/ha was generally found to be optimum for root yield of cassava (Nair *et al.*, 1980).

Table 17. Root yield and quality of cassava as affected by different sources and levels of potassium.

Treatment	Root yield (t/ha)	Starch (FW. basis) (%)	HCN (ppm)
Schoenite	28.90	27.7	95.6
Syngenite	27.69	28.6	97.2
KCl	28.09	29.0	91.2
Wood ash	29.20	28.7	84.3
0 kg K_2O/ha	25.54	26.8	105.6
50 kg K_2O/ha	27.68	28.1	92.8
100 kg K_2O/ha	30.74	29.1	80.0
150 kg K_2O/ha	29.94	28.7	87.4
C.D. (0.05) for levels :	3.02		

Source : Nair *et al.*, 1980.

Split application of K, viz. half dose as basal and half dose after one/two months after planting, was found to be superior to other split applications. The starch and dry matter content of roots were also greater for the above split application (Mohankumar *et al.*, 1971). Application of K at 100 kg K_2O/ha was found to produce maximum yields of 28.2 t/ha as compared to 21.6 t/ha in the control plot, the increase in yield being around 30%. The root yield was found to decrease beyond 100 kg K_2O/ha (Figure 6), whereas the concentration of K in different plant parts increased, which may be attributed to luxury consumption of K (Mohankumar *et al.*, 1971).

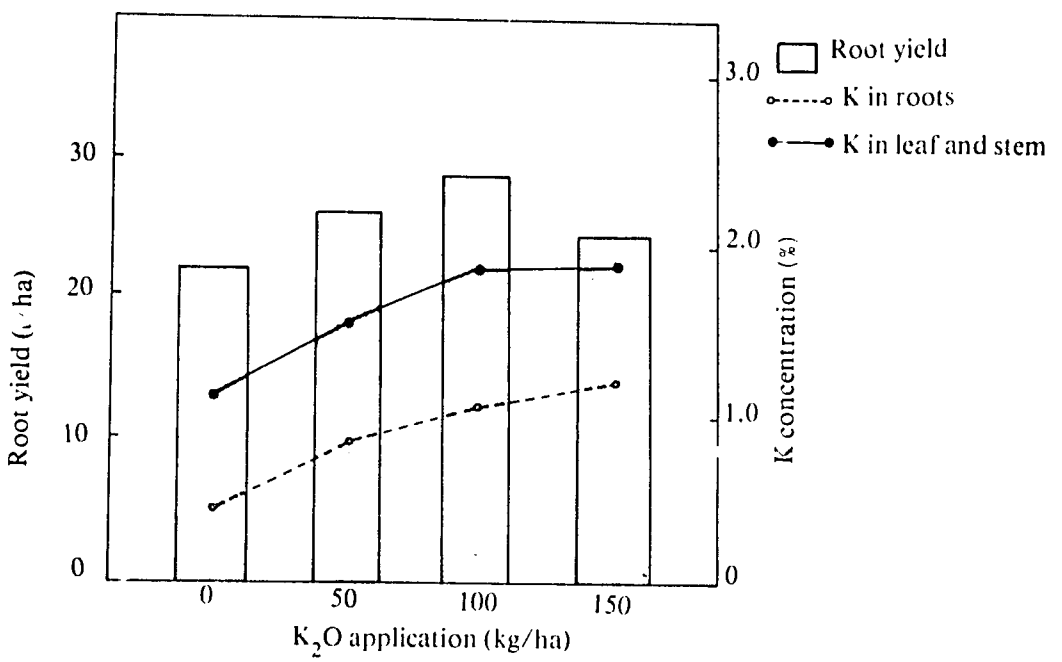

Figure 6. Root yield and K concentration of cassava at different levels of potassium application.

Ashokan and Sreedharan (1977) observed a maximum root yield of cultivar H-97 with the application of 93 kg K_2O/ha and Nair and Sadanandan (1985) with 125 kg K_2O/ha for cultivar H-2304 in red loam soils of Kerala. Ramaswamy and Muthukrishnan (1980) did not observe any significant effect on root yield due to higher levels of K application.

A significant influence on root size due to application of 100 kg K_2O/ha was reported by CTCRI (1972). Pushpadas and Aiyer (1976) also reported an increase in number of roots per plant with K application. In a coconut garden at Pilicode intercropped cassava did not show any significant yield increase due to K application at higher levels (KAU, 1984). Pushpadas and Aiyer (1976) observed maximum starch yield at 208 kg K_2O/ha, whereas Nair *et al.* (1980) reported only a slight increase in starch content by K fertilization.

For a sandy loam soil of Trichur (Kerala) having 153 ppm available K, application of 50 kg K_2O/ha along with 50 kg N/ha was sufficient to produce maximum yields (Ashokan and Vikraman Nair, 1982). In a red sandy loam soil, after its available K content had decreased from 75 to 32 ppm by growing cassava intercropped with guinea grass in succession, cassava also showed a response to the application of 100 kg K_2O/ha and this dose was found to maintain the soil at a reasonable K status (Table 18). On the basis of a critical level of 1.85% K in the leaf blade, the optimum amount of K for this exhausted soil was calculated to be about 128 kg K_2O/ha, as obtained from the response curve (Aiyer and Nair, 1987).

Table 18. Cassava root yield and potassium status of the soil before and after growing cassava with various levels of potassium fertilizer.

Treatment (kg K_2O/ha)	Root yield (t/ha)	Available K (ppm)		Total K (ppm)	
		Before cropping	After cropping	Before cropping	After cropping
0	17.9	32	29	1141	1133
50	24.2		42		1140
100	30.9		63		1167
150	28.3		84		1183
200	27.5		93		1197

Source : Adapted from Aiyer and Nair, 1987.

4) N : K Interaction: The interaction of N and K application on cassava was studied using different NK ratios. The root yield response indicated that application of 100 kg N and 100 kg K_2O/ha was the optimum (average yield 27.1 t/ha) as compared to 23.6 t/ha when 100 kg N and 50 kg K_2O/ha were applied to different cultivars (Table 19).

It was also observed that with increasing doses of K application the amount of K in the soil increased after the harvest of the crop, thereby suggesting the possibility of a small residual effect due to high rates of K application above 100 kg K_2O/ha (Rajendran *et al.*, 1976).

Table 19. Root yield of three cassava cultivars at different levels of N and K application.

Treatment N: K_2O (kg/ha)	Root yield (t/ha)			
	H-165	H-97	M-4	Mean
100 : 50	26.3	25.6	18.9	23.6
100 : 75	30.2	25.1	17.3	24.2
100 : 100	32.7	30.[illegible]	18.5	27.1
100 : 150	29.9	24.5	18.9	24.4
100 : 200	29.6	24.5	17.9	24.0
CD (0.05) for cultivars : 4.38				
for treatments : 1.97				

Source : Rajendran *et al.*, 1976.

Liming:

Liming is a common practice for ameliorating soil acidity and thereby increasing the efficiency of applied nutrients. On a laterite soil in Kerala the application of 1000 kg ha of $CaCO_3$ increased cassava yields from 16.7 to 25.2 t/ha, while the combination (equal proportion) of $CaCO_3$ and $MgCO_3$ at a total level of 1000 kg/ha increased yields to 23.5 t/ha. By the application of these liming materials the starch content of roots increased and the HCN content decreased (Nair and Varghese, 1970).

Further detailed studies using different levels of lime as burned lime (CaO), ranging from 0 to 2000 kg CaO/ha, in conjunction with the recommended dose of NPK at 100 kg/ha each, revealed that the increase in root yield was as high as 38.6% at 2000 kg CaO/ha as compared to the control (Table 20).

Table 20. Root yield and quality as affected by different levels of lime.

Level of lime (kg CaO/ha)	Root yield (t/ha)	Starch (%) (DW basis)	HCN (ppm)
0	18.76	86.5	54.8
500	22.19	88.4	46.1
1000	23.54	88.4	50.1
1500	22.66	89.3	46.2
2000	26.00	88.4	40.8
CD (0.05) :	3.35		

Source : Mohankumar and Nair, 1985.

Lime not only increased the root yield but also improved the quality by increasing the starch content and decreasing the level of HCN. Application of 2000 kg CaO/ha was found to increase the soil pH by 2 units (from 4.55 to 6.61) 3 months after planting (Figure 7). It also increased the available P level and exchangeable Ca content of the soil. The residual effect of lime on the productivity of the succeeding cassava crop was not significant and annual application of lime at 2000 kg CaO/ha was found to be beneficial (Mohankumar and Nair, 1985).

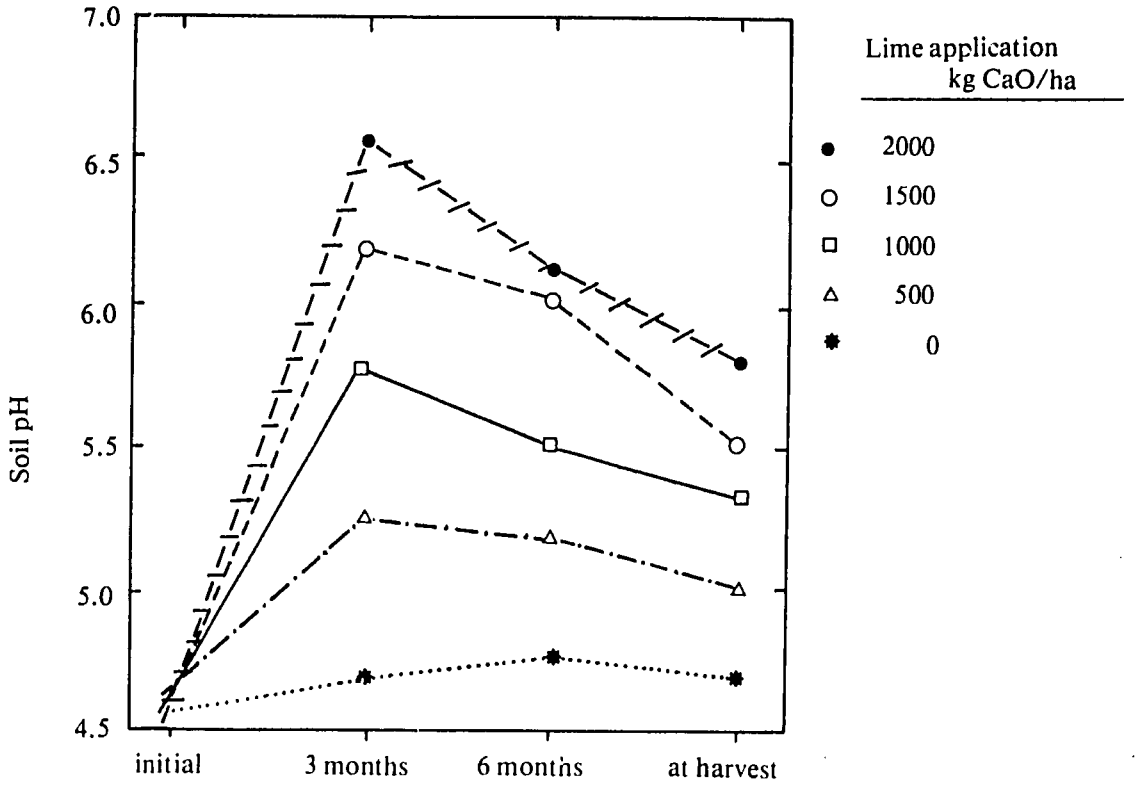

Figure 7. Soil pH at different stages of the cassava crop as affected by varying levels of lime application.

Sulphur:

The response of cassava to S application at 50 kg S/ha through S-containing fertilizers (single superphosphate, ammonium sulfate and ammophos) in an acid laterite soil of low available S content (6.62 ppm), was found to be significant and the yield increase was 3.94 t/ha, i.e. 18% more than the control (Figure 8). Application of S resulted in an increase in starch and methionine content and a decrease in HCN content of roots. The available S content of the soil and S uptake by the plant also increased due to S application, (Figure 9) (Mohankumar and Nair, 1983).

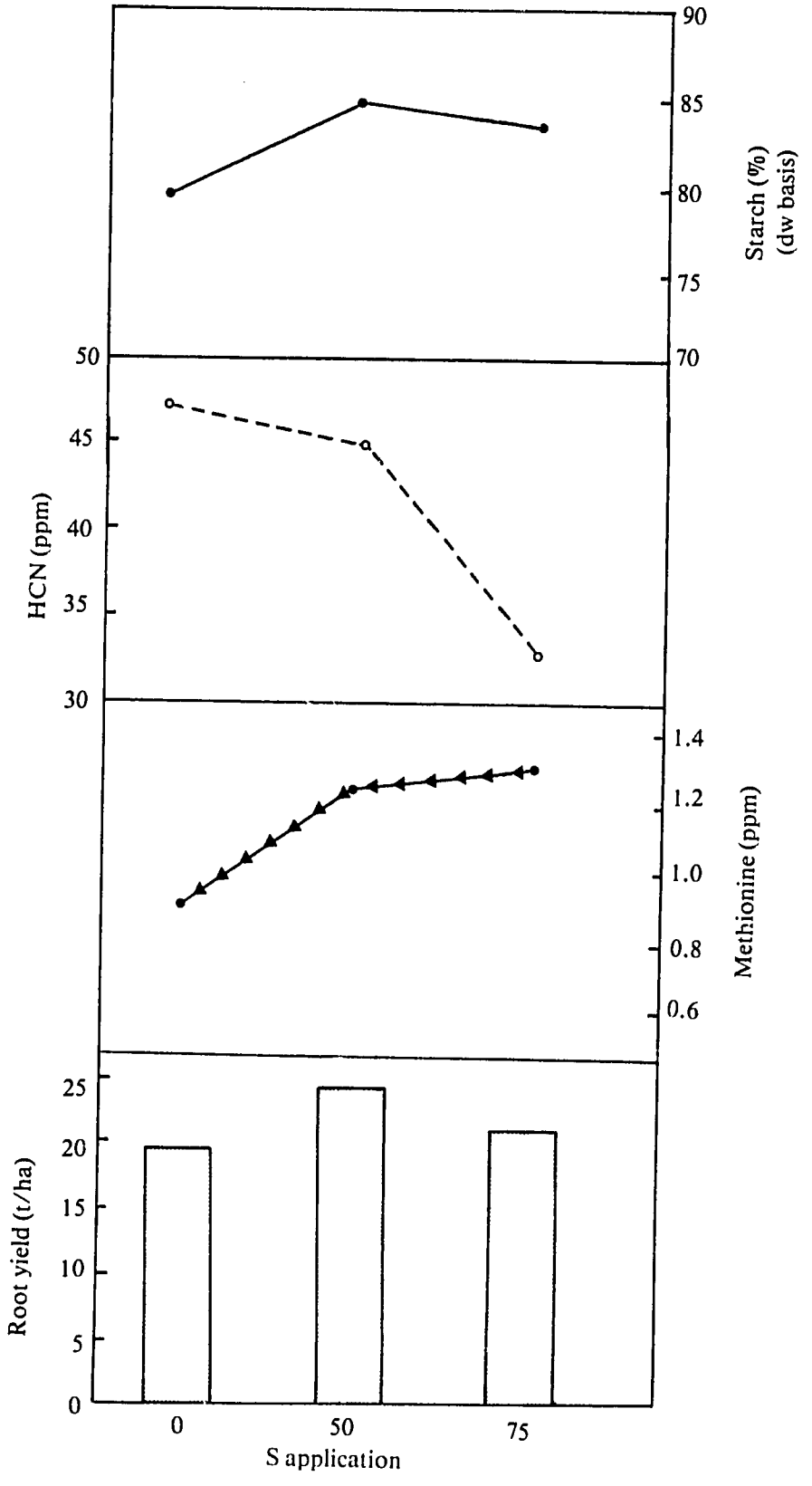

Figure 8. Effect of sulfur application on cassava root yield, and the starch, HCN, and methionine content of roots.

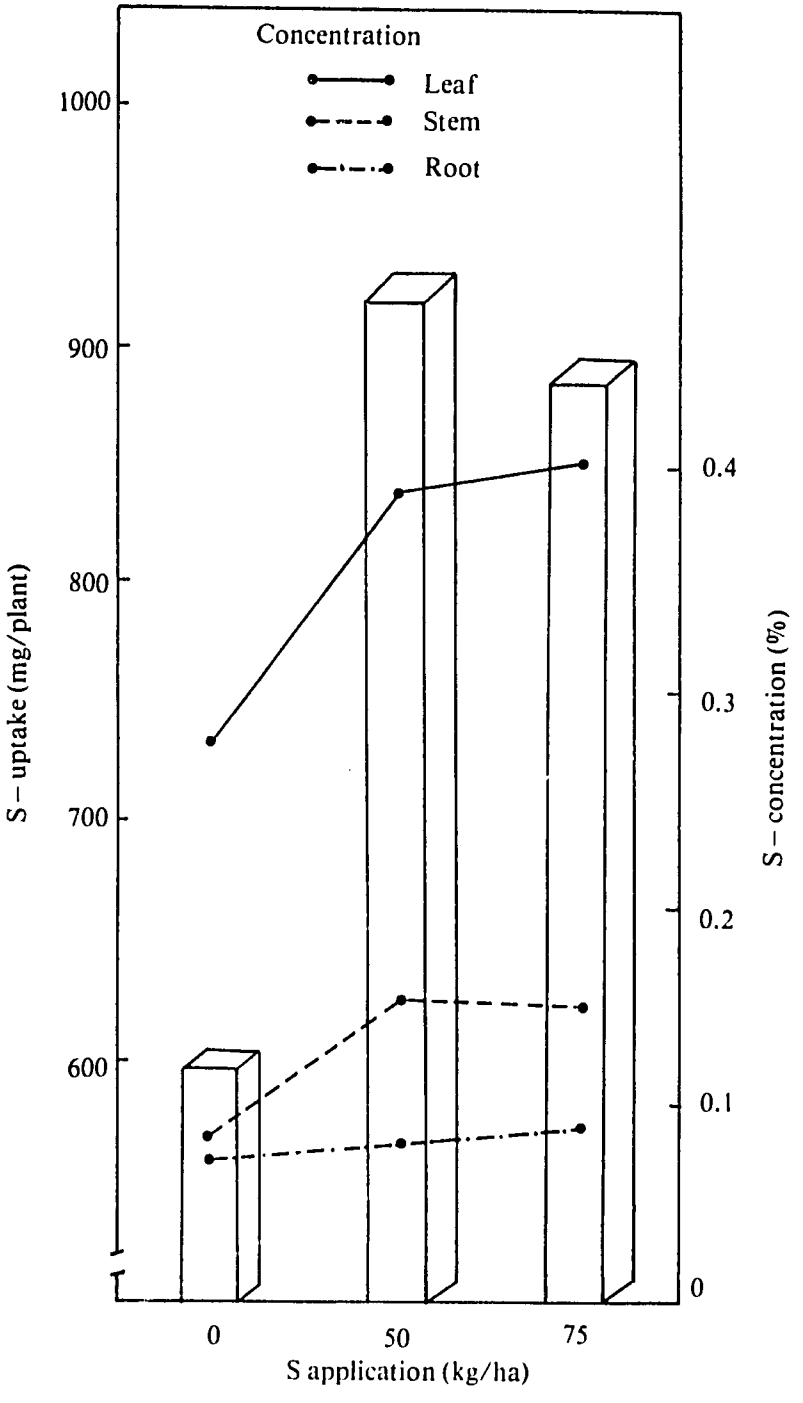

Figure 9. Effect of S application on total S-uptake and S concentration in the plant.

Micronutrients:

With the introduction of high yielding cultivars and with the use of high analysis fertilizers, the application of micronutrients, particularly zinc, has gained considerable importance. In acid laterite soil of Kerala, cassava responded significantly to soil application of Zn, Mo and B at 12.5, 1.0 and 10.0 kg/ha of Zinc sulfate, ammonium molybdate, and borax, respectively, along with 100 kg/ha each of N, P_2O_5 and K_2O. Yield increases of 4.0, 2.8 and 3.1 t/ha were obtained by the application of Zn, Mo and B at the above rates (Table 21) (Nair and Mohankumar, 1980).

Detailed studies using different levels of Zn., viz. 0, 2.5 and 5.0 kg Zn/ha, showed that the application of 2.5 kg Zn/ha as $ZnSO_4 . 7H_2O$ resulted in the highest root yield, increasing the yield by 3.0 t/ha, i.e. 12.8% over the control. Application of Zn also increased the starch and reduced the HCN content of roots (Table 22) (Mohankumar and Nair, 1985).

Table 21. Root yield, starch and HCN content of cassava as influenced by micronutrient applications.

Treatment	Rate	Yield (t/ha)	Starch (%)	HCN (ppm)
Mn	25 kg/ha of Mangasese sulfate	26.8	27.0	101.7
Zn	12.5 kg/ha of Zinc sulfate	29.4	29.6	90.3
Cu	12.5 kg/ha of Copper sulfate	26.9	27.2	99.2
B	10 kg/ha of Borax	28.5	28.1	96.8
Mo	1 kg/ha of Amm. molybdate	28.2	29.5	115.9
All		30.1	29.2	110.5
Control		25.4	27.6	119.6
CD (0.05) :		1.6		

Source : Nair and Mohankumar, 1980.

Table 22. Yield and quality of cassava at different levels of zinc application.

Levels of Zn (kg/ha)	Root yield (t/ha)	Starch (%)	HCN (ppm)
0	23.4	24.9	52.0
2.5	26.4	25.3	41.6
5.0	26.5	26.7	38.1

Source : Mohankumar and Nair, 1985.

Future Directions and Priority Areas

1. Multiple cropping systems with cassava: Since root crops, especially cassava, are well adapted to a wide range of soil and climatic conditions, they can be successfully introduced in non-traditional areas both as a monocrop and mixed crop. In multiple cropping systems shorter duration varieties of cassava may be introduced, and shade tolerant varieties of cassava, which can grow well under coconut, are to be developed.

2. Water management: Preliminary studies on irrigation of cassava showed that the crop is highly responsive to irrigation in times of moisture stress. Hence it is necessary to initiate

water management studies on cassava to understand the critical times of irrigation and the crop's water requirement. This study further envisages soil conservation, water nutrient interaction and agronomic practices for slopy land. Water management studies are also important for off-season planting in order to ensure the steady supply of raw materials to the starch industry.

3. Development of agro-techniques for cassava under low-land conditions: Since the soil physical condition, moisture regime, fertility status, moisture holding capacity etc. are all different under dry v.s. low land conditions, detailed studies have to be undertaken for the formulation of packages of practices under each situation.

4. Low-input technology: Replacement of FYM through *in situ* cultivation and incorporation of short duration dual purpose leguminous crops, economizing P fertilization by the use of citrate soluble rock phosphate, reducing the level of application, and selection of suitable crops for sequential cropping are some of the low-input technologies which need attention. Preliminary studies conducted along these lines are encouraging.

5. Cultivars: Production of high quality planting material of high yielding and acceptable quality cultivars for large scale cultivation in farmers' fields.

6. Crop-weather studies: Research on the effect of various meteorological parameters on cassava yield would give useful information about the importance of climatic characteristics on the growth and yield of cassava under a particular situation.

7. Nutrient budgeting and partial production effeciency of various nutrients: As only a portion of the applied nutrients is used by the crop, the fate of the added nutrients in the soil is different for various elements. Hence it is important to have a budgeting of the nutrients added to the soil so as to assess the removal by the crop, various losses and fixation in the soil.

8. Micro-nutrient studies: Due to continuous cultivation of cassava, the soil may become exhausted and may not be able to supply all the essential elements, thus the crop may exhibit deficiency symptoms of the most limiting elements or suffer from yield reductions due to hidden hunger. Identification and supply of these limiting elements are very important at the appropriate stage.

9. Basic studies on nutrient uptake patterns and utilization: Soil tests and crop response correlation studies are very useful in the refinement of the critical limits of nutrients in soil for efficient use of fertilizers for various crops.

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AGRONOMIC RESEARCH ON CASSAVA IN THE PHILIPPINES

Federico G. Villamayor, Jr.[1/]

Introduction

The Philippines has a total land area of about 30 million hectares, 41% of which are devoted to different agricultural crops. Of these agricultural lands (Table 1), the major crops grown are corn (29%), rice (28%), and coconut (27%). Cassava occupies only a total of 218,000 hectares, or only 1.8% of the total agricultural land. This shows that cassava is a very minor crop in the country, except in Sulu, Basilan, Tawi-tawi and other parts of Mindanao where cassava is the main carbohydrate source, particularly for the Muslim Filipinos. However, in many marginal lands where rice and corn are not suitable, cassava and sweet potato are the usual energy source for the farmers. In terms of uses, cassava is mainly utilized as food (staple and snack items), as raw materials in starch factories and as animal feed.

Table 1. Land utilization among selected crops in the Philippines for crop year 1986.

Crop	Area (Ha)	Percent of total
Rice	3,402,610	27.81
Corn	3,544,730	28.97
Coconut	3,261,473	26.65
Cassava	218,100	1.78
Sweet potato	164,770	1.35
All others*	1,645,505	13.44
Total	12,237,238	100.00

*Include sugarcane, tobacco, cotton, abaca, vegetables, spices and fruit trees.

Source : BAECON, 1987.

Cassava Growing Areas

Geographically, the Philippines can be divied into three main areas namely, Luzon (Northern Philippines), Visayas (Central Philippines), and Mindanao (Southern Philippines). The top ten cassava producing provinces are shown in Table 2 and the distribution of cassava growing areas is indicated in Figure 1. About 82% of cassava production for crop year 1986 were accounted for by these 10 provinces. Cassava production was mainly concentrated in

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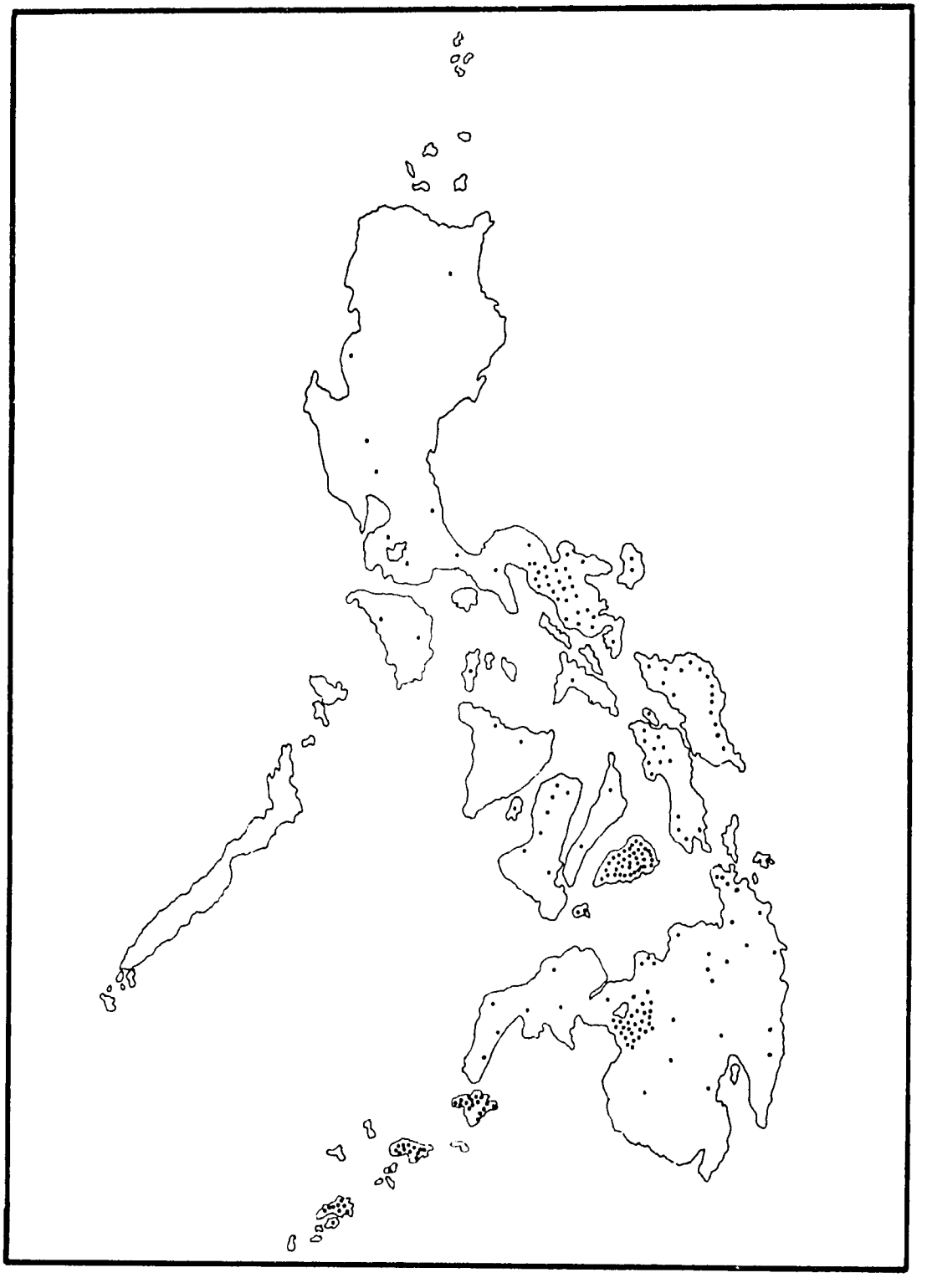

Figure 1. Cassava production areas in the Philippines. Each dot represents 1000 ha in 1986.

three Mindanao provinces (Lanao del Sur, Basilan, and Sulu), five Visayan provinces (Bohol, Leyte, Negros Occidental, Western Samar and Eastern Samar) and two Luzon provinces (Camarines Sur and Albay). The relatively high production data for Lanao del Sur is due to the presence of three starch factories with the total annual rated capacity of 174,000 tons of fresh roots (Jayme, 1982).

The data presented in Table 2, taken from the national office of the Bureau of Agricultural Economics (BAECON), should be treated with reservation as they are not accurate. Perhaps, what should be given credence is the relative values or ranking and not the figures *per se*. For example, the data supplied by the BAECON provincial office of Basilan showed an area of 9,100 hectares in contrast to 16,170 hectares (Table 2) and a production of 182,000 tons as opposed to 150,192 (Table 2) or a yield of 20 t/ha versus 9.3 t/ha (Table 2). This comment is not meant to criticize the BAECON but merely to point out difficulties in making yield estimates for cassava, especially for subsistence farmers who harvest the crop in a staggered manner as shown in Table 3 (Villamayor *et al.*, 1987). The estimate of yield by farmers is usually low compared with that obtained through actual yield sampling. The yield estimates of BAECON and those of farmers are very similar.

Table 2. The ten leading cassava producing provinces in the Philippines for crop year 1986.

Provinces	Production (t)	Percent of total	Area (ha)	Percent of total	Average yield (t/ha)
Lanao del Sur	714,000	41.35	27,600	12.65	25.9
Basilan	150,192	8.70	16,170	7.41	9.3
Camarines Sur	146,598	8.49	19,500	8.94	7.5
Bohol	140,728	8.15	37,100	17.01	3.8
Sulu	107,638	6.23	23,090	10.59	4.7
Albay	49,655	2.88	5,670	2.60	8.8
Leyte	34,928	2.02	9,676	4.44	3.6
Negros Occidental	25,122	1.46	6,510	2.98	3.9
Western Samar	24,642	1.43	5,550	2.54	4.4
Eastern Samar	19,250	1.11	2,500	1.15	7.7
Total for 10 Provinces	1,412,745	81.82	153,366	70.31	9.2
Total for the philippines	1,726,587	100.00	218,000	100.00	7.9

Source : BAECON, 1987.

Table 3. Frequency distributions (n = 100) of yield estimated by cassava farmers and that based on field sampling in Leyte.

Yield (t/ha)	Yield estimates	
	Farmers	Field sampling
0.1 4.0	82.5	9.0
4.1 8.0	14.0	22.0
8.1 12.0	1.0	42.0
12.1 16.0	2.5	27.0

Source : Villamayor *et al.*, 1987.

Climatic and Edaphic Characteristics of Cassava Growing Areas

Based on the annual rainfall distribution, the country can be divided into 12 agroclimatic zones, as shown in Figure 2 (Angus and Manalo, 1979). A month is considered wet when rainfall exceeds 200 mm and dry when rainfall is less than 100 mm. The type of climate for the top ten cassava growing provinces is shown in Table 4. A representative rainfall distribution for each province is shown in Figure 3, except for Lanao del Sur and Basilan where data were not available. Generally, there are relatively more wet months than dry months and rainfall exceeds 2,000 mm annually for these ten provinces. There is also a minor difference within a given agroclimatic zone in terms of peak rainfall exceeding 500 mm per month. For example, Western and Eastern Samar belong to the same agroclimatic zone, but the latter has three months exceeding 500 mm of rain (Figures 2 and 3).

Table 4. Agroclimatic zones and dominant soil texture types of the ten major cassava growing provinces.

Provinces	Climatic zone	Dominant soil texture
Lanao del Sur	B1, C1	Silt loam, sandy loam, clay loam
Basilan	C2, C3, E2	Clay loam
Camarines Sur	C1, C2	Clay, clay loam, loam
Bohol	D1, D2, E2	Clay, clay loam, silt loam
Sulu	D2	Clay loam, loam, silt loam
Albay	A1, B1, C1, C2	Clay, clay loam, loam, silt loam
Leyte	D1, D2, C1, C2	Clay, clay loam, silt loam, sandy loam
Negros Occidental	B2, C2, D2	Clay, clay loam, silt loam, loam
Western Samar	B1	Clay, clay loam, loamy sand
Eastern Samar	B1	Clay, clay loam, silt loam, loamy sand

Source : Angus and Manalo, 1979; PCARR, 1978.

Table 4 shows that the majority of the soils in the cassava growing provinces have a clay or clay loam texture. The Bureau of Soils, Department of Agriculture, is still in the process of classifying Philippines soils using the USDA Soil Taxonomy System. For the area already studied, there are at least four soil orders used for cassava cultivation namely, Inceptisols, Alfisols, and Mollisols in Bohol, and Ultisols in Albay. Figure 4 shows a preliminary soil map adapted from the FAO Soil Map of the World.

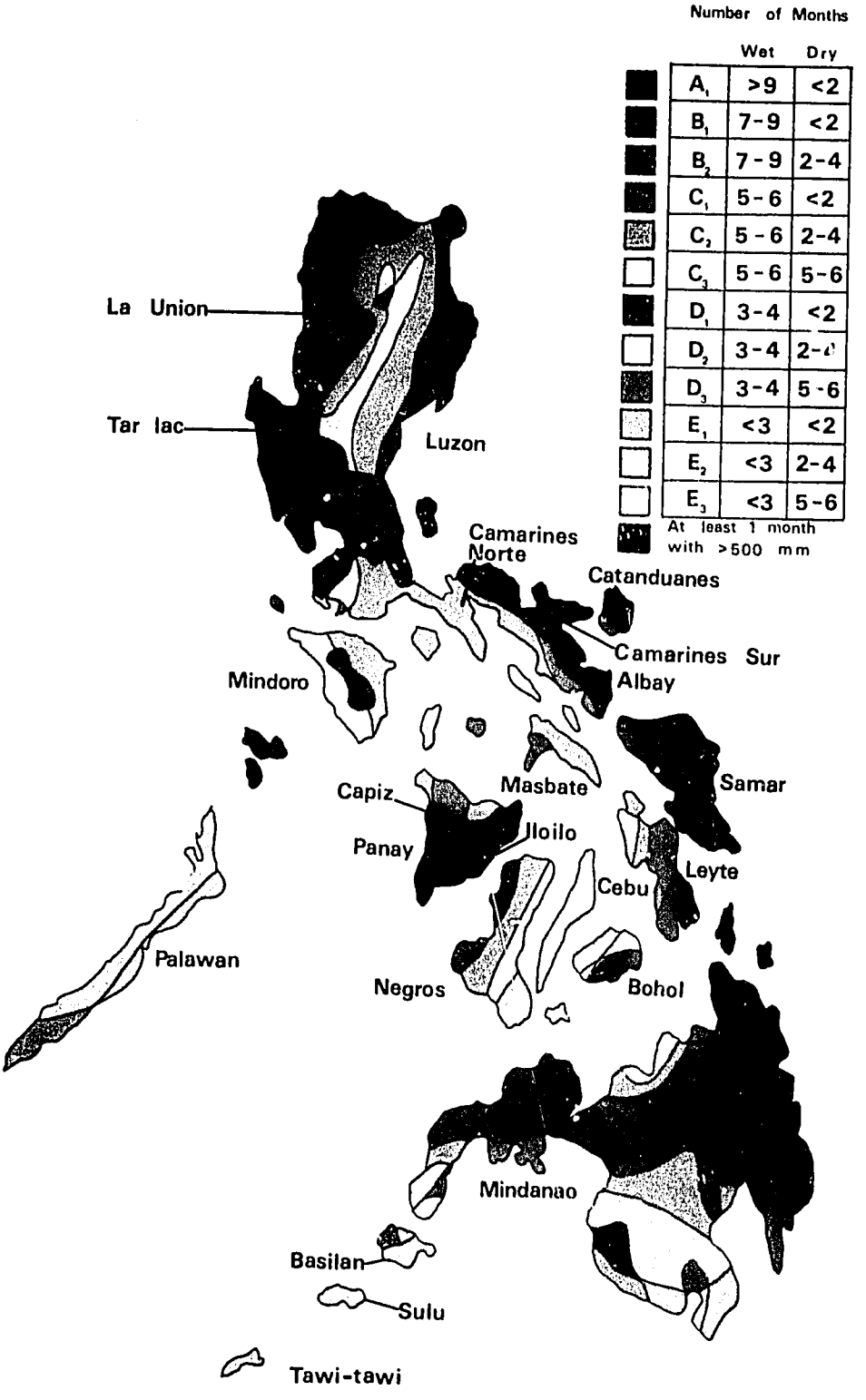

Figure 2. Agroclimatic map of the Philippines based on rainfall distribution (Adapted from Angus and Manalo, 1979). Dry month: <100 mm rain; wet month: >200 mm rain.

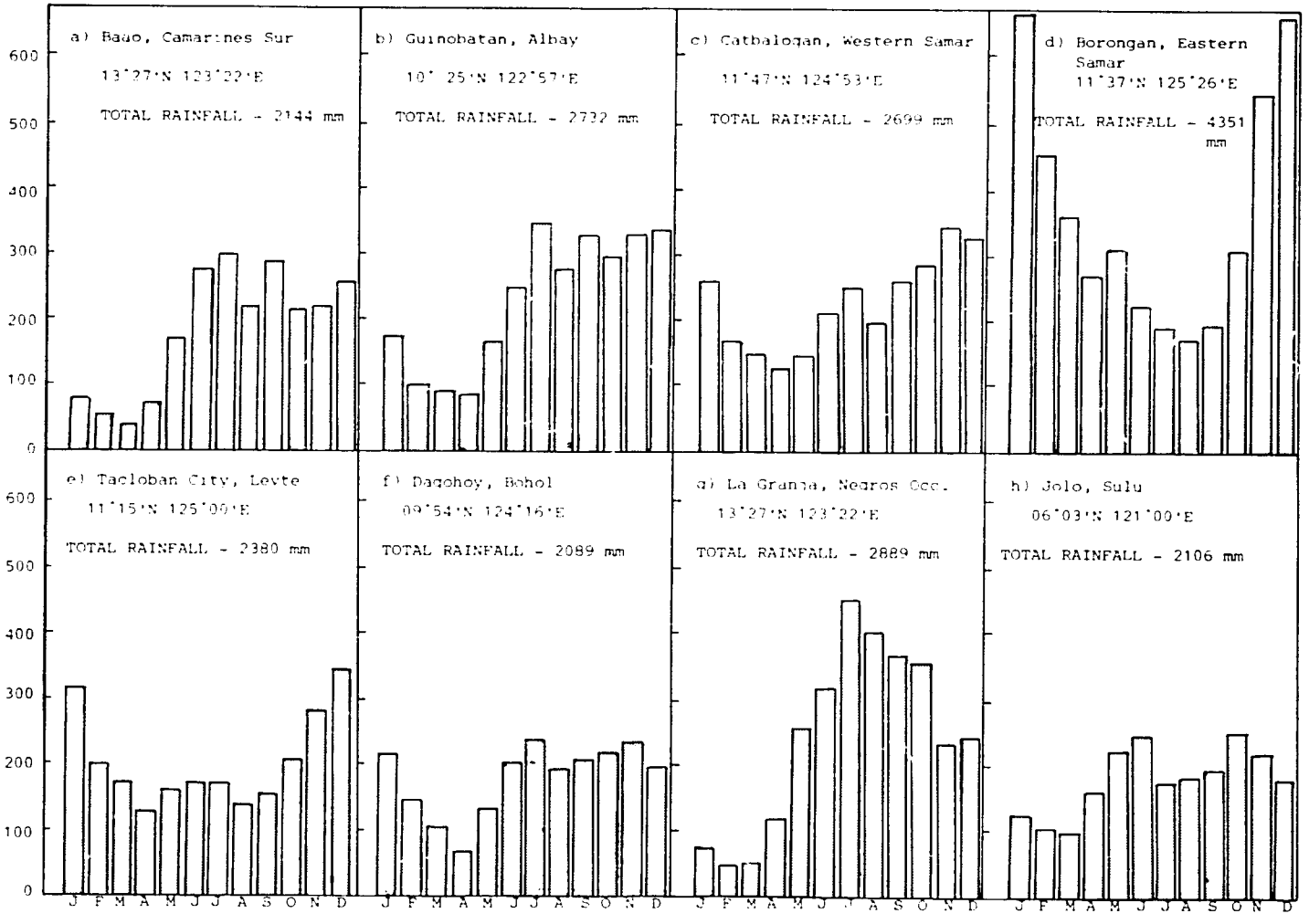

Figure 3. Rainfall distribution in a) Baao, Camarines Sur b) Guinobatan, Albay c) Catbalogan, Western Samar d) Borongan, Eastern Samar e) Tacloban City, Leyte f) Dagohoy, Bohol g) La Granja, Negros Occ. h) Jolo, Sulu.

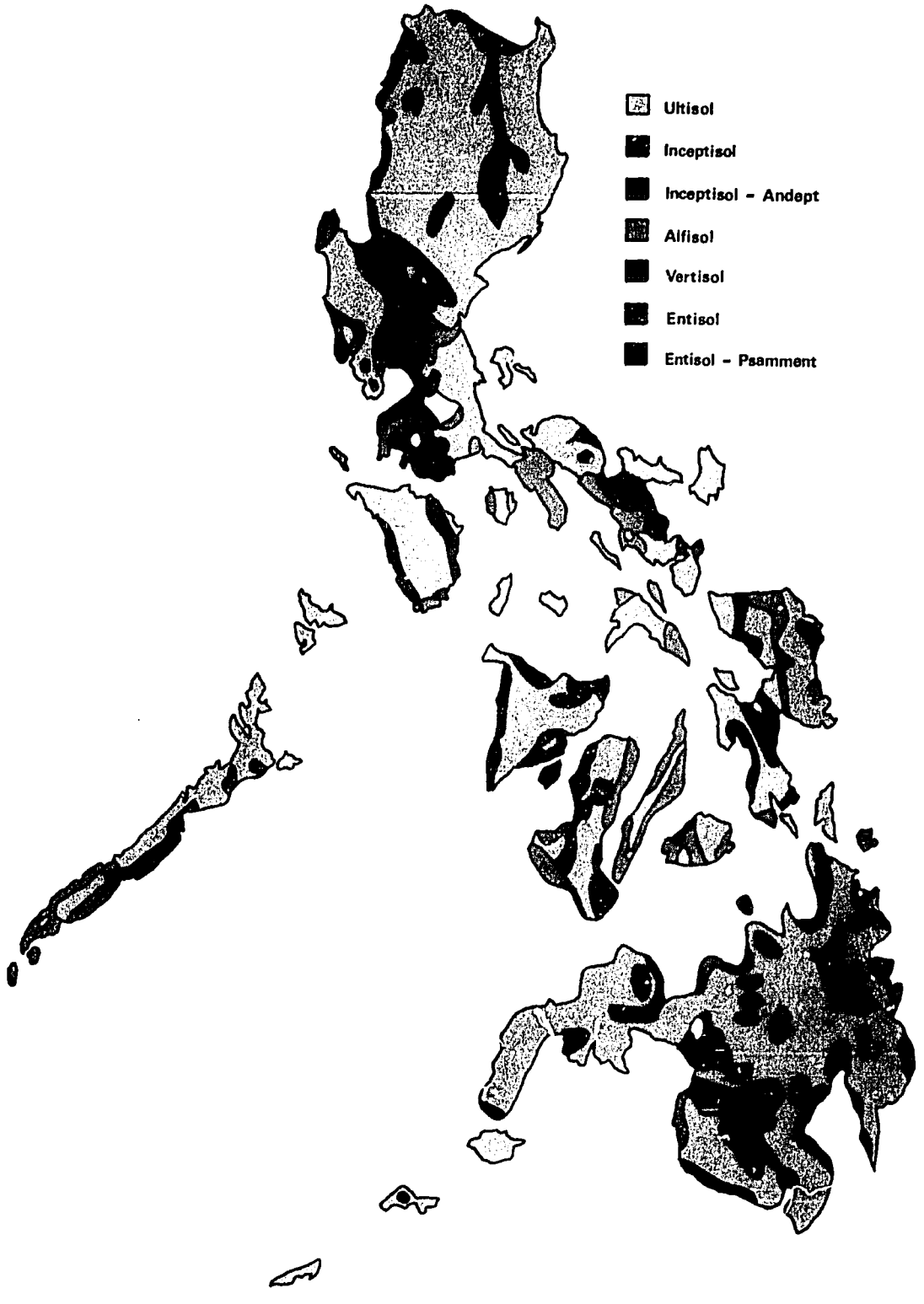

Figure 4. Soil map of the Philippines.

Source : Adapted from FAO Soil Map of the World, 1979, by R. Howeler.

Table 5. Frequency distribution of soil chemical characteristics in cassava growing areas of Leyte with n = 100.

Soil characteristics	Frequency (%)	Soil characteristics	Frequency (%)
pH		Olsen P (ppm)	
4.0 – 5.0	7.0	1.0 – 5.0	88.0
5.1 – 7.0	79.0	5.1 – 10.0	5.0
7.1 – 9.0	14.0	> 10.0	7.0
OM (%)		NH_4Ac K (ppm)	
1.0 – 4.0	48.0	1 – 100	19.0
4.1 – 8.0	41.0	101 – 200	58.0
8.1 – 12.0	11.0	> 200	23.0

Source : Villamayor *et al.*, 1987.

Results of a study on some soil chemical properties of areas grown to cassava in Leyte are shown in Table 5 (Villamayor *et al.*, 1987). The nutrients that appear to be limiting are mainly N and P. The soil pH is generally favorable, while soil K seems to be adequate in most farms sampled.

Cultivation Methods

The methods employed in the production of cassava vary according to the type of farms, as summarized in Table 6. The differences in the production methods are mainly due to the size of the farm, the topography, the intended use of the product, and the financial resources of the grower.

In subsistence farms, cassava is primarily grown for food in marginal lands, usually having a rolling or hilly topography. There is minimal land preparation, no insect or disease control, no fertilization, and minimal weed control. In short, there is minimum labor input. Harvesting is as early as four months when there are already roots big enough for cooking, and continues until all the crop is harvested. Some farmers plant immediately the harvested hills but in most cases the land is fallowed or rotated with other crops.

In the case of plantations, cassava is grown in flat to rolling lands with all necessary inputs to ensure high production. Better cultural management practices are used in these farms because of available financial resources. The higher the production, the longer the starch factory operates and the more profit the factory obtains. The plantation and the starch factory have the same owner.

The commercial farms are hybrids between subsistence and plantation farms. These are usually located at the periphery of the starch factories. They sell most of the produce to the starch factory. They usually get technical and financial assistance from the factories, but they have to sell the produce at a pre-agreed price. This type of relationship is usually mutually beneficial.

Table 6. General comparison among subsistence, commercial and plantation type of cassava farms in the Philippines.

Factors	Subsistence	Commercial	Plantation
Farm size (ha)	< 0.50	1 - 10	>100
Topography	Rolling to hilly	Flat to rolling	Flat to rolling
Land preparation/cultivation	Minimal	Adequate	Adequate
Source of power	Human, animal	Animal, tractor	Tractor
Variety	Edible	Edible, not edible	Not edible
Quality of planting material	Poor to good	Good	Good
Planting time	Onset of rainy season	Onset of rainy season	Stagger as long as rain is available
Planting position	Vertical, diagonal, horizontal	Horizontal	Horizontal
Number of stakes per hill	More than one	One	One
Fertilizer usage	None	Oftentimes	Always
Weed control	Poor to fair	Fair to good	Good
Insect pest/disease control	None	None	Sometimes
Harvesting method	Stagger, selection of plants with big roots	Once	Stagger by area
Estimate of total production (%)	85	5	10
Harvesting time	4 mo and above	> 10 mo	> 10 mo
Yield levels (t/ha)	< 10	10 - 20	> 20
Cropping pattern	Fallowed/Rotate with other crops	Successive cassava at least twice	Continuous cassava
Cropping system	Mixed/Intercropped	Monocrop	Monocrop
Main root use	Food	Cash	Starch
Source of labor	Family	Family/Hired hands	Hired hands

Past Agronomic Research

Agronomic research in the past, particularly before the second World War, was mainly concentrated at the University of the Philippines at Los Banos, where several foreign varieties were assessed for adaptation. Uichanco (1959) summarized the results of the different experiments on cassava in the book "Field Crops". After this period, agronomic research was only minimal, until about a decade ago when interest on root crops, especially cassava, was renewed with the establishment of the Philippine Root Crop Research and Training Center (PRCRTC) based at the Visayas State College of Agriculture (ViSCA).

In the subsequent discussion the topics will be presented chronologically according to the production cycle starting with land preparation up to harvesting and including cropping systems. Unpublished data will be presented whenever possible, especially for the research conducted at ViSCA. Published research will only be mentioned and cited.

Land preparation:

Santos (1967) reported that germination and yield were significantly affected by the method of land preparation. The ordinary method, consisting of harrowing-plowing-harrowing-and making furrows, gave the highest percentage germination and yield followed by harrowing-plowing-planting, plowing-planting, and lastly by harrowing-punching hole for planting. Similarly, Pardales (1986) showed conventional tillage (plowing and harrowing an entire area) and minimum tillage (row plowing only plus herbicide) to be better than zero tillage. Castroverde (1983) also showed minimum tillage together with herbicide application to be profitable. These results suggest that tillage operations are necessary to obtain a loose and well-aerated soil for the development of the storage roots. However, 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 (Abenoja and Baterna, 1982).

In terms of plowing depth, Villamayor (1983a) found no advantage in preparing the soil deeper than 20 cm. Planting on ridges or mounds in areas subject to waterlogging is preferable to planting in flat beds or furrows as the yield is generally higher in the former than in the latter (Labra and Tisang, 1979; Secreto, 1981) as shown in Table 7.

Table 7. Root yield of cassava (cv. Golden Yellow) at 8 months after planting as affected by seedbed preparation and position of planting in VISCA, Leyte.

Treatment[1/]	Root yield (t/ha)	
	Marketable	Total
Seedbed preparation (*)		
Ridge	31.64	35.0
Flat bed	26.91	30.9
Position of planting (NS)		
Vertical	30.64	34.31
Horizontal	29.67	33.61
Inclined	27.57	30.95

1/ * - significant; NS - not significant.

Source : Labra and Tisang, 1979.

Selection and preparation of planting materials:

The presence of scale insects on the planting stakes could 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, 1985; Villamayor and Perez, 1987).

The performance of stakes produced under shade was not reduced compared with those normally produced in the open (Villamayor and Perez, 1986). The first planting stakes produced under shade even gave higher yields than those produced in the open, but there were no yield differences for the succeeding stake evaluations (Table 8).

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 cm and 50 cm (Dacpano,

Table 8. Cassava stake production (cv. Golden Yellow) in the open and under coconut (ca. 50% shade) and yield evaluation of the stakes eight months after planting (MAP) in the open in Baybay, Leyte.

Place of production	No. of stakes[1/] /m^2		Total root yield (kg/m^2)	
	6 MAP	11 MAP	1st Trial	2nd Trial
Open field	8.57	20.47	1.01	2.05
Under coconut	7.03	16.70	1.51	2.17
F-test	NS	NS	*	NS
CV (%)	13.21	9.55	5.93	14.50

1/ Length is 25 cm.

Source : Villamayor and Perez, 1986.

Table 9. Root number and root weight of cassava (cv. Golden Yellow) using various lengths of planting stakes in Bacnotan, La Union.

Stake length (cm)	Root number (#/plant)	Root yield (t/ha)
10	9.2	19.5
15	8.9	23.8
20	9.7	21.2
25	8.8	20.7
30	8.2	21.6
F-test	ns	ns
CV (%)	8.05	11.0

Source : Dacpano, 1980.

Table 10. Shoot number and root yield of cassava (cv. Aipen Valencia) as affected by length of stakes planted horizontally in Iloilo.

Stake length (cm)	Root yield (kg/plot)	Shoot number (#/plot)
15.2	6.96 c	24 d
30.5	10.11 b	45 c
45.7	11.77 b	57 bc
61.0	12.86 ab	74 ab
76.2	15.10 a	78 a

Mean separation (LSD, 0.01)

Source : Ganado, 1956.

1980; Credo, 1982; Velasco, 1982) as shown in Table 9. Others showed short stakes to be better than longer stakes (Pama, 1965; Pardales and Forio, 1979; Mateo, 1981; Apilar and Villamayor, 1981; Soriano, 1986), while still others showed the long stakes to be better than short stakes (Palis, 1938; Tadong, 1955; Ganado, 1956) as shown in Table 10. Apparently the disagreement in results was due to the differences in the length of the stakes used in the study and the position of planting. In general, short stakes are better than long stakes when planted vertically and long stakes better than short stakes when planted horizontally.

There was a positive correlation between stake circumference and yield. Neri (1966) obtained the highest yield using stakes with 9.5 to 10.0 cm circumference and the lowest at 5.0 cm. On the other hand, Villamayor (1983b) did not find significant differences among stakes differing in diameter as a result of high density planting.

The best part of the plant to be used as planting material is the basal portion of the stem followed by the middle portion and then the top (Galang, 1931; Huertas, 1940; Ocampo, 1956, Salvosa, 1980) as shown in Table 11. In general, any part may be used except those nearest to the root and the green portion at the top (Guanzon, 1927, Bucado, 1979). When planting material is scarce, even split stakes could be used without affecting the yield as long as planting was horizontal (Aparra, 1981).

Table 11. Root yield of cassava (cv. Valencia) using different stem parts as planting stakes in Iloilo.

Part of stem	Root yield (kg/plot)
Top	7.91 c
Middle	10.41 b
Base	12.49 a

Mean separation (LSD, 0.01)

Source : Ocampo, 1956.

The manner of cutting the stakes could affect yield. Pestano (1982) claimed that slant cutting (beveled) gave higher yield than straight (transverse) cutting (Table 12).

Ulat (1980) and Aparra (1981) reported that soaking stakes in growth regulators such as NAA and IBA had no affect on yield, while Javier and Mamiepic (1978), Apa-ap (1979) and Minao (1981) showed that soaking stakes in a NAA solution increased cassava yield due to production of more storage roots.

Table 12. Storage root yield as affected by slanted or transverse method of cutting the stem in Mambusao Capiz.

Method of cutting the stem	Root yield (t/ha)
slanted	14.73 a
transverse	8.40 b

Mean separation (LSD, 0.01)

Source : Pestano, 1982.

It was reported that planting grafted *Manihot glaziovii* (scion) and *Manihot esculenta* (stock) stakes, known in Indonesia as the Mukibat system, was better than the traditional system of just planting the cultivated *M. esculenta* (Ahit *et al.*, 1981). However, a follow-up study (Miras, 1983) showed the Mukibat system to be no better than the traditional. In fact, the traditional system produced roots with higher dry matter content (Table 13).

Table 13. Root yield, number and dry matter content under the traditional and Mukibat system of planting in ViSCA, Leyte.

Planting system	Root number (#/plant)	Root yield (t/ha)	Root dry matter (%)
Traditional	6.60	17.31	50.23
Mukibat	5.54	13.88	47.29
F-test	NS	NS	*
CV (%)	37.0	12.37	3.39

Mean separation (LSD, 0.01)

Source : Miras, 1983.

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 the tree canopy, and protected from direct sunlight, did not affect the yield of the crop (Villamayor and Perez, 1983), but storage for two or three months significantly reduced yield though germination was not markedly reduced. Treatment of stakes to be stored with coal tar had no effect on viability and shoot development (Mendaira, 1973).

For long-term storage of three or four months (Villamayor, Perez and Destriza, unpublished data), it was found 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 significantly reduce the yield compared with the use of unstored stakes (Table 14).

Table 14. Yield evaluation of cassava stakes (cv. Golden Yellow) stored vertically in the open for various duration and covered with coconut fronds in ViSCA, Leyte.

Storage duration (mo)	Root yield (kg/m^2)	Root number (#/m^2)
Zero (control)	3.1 a	12.6 a
One	1.6 c	9.6 b
Two	2.4 b	9.5 b
Three	2.7 ab	11.2 ab
Four	2.8 ab	11.4 ab

Mean separation (LSD, 0.05)

Source : Villamayor, Perez and Destriza, unpublished data.

Planting:

Cassava can be planted anytime 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 yield is reduced when planting is delayed towards the dry season (PRCRTC, 1986). A significant positive correlation was observed between rainfall received during the initial seven months period and yield (Villamayor and Davines, 1987). Bernards and Esquerra (1981) also recommended planting 3 – 5 months before the onset of the dry season to avoid spider mite damage.

Planting is usually done manually but a mechanical planter is available that can plant a hectare in seven hours (Dimacali, 1964). In one pass the implement furrows the soil, drops fertilizer and planting stakes, covers the stakes and compacts the soil. In cassava plantations in Mindanao, modified sugarcane planters are being used in planting cassava.

Planting position, whether vertical, slanted or horizontal, did not affect yield (Calang, 1931; Deocariga, 1956; Villanueva and Labra, 1978; Labra and Tisang, 1979; Tizon 1980; Abenoja, 1981; Credo, 1982; Soriano, 1986). In vertical planting, the inverted position should be avoided since germination is low (Basug, 1971) and the yield is reduced (Evangelio, 1981). On the other hand, Reyes and Esperidion (1976) reported 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 lighter 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, unpublished data). This was probably due to the development of the underground part of the stem into storage organs and 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 (Table 15).

Table 15. Root yield of cassava (cv. Golden Yellow) four months after planting as affected by the depth of planting and removal of underground shoot in VISCA, Leyte.

Depth of planting	Root yield (kg/plant)
15 cm, 10 cm aboveground	0.48 ab
25 cm, whole stem buried	0.12 c
25 cm, underground shoot removed	0.30 bc

Mean separation (LSD, 0.05)

Source : Villamayor, unpublished data.

PCARRD (1983) recommends planting only one stake per hill, but about 45% of farmers surveyed plant two stakes per hill (Villamayor *et al.*, 1987). Jarbadan (1963) and Real (1978) reported that two stakes per hill gave the highest yield compared with one, three or four stakes.

Cotejo and Forio (1979) reported that the yield of four plants immediately adjacent to a missing hill was increased, such that the total yield was equal to that of five complete hills, suggesting that 20% missing hills can be tolerated. A more systematic study by Villamayor and Labayan (unpublished data) showed that cassava can tolerate about 30% missing hills without yield reduction, regardless of variety, population density and fertilization levels used (Table 16 and 17). 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 (DAP).

Table 16. Summary of results of experiments on the effect of missing hills on yield as influenced by variety, population and fertilization, in ViSCA, Leyte.

Treatments	Yield (t/ha)	Treatments	Yield (t/ha)	Treatments	Yield (t/ha)
Variety (NS)		Population (NS)		Fertilizer (NS)	
Golden Yellow	22.75 a	10,000 pl/ha	11.04 a	00 - 00 - 00	26.26 a
CMC-40	22.61 a	20,000 pl/ha	11.50 a	25 - 25 - 25	30.57 a
		40,000 pl/ha	9.12 b	50 - 50 - 50	26.31 a
CV (%)	14.59	CV (%)	9.52	CV (%)	17.27
Missing hill (NS)		Missing hill (NS)		Missing hill (*)	
0%	24.68 a	0%	10.98 a	0%	30.23 a
10%	24.17 a	10%	10.36 a	30%	28.54 a
20%	26.48 a	20%	10.11 a	35%	25.88 b
30%	21.38 a	30%	10.77 a	40%	26.21 b
CV (%)	15.95	CV (%)	17.28	CV (%)	11.53
Interaction (NS)		Interaction (NS)		Interaction (NS)	

Mean separation (LSD, 0.05)

Source : Villamayor and Labayan, unpublished data.

Table 17. Yield of cassava (cv. Golden Yellow) under different periods of replanting missing hills in ViSCA, Leyte.

Replanting time of missing hills	Total[1] root yield (t/ha)	Root yield[2] of sample plants (kg/plant)
1. Control, 0 missing hill (MH)	20.06 a	1.71
2. 35% MH unreplanted	22.87 a	2.62
3. 35% MH replanted 13 days after planting (DAP)	22.93 a	0.96
4. 35% MH replanted 20 DAP	19.56 a	0.48
5. 35% MH replanted 27 DAP	18.20 a	0.11
6. 40% MH unreplanted	21.09 a	3.68
7. 40% MH replanted 13 DAP	19.78 a	1.03
8. 40% MH replanted 20 DAP	14.98 b	0.54
CV (%)	14.26	28.13

1/ Mean separation (LSD, 0.05)

2/ The replanted plants, those adjacent to missing hills (tr. 2 and 6) or those with complete borders (tr. 1).

Source : Villamayor and Labayan, unpublished data.

As much as possible, cassava should not be planted under shade as yields are reduced under such conditions (Navarez, 1976).

Plant population/spacing :

Planting density from 7,000 to 28,000 plants/ha did not seem to affect total yield (Ajoc, 1976; Secreto, 1981; Caliboso, 1981; Villamayor and Destriza, 1982), but there was a trend that marketable yield decreased with increasing plant density (PRCRTC; 1979; Villamayor and

Destriza, 1982). On the other hand, Occiano (1980) and Bansil (1980) found the 75 × 75 cm spacing to be better than the 75 × 50 cm, 75 × 30 cm or 75 × 25 cm. At a row spacing of one meter, Retis and Cerrudo (1976) and Espinas (1979) obtained higher yields at 75 cm spacing between hills compared with 60, 50 and 40 cm spacing or 50, 100 and 125 cm spacings, 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, 1982). 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.

Weed control/cultivation :

The critical period for weed control in cassava was during the first two months of growth (Bacusmo, 1978; Jumadiao, 1982) as shown in Table 18. Cultivation is also beneficial to cassava. Lastimoso (1979) found that cassava yields were highest with three times cultivation at three week intervals. Villamayor and Reoma (1987) found off-barring two weeks after planting (WAP) followed by handweeding within the row 3 WAP and hilling-up 5 and 7 WAP to be the most profitable among the treatments used under ViSCA conditions.

Table 18. Root number and root yield of cassava (cv. Golden Yellow) under various duration of weed control in Catarman, Samar.

Weed control duration (days)	Root number (# plant)	Root yield (t/ha)
0	5.17 b	8.35 b
30	5.13 b	9.42 b
60	7.20 a	17.68 a
90	7.57 a	17.53 a
120	8.00 a	19.20 a
150	7.33 a	22.83 a
180	7.74 a	23.03 a

Mean separation (DMRT, 0.05)

Source : Jumadiao, 1982.

Irrigation :

There are no studies 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.

Fertilization/Liming :

Many studies have been conducted on the response of cassava to NPK levels, singly or in combination, comparisons between levels of fertilizers, and between organic and inorganic

fertilizers, especially by undergraduate students in many parts of the country (Rosalas, 1969; Masjiril, 1972; Reston, 1976; Monte de Ramos, 1977; Malaki, 1977; Ortega, 1978; Cotajo and Talatala, 1978; Abenoja, 1978; Awa, 1979; Serrame, 1980; Gomez, 1980; Pineda, 1980; Bucud, 1980; Pangan, 1980; Oso, 1980; David, 1981; de Guzman, 1982; Lagrimas, 1982; Tomas, 1982; de la Roza, 1982; Aganon, 1982; Agustin, 1983; Musngi, 1985). Since the response of cassava will depend on the initial fertility of the soil, agroclimatic conditions, amount and source of fertilizers, methods of application and even varieties, it is expected that there will be differences in results. Some showed no response (Suerte, 1980; Villaflor, 1981; Tomas, 1982; Lagrimas, 1982), while others showed positive responses (Malaki, 1977; Pangan, 1980; Pineda, 1980; de Guzman, 1982; de la Rosa, 1982; Agustin, 1983; Musngi, 1985). Liquid fertilizers have also been tried but the effect was minimal (Silagan, 1982).

The lack of response in some cases is 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 10 months. An example of a positive response to N fertilization is the work of Abenoja (1978), as shown in Table 19. The soil used had a pH of 6.9, 2.0% organic matter, 19 ppm (Olsen) P and 372 H_2SO_4 extractable K.

Table 19. Total root yield of cassava (cv. Golden Yellow) under different levels of fertilizer in ViSCA, Leyte.

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	29.29 b

1/ Initial soil analysis: 2.0% OM, 19 ppm Olsen P, 372 ppm H_2SO_4 extractable K.

Source : Abenoja, 1978.

Table 20. Root yield during the first, third, fourth and sixth cropping as affected by the application of different sources of fertilizer and their residual effect in ViSCA, Leyte.

Fertilizer source[1]		Root yield (t/ha)			
		Crop I	Crop II	Crop IV	Crop VI
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 dung (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 b
T4	cow manure (4.4 t/ha)	39.07 a	27.51 ab	25.13 a	16.14 b
T5	guano (0.6 t/ha)	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; manure applied up to the 3rd crop only.
Mean separation (DMRT, 0.05).

Source : Quirol and Amora, 1987.

Table 21. Effect of different sources of fertilizer on the soil chemical characteristics at the end of the sixth crop in ViSCA, Leyte.

Fertilizer source[1]	Chemical analysis[2]		
	OM (%)	Olsen P (ppm)	NH_4Ac K (ppm)
To - Control	2.55	4.8	42.7
T1 - inorganic (60 - 60 - 60)	3.31	13.7	96.7
T2 - chicken dung (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 (0.6 t/ha)	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.

Continuous application of the same level of fertilization every cropping season could not maintain the yield of cassava in ViSCA (Quirol and Amora, 1987) as shown in Table 20. This was probably due to a marked reduction in the amount of K in the soil (Table 21). Table 20 also showed that animal manure had some residual effect, especially during the cropping season immediately after the last application.

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 22. There was also little or no response in two areas (Butigan II and Igang) which are near the river and have alluvial soils.

Green manure and animal manure increased cassava yields (Lauron, 1980, Lorenzo, 1980; Ratilla, 1983; Castroverde, 1983; Molina, 1983; Mirambel, 1983; PRCRTC, 1985; Pascual *et al.*,

Table 22. Total root yield and net income of cassava (cv. Golden Yellow) without fertilization (F0), 1/2 the fertilizer recommendation (F1) and full fertilizer recommendation (F2) in various locations in Baybay, Leyte.

Location Fertilization recommendation (N-P_2O_5-K_2O in kg/ha)	Total root yield (kg/ha)			Net income (P)[3]		
	F0	F1	F2	F0	F1	F2
Maganhan (35 - 35 - 35)	9.00	18.32	20.05	1,495	7,174	7,825
Igang[1] (50 - 50 - 50)	20.83	21.73	26.76	9,445	9,253	10,848
Cantagnos (40 - 30 - 30)	5.67	16.08	23.21	- 1,516	4,468	8,278
Butigan I (40 - 30 - 30)	10.66	14.60	16.10	2,765	4,669	5,405
Butigan II[1] (40 - 30 - 00)	21.16	21.62	20.46	10,147	9,921	8,557
Can-ipa (40 - 30 - 00)	11.58	21.56	18.90[2]	4,069	10,304	7,686
Bubon	15.44	23.29	26.25	6,551	11,589	12,838

1/ Near the river
2/ Lodged at 6 months
3/ Exchange rate : P20 = $1

Source : Villamayor and Destriza, 1986.

Table 23. Root yield of cassava (cv. Golden Yellow) and net return under various soil amendments in ViSCA, Leyte.

Type of soil amendment 1/	Total root yield 2/ (t/ha)	Net return 3/ (P)
Control	5.45 e	- 1,773.21
10 tons coal ash/ha	6.88 e	- 2,268.08
10 tons chicken dung/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_2O_5-K_2O/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 : P20 = $1

Source : Mirambel, 1983.

1987; Quirol and Amora, 1987). As an example, the data of Mirambel (1983) on the effect of animal manures is shown in Table 23. It was also noted 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 herbage 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; Cocejo and Talatala, 1978). This is illustrated in Table 24. However, if application was delayed to 90 days, yields were reduced (David, 1981). The best application time of complete fertilizer was 1/2 basal and 1/2 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).

Table 24. Root yield of cassava (cv. Golden Yellow) aplied with 90 - 60 - 60 kg N-P_2O_5-K_2O/ha at different times after planting in ViSCA, Leyte.

Time of application			Total root yield (t/ha)
Planting	1 Month	2 Months	
1/2 N, all P and K	1/2 N		31.62 c
1/3 N, all P and K	1/3 N	1/3 N	29.29 bc
1/3 N, 1/2 P and K	1/3 N, 1/2 P and K	1/3 N	30.13 c
1/2 N, all P and K		1/2 N	26.99 bc

Mean separation (DMRT, 0.05)

Figures selected from a bigger set of data.

Source : Abenoja, 1978.

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 three varieties of cassava at 6, 8, 10 and 12 MAP.

Topping/pruning :

Abenoja and Cerna (1983) found that removing the upper 15 cm shoots at 4, 6 or 8 week intervals, starting at 4, 5 or 6 MAP, did not affect yield. On the other hand, Villamayor and Labayan (1982) found that a single topping of 20 cm shoot length or longer at 3 MAP reduced yields significantly. Santiago (1980) reported that topping 2 – 3 MAP reduced yields significantly, while Arana (1979) reported an increase in 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 conditions of the plant at the time of pruning, whether vigorously growing or stunted.

The author observed that cassava (cv. Golden Yellow), cut-back at 6 – 8 MAP for planting materials and harvested about 6 months later, had very large roots and yet tasted like young roots. According to one agricultural technician, some farmers practice pruning as a form of root storage.

Pruning at about 30 cm above the ground 6 MAP lead to a yield reduction when harvested 10 MAP, but the planting material produced was about twice that of unpruned plants (Villamayor and Destriza, 1981). The author also observed that cassava pruned four times, about every 6 – 8 months for production of planting material, remained alive, but had many rotten roots.

Harvesting :

The crop should be harvested at the right time to get the maximum return. If harvested early, yields will be low and if harvested late, yields may be high, but the starch and dry matter content may be low and roots may become fibrous (Soliven, 1921; Sison, 1921; Hernaez, 1954; Uichanco, 1959).

Table 25. Fresh roots, dry matter and starch yield and number of rotten roots of cassava (cv. Golden Yellow) at different ages of harvest in VISCA, Leyte.

Age at harvest (mo)	Yield (t/ha)			Rotten roots (#/m^2)
	Fresh roots 1/	Dry matter 2/	Starch 2/	
6	20.3 b	8.73	7.24	0.00 b
7	20.3 b	9.01	7.25	0.36 b
8	21.5 b	9.00	9.13	0.72 b
9	26.6 a	11.23	9.70	1.07 b
10	28.9 a	12.01	9.31	1.07 b
11	28.1 a	11.75	8.51	4.29 a
12	28.2 a	11.09	9.42	5.00 a

1/ Mean separation (DMRT, 0.05)

2/ Derived data not analyzed

Source : Data *et al.*, 1987.

The right time of harvest also depends on the variety. The variety Golden Yellow can be harvested from 8 – 12 MAP with minimal changes in quality in terms of starch and sugar contents and acceptability (Data *et al.*, 1987) as shown in Table 25. However, varieties like Java Brown and Kadabao have to be harvested more than 12 MAP to get optimum yields (personal observation).

Harvesting is the most expensive operation in cassava production (Catambay, 1938). A cassava grower of Bohol mentioned that harvesting costs account for 20% of his expenses. He pays P50.00/t for harvesting, which includes sacking. One man can harvest more than a ton per day.

For faster and cheaper harvesting, the use of a two-animal team and a sod plow is recommended (Catambay and Yango, 1935). An additional advantage of this method is the elimination of plowing for the next crop. 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).

Cropping systems :

Intercropping legumes, like peanut, soybean, mungbean, cowpea, pigeon pea and bushbean, 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 casava (Laguna, 1982; Corpin, 1977) as shown in Tables 26 and 27. However, others showed a reduction in yield (Evagelio and Posas, 1983; Alava, 1980). Obviously the results vary with differences in the kind of intercrop, the spacings used, the growth durations, the timing of planting of the maincrop 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. Similarly, Martinez (1947) reported that intercropping corn between rows and between hills of cassava gave a fairly good yield of roots when the two crops were planted at the same time. Also, Abit (1979) found that intercropping sorghum or corn did not affect the yield of cassava when both crops were planted at the same time or when the cereals were planted one or two weeks later. On the other hand, Rosete (1981) found that planting mungbean seven days after cassava resulted in the best LER, but planting mungbean 4 weeks after cassava gave the highest economic benefit.

Table 26. Marketable root yield of cassava (cv. Golden Yellow) and grain yield of legume intercrops in VISCA, Leyte.

Intercropping scheme 1/	Marketable root yield 2/ (t/ha)	Grain yield (t/ha)
Cassava alone	13.8 b	–
Bushbean	17.7 ba	0.29
Soybean	16.8 ba	0.34
Peanut	15.5 ba	0.44
Mungbean	18.7 a	0.21

1/ One row of legumes planted 50 cm away from cassava rows and spaced 75 cm apart with 3 plants/hill. Cassava and the legumes fertilized each with 15 – 15 – 15 kg N-P_2O_5-K_2O/ha

2/ Mean separation (DMRT, 0.05)

Source : Corpin, 1977.

Table 27. Total root yield of cassava at 7 months after planting and grain yield of mungbean as affected by the number of rows of mungbean planted between 1 meter wide rows of cassava in ViSCA, Leyte.

Intercropping scheme[1/] row #/population/row distance	Total root yield[2/] (t/ha)	Grain yield[2/] (kg/ha)
Control (no intercrop)	16.96 bc	–
one/96,000 pl/ha/1.0 m	15.93 bc	655 b
two/192,000 pl/ha/33.33 cm	19.38 ab	1,206 a
three/288,000 pl/ha/25 cm	21.43 a	847 b
four/384,000 pl/ha/20 cm	13.39 c	951 ab

1/ Mungbean planted one week before cassava and fertilized with 0 – 25 – 25 kg N-P_2O_5-K_2O/ha while cassava was fertilized with 45 – 60 – 60 kg N-P_2O_5-K_2O/ha.

2/ Mean separation (DMRT, 0.05).

Source : Laguna, 1982.

Alava (1980) showed that bush sitao *(Vigna unguiculata* × *Vigna sesquipedalis)* cassava combination to be better in terms of yield and income than the corn-cassava combination. Furthermore, corn 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 corn 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 corn did (Table 28). 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 (Table 29).

The 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 cassava and the mungbean yields (Table 26). Also Villamayor and Destriza (1982) found

Table 28. Yield characteristics of cassava (cv. Golden Yellow) at eight months after planting and the yield of intercropped sweet corn (cv. Hawaiian Supersweet) 75 days after planting in ViSCA, Leyte.

Intercropping scheme	Root yield (t/ha)	Root number (#/ha)	Corn ear yield (t/ha)
Cassava alone (control)	38.6 a	20.8 a	–
One hill of corn (2 pl/hill) between cassava hills	35.6 a	20.0 a	3.91
Two hills of corn (2 pl/hill) between cassava hills	27.8 b	18.1 a	5.58
CV (%)	11.3	9.7	

Mean separation (LSD, 0.05)

Source : Villamayor and Destriza, unpublished data.

Table 29. Yield characteristics of cassava (cv. Golden Yellow) at seven months after planting, and the yield of field corn (Acc. Across 8223) four months after planting in ViSCA, Leyte.

Intercropping scheme	Cassava root yield (t/ha)	number (#/ha)	Corn grain yield (t/ha)
Cassava alone (control)	26.3 a	13.2 a	–
One hill of corn (2 pl/hill) between cassava hills	18.0 b	8.4 b	2.91
Two hills of corn (1 pl/hill) between cassava hills	19.2 b	9.7 b	2.92
CV (%)	12.1	9.8	

Mean separation (LSD, 0.05)

Source : Villamayor and Destriza, unpublished data.

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 meter to 2.5 m, did not significantly affect cassava yields (Table 30) probably due to the reduction of cassava population

Table 30. Effect of widths of ipil-ipil *(Leucaena leucocephala)* buffer strips on the total root yield of cassava (t/ha) in marginal hilly areas of Leyte.

Width of Ipil-ipil buffer strip	Effective population (plants/ha)	Cropping sequence			
		1	2	3	4
T0 – control (no buffer strip)	10,000	16.88	22.38	15.25	15.92
T1 – 1 m ipil-ipil strip every 5 m	8,333	13.94	18.99	16.66	12.55
T2 – 1.5 m ipil-ipil strip every 4.5 m	7,500	14.22	20.07	18.49	11.58
T3 – 2.5 m ipil-ipil strip every 3.5 m	5,833	12.61	16.22	24.30	12.21
F – test		ns	ns	ns	ns

Source : Pascual *et al.*, 1986.

as a result of the ipil-ipil strips. Padullo (1983) found that ipil-ipil grown in between cassava may or may not affect yields depending on the spacing between ipil-ipil hills (Table 31). 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 herbage applied to the soil after each pruning, had a similar yield as monocropped cassava applied with 60-40-40 kg N-P_2O_5-K_2O/ha (Table 32).

Crop rotation is recommended, especially with legumes, to minimize nutrient depletion. Escalada *et al.* (1983) found that the yield reduction was less when cassava was rotated with

Table 31. Yield of cassava (cv. Golden Yellow) and weight of eroded soil and ipil-ipil *(Leucaena leucocephala)* herbage under different distances of planting ipil-ipil as intercrop with cassava spacing of 1 × 0.75 m.

Ipil-ipil spacing	Total root yield (t/ha)	Eroded soil (t/ha)	Ipid-ipil[1/] herbage (t/ha)
Control (no ipil-ipil)	14.14 bc	4.23 a	–
1 m × 10 cm	14.93 a	0.78 f	5.50 a
1 m × 20 cm	14.94 a	1.85 e	3.30 b
1 m × 30 cm	14.82 a	2.44 d	2.62 b
1 m × 40 cm	13.64 c	2.80 c	2.58 b
1 m × 50 cm	13.72 c	3.47 b	2.17 b

1/ Sum of four prunings at 30 cm height starting 175 days after planting and every 45 days thereafter (4x). Mean separation (DMRT, 0.05)

Source : Padullo, 1983.

Table 32. Total root yield (t/ha) of cassava (cv. Golden Yellow), planted in between strips of N-fixing trees, with their prunings applied to the soil. Data are the average of two seasons.

Treatment[1/]	N-fixing trees		
	Gliricidia sepium	Albizia falcataria	Parkia roxburghii
Inorganic fertilizer (60 – 40 – 40)	25.53	24.32	29.36
Pruned 50 cm above ground	30.59	28.85	29.13
Pruned 100 cm above ground	27.88	25.69	27.52
Cut and carry (1 t/ha)	24.84	32.83	35.26
Cut and carry (2 t/ha)	24.55	30.36	28.23

1/ F-test: all not significant

Source : Pascual *et al.*, 1987.

Table 33. Yield of cassava planted in Camiling, Tarlag at different cropping systems.

Cropping system	Total root yield (t/ha)			
	1st	2nd	3rd	Total[2/]
Monocrop (CAS-CAS-CAS)	22.56	15.11	8.82	46.49 a
Rotation (PEA-CAS-PEA-CAS)[1/]	27.63		18.84	46.11 a
Fallowing (FAL-CAS-FAL-CAS)	19.05		13.48	32.53 b

1/ Peanut yield was 992 and 3,061 kg/ha for the first and second crop, respectively.
2/ Mean separation (LSD, 0.05)

Source : Javier and Laranang, 1987.

legumes 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 greater economic benefit compared with successive croppings of cassava or cassava alternated with fallow (Table 33).

Current Agronomic Research

There is very little work now being done on the cultural management of cassava because of the great amount of research that has already been conducted in the past 10 years. Presently, the ongoing studies being conducted, or under the supervision of ViSCA researchers, are as follows: affect of irrigation on the productivity of root crops with the first phase under pot conditions; screening for drought tolerance and identification of physiological characteristics related to adaptation to drought; screening for tolerance to shade and acidity; effect of slant and transverse stake cutting on yield; effect of location (climatic factors) on the HCN and general acceptability of cassava; intercropping sweet potato and cassava; effect of mycorrhizal inoculation and the use of fast growing N fixing trees and leguminous cover crops as fertilizers for cassava grown under hillside conditions. It is possible that other research institutions are still conducting research on cultural management.

Future Agronomic Research

Based on the previous and current research and the need of the different types of cassava growers, there is still some agronomic topics that need attention. However, only the research needs of the subsistence and commercial farms will be mentioned as the plantations usually conduct their own research. Moreover, these needs are not necessarily mutually exclusive.

The resource-poor subsistence farmer requires acceptable management strategies that will maintain, if not improve, the productivity of cassava, particularly for the hilly lands, without addition of costly inputs. For example, what crops should be rotated or intercropped with cassava that will enrich the soil and/or minimize erosion ? Is there a possibility of using microbes like *Azospirillum* as inoculant to fix N for cassava ? (This technology is currently being verified in farmers field for corn in the Philippines). Can pests like mites, scale-insects and whiteflies be controlled without using chemicals, like interplanting certain crops with repellent properties ? For those farmers planting under coconut, what cultural management practices should be adopted to increase yield ? How will variety, plant population, growth duration, fertilization and time of planting influence cassava yields under coconut ? For mature cassava plants, is there a way of rejuvenating the plant to make the roots more edible ? Will pruning, as practiced by some farmers, really improve the quality of the storage roots ?

For the commercial farms, a more appropriate fertilization scheme should be developed that will take into account not only the soil characteristics but the climatic factors as well. It is not practical to conduct fertilizer trials for each specific location. What is needed are comprehensive and integrated fertilizer trials, conducted over several soil types and climates and for several seasons, so that the fertilizer recommendations will be more specific rather than general. How much, when, and how do you apply fertilizers are questions that need specific answers for a particular location. All the fertilizer trials in the past involved only N, P and K. With successive

cassava croppings, it is possible that other nutrients are already limiting production and this needs to be looked into.

To increase the productivity of the farm and hopefully the income of the farmers, verification trials on different intercropping and rotation schemes with cassava as the main crop need further attention.

Future Directions for Development

The root crops commodity team of the Philippine Council for Agriculture Forestry and Natural Resources Research and Development (PCARRD), which assists in setting research priorities and monitoring and evaluating research on root crops, is of the opinion that there is already enough information on the cultural management of the crop. In fact, for the last several years, research emphasis has been on root crop processing and utilization. Similarly, the staff of the Philippine Root Crop Research and Training Center (PRCRTC) believes that there is sufficient information on the cultural management of cassava. Thus, the emphasis in research will shift to minor root crops like yam and arrowroots. Even a farmer, when asked about his problems on cassava production, answered that marketing and a low price are his main problems. Farmers claim they can produce anytime the volume required as long as there is a ready market and the price is right.

For the cassava producers to prosper, it is necessary that all potential domestic markets be fully explored. The market for the fresh roots is saturated because of the high retail price. The starch factories, on the other hand, are operating below 50% capacity for lack of raw materials.

Farmers are getting only from 15.00 to 22.50 US dollars per ton of fresh roots (farmgate price). If the price could be increased slightly, farmers may plant more cassava and the starch factories could operate at a higher efficiency as a result of more raw materials. Perhaps the government can offer tax incentives to the starch factories, so the latter can offer higher prices for the raw materials. This will need further analysis.

One of the large potential markets is the bakery industry. The Philippines is importing close to a million tons of wheat annually. If the law requiring 10% substitution of wheat flour with cassava flour were fully implemented, this demand would be equivalent to about 100,000 tons of cassava flour or about 250,000 tons of fresh roots or 12,500 hectares more of cassava at 20 t/ha. Again, the government needs to assess the situation. The Board of Investment can possibly offer tax incentives to those who would venture into flour manufacturing. Perhaps these starch factories that are no longer operating can be converted into flour factories.

The biggest potential is probably in the use of cassava in animal feed. The potential requirement of feed from corn or root crops is about four million metric tons annually. The feedmillers are willing to use cassava instead of importing corn as long as cassava chips can be supplied in big volumes throughout the year. Unfortunately, the feedmills are located near urban centers far from the production areas. This would entail large handling and transportation costs, not only due to the distance involved but also due to the bulkiness of the product. Furthermore, the production sites are located in areas with a long wet season. Continuity of supply is therefore a potential problem since artificial drying is not economical. One alternative is to

establish satellite feedmills in the production sites to supply the feed requirements of animals in the rural areas. The pilot feedmill at ViSCA has shown that it is profitable to produce and market root crop-based animal feed, not only due to the lower cost of production but also due to the lower marketing costs. The establishment of a good business linkage between feedmillers and cassava producers have to be worked out for a more effective partnership. This should ultimately result in greater benefits, both for cassava producers as well as for meat consumers.

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RESEARCH OF CASSAVA CULTIVATION TECHNIQUES IN CHINA

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The land suitable for cassava cultivation in China is the region south of the Yangzhi River, totalling about 2 million km^2 (200 million hectares) with mountainous and low hilly lands that await exploitation. However, the present area under cassava in China is only around 400,000 hectares, while the yield is only about 9 t/ha. Therefore there is a tremendous potential for cassava development and it is very important to increase cassava research and to study efficient ways of cultivation as well as to expand its market at home and abroad.

Soil and Climatical Conditions in China's Cassava Growing Areas

According to the soil and climatical conditions shown in Table 1, the area suitable for cassava growing in China may be divided into three ecological zones (Figure 1) :

1. Tropical zone – This lies mainly between 18° and 22°N, embracing Hainan Island and Leizhou Penninsula of southern Guangdong, as well as Xishaungbanna in south Yunnan. Cassava can be planted and harvested year-round in this zone, but planting and harvesting are largely done in the spring and late autumn, respectively. The potential yield level in this zone is quite high, with a maximum of over 60 t/ha, but it's still possible to further expand the growing area and increase the yield. The zone is characterized by distinct dry and wet seasons and cassava production is often affected by typhoons.

2. South subtropical zone – This is the principal cassava producing area that mainly lies between 22° and 25°N, covering most parts of Guangdong, Guangxi, as well as the southern parts of Fujian and Yunnan. Cassava is usually planted between February and April and harvested between November and January with a yield of 7.5 t/ha and a maximum of more than 30 - 40 t/ha. The zone is susceptible to cold air from northern China, and low temperatures and drought during the winter and early spring are the major factors affecting cassava production.

3. Middle subtropical zone – This is the zone where cassava production may potentially expand, situated between 25° and 32°N, and including the low hilly area south of the middle and lower reaches of the Yangzhi River. The yield in the zone is only around 7 t/ha. Planting and harvesting are usually carried out between March and April and between November and December, respectively. But presently only a small proportion of the potentially suitable land

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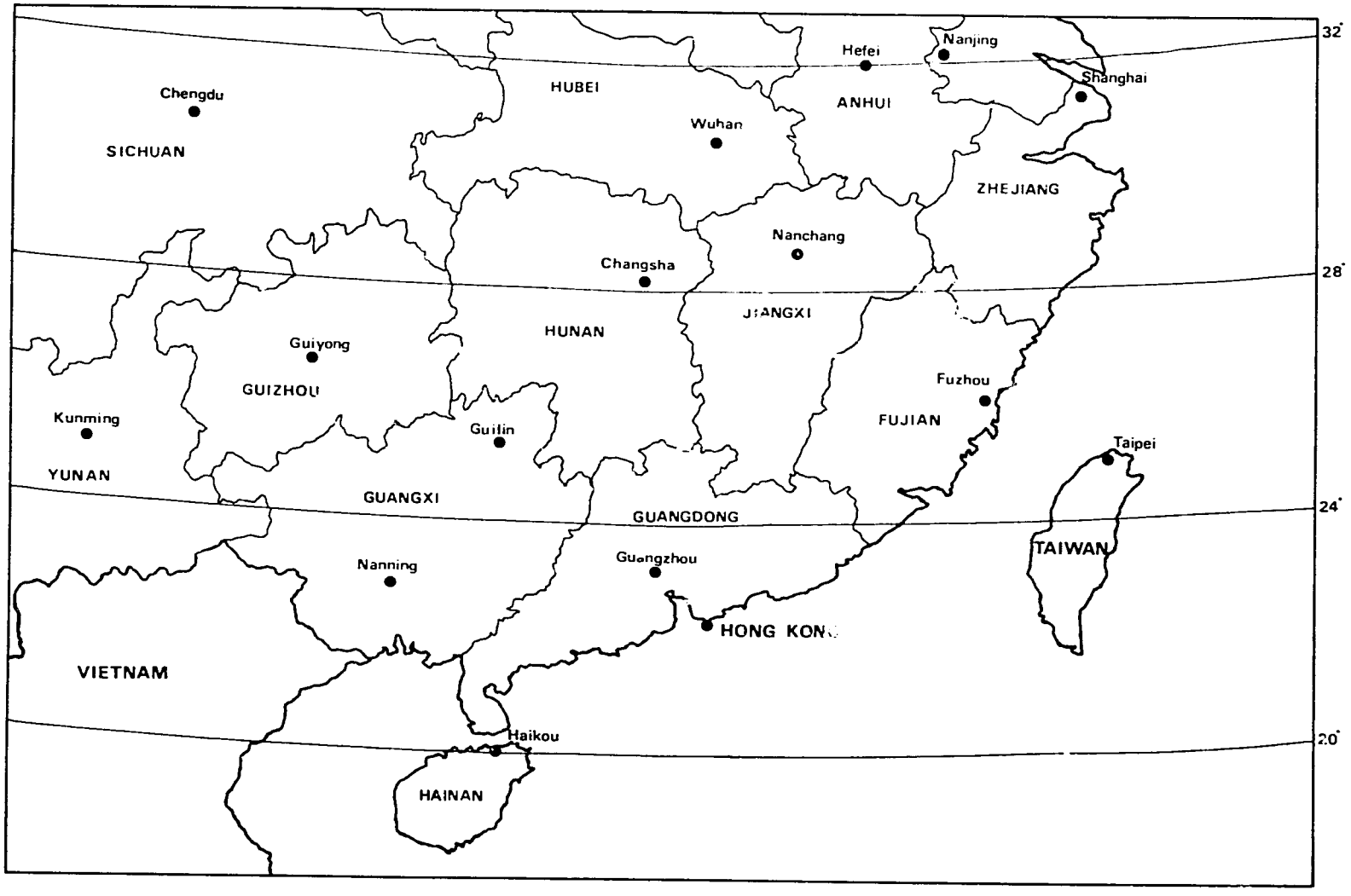

Figure 1. Potential cassava-growing region in south-east China.

Table 1. Climatic and soil conditions in the three ecological regions suitable for cassava production in China.

Item	Tropical zone	South subtropical zone	Middle subtropical zone
Latitude	18° – 22°N	22° – 25°N	25° – 32°N
Area (km2)	105,300	409,100	1,520,000
Mean annual temperature (°C)	> 24	22 – 24	> 16 – 22
Annual rainfall (mm)	1800 – 2500	1200 – 1800	1000 – 1500
Frostfree days	> 300 – 350	ca. 300	250
Soil type	Laterite	Laterite red soil	Red yellow soil
pH	4.5 – 5.7	4.9 – 5.3	5.0 – 5.5
Organic matter (%)	0.43 – 3.61	0.29 – 1.78	0.30 – 4.15
Total N (%)	0.06 – 0.147	0.013 – 0.087	0.008 – 0.192
Total P (%)	0.017 – 0.026	0.018 - 0.035	0.06
Total K (%)	0.01 – 2.09	0.7 – 1.12	1.50 – 1.80
Principal variety	SC205	SC205/SC201	SC201
Planted area ('000ha)	35	350	26
Yield (ton/ha)	12 – 15	7.5	7.0
Total production ('000 tons)	> 420	> 2650	> 180
% of total area	9	85	6
% of total output	13	81	6

Source : Li Qingkui (1983) and Hou Guanggun *et al* (1982).

has been devoted to cassava, so that the prospects of development are quite good in this zone, where the cold spells in winter and early spring are longer and the storage of stem cuttings during the winter is more difficult.

Figure 2 shows that the rainfall distribution in southern China is unimodal, with the most heavy precipitation occuring during the summer months of May through August. In the north-eastern region, as indicated by data from Guilin, Changsha and Guangzhou, the rainfall is particularly heavy in the late spring, while in the south-east it is slightly delayed towards the late summer. Total precipitation tends to increase from north to south (Table 1).

Figure 3 shows the distribution of soils in southern China. In the tropical zone of Hainan island and the Leizhou Penninsula soils are classified mainly as Oxisols with only small areas of Ultisols and Inceptisols in the mountainous part of central Hainan. In the south subtropical zone, where the majority of cassava is grown, the upland soils are principally classified as Ultisols, while the valley bottoms, used mainly for rice production, are mainly Vertisols and Entisols. In the northern and western part of Guangxi there are large areas of limestone-dirived soils, classified as Calcortholls, while in Yunnan Province there are also large areas of yellow earths classified as Dystrochrepts. As indicated in Table 1, cassava soils in China are characterized

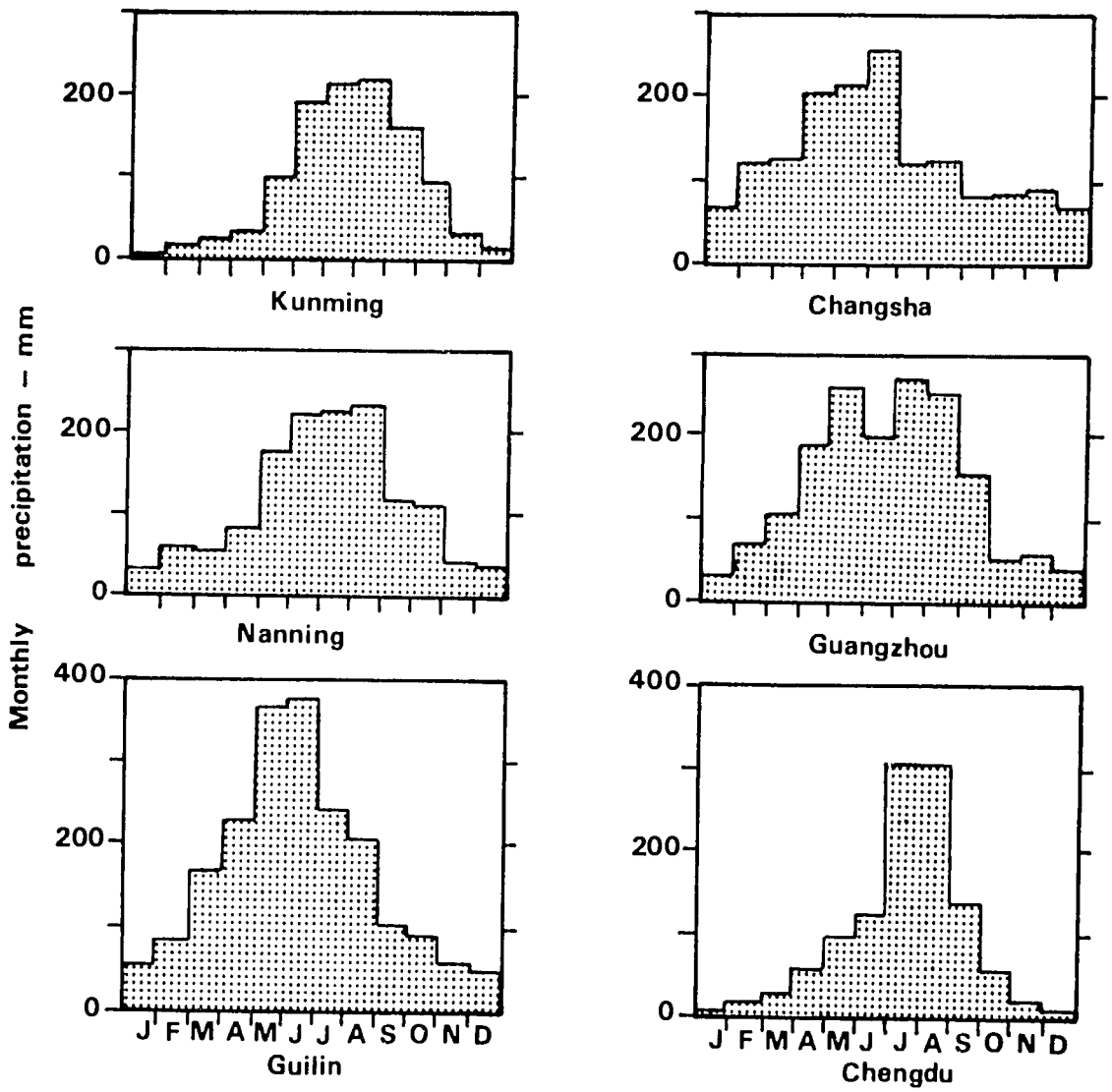

Figure 2. Rainfall distribution at six locations in south-eastern China.

Source : Huke, 1982.

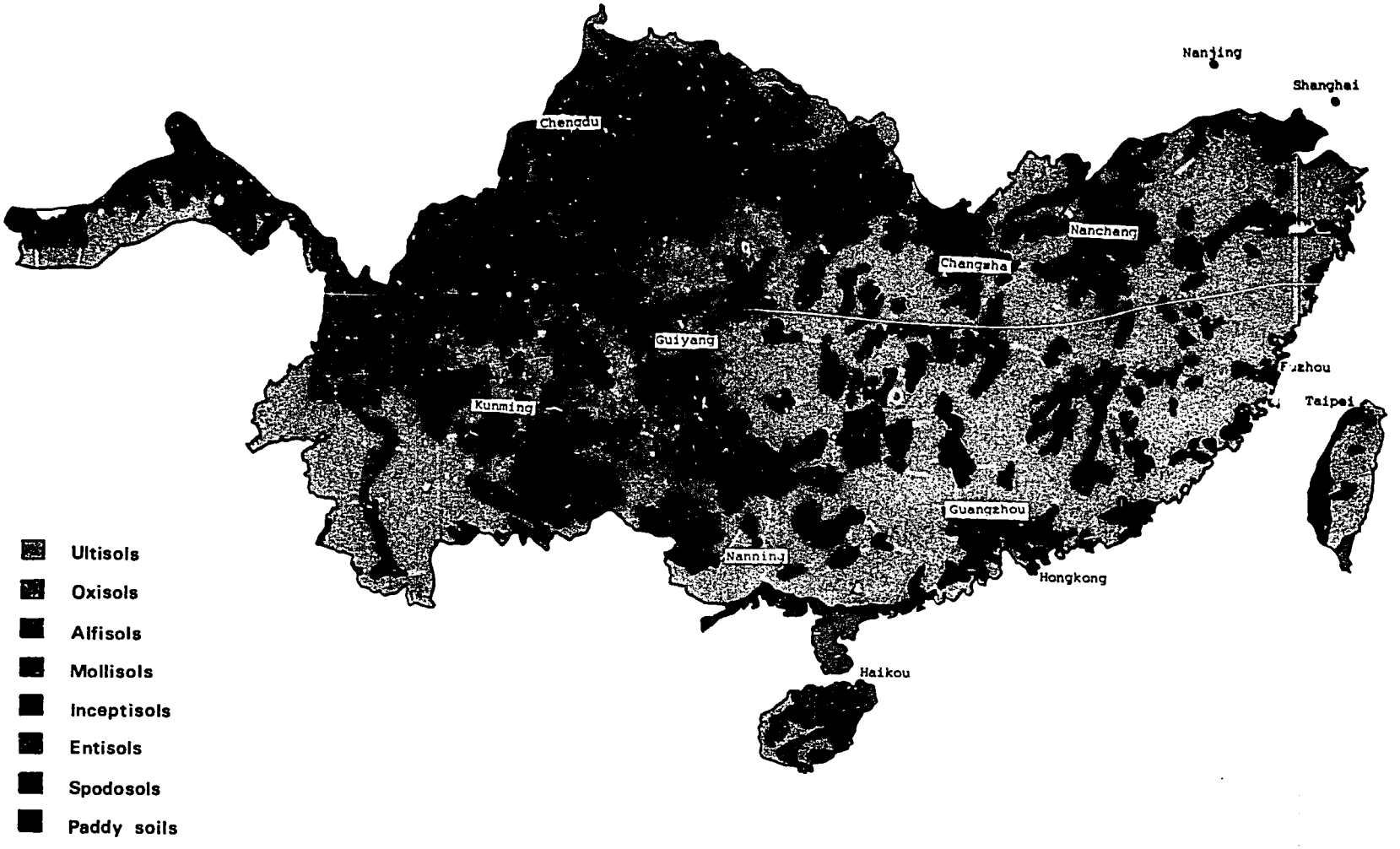

Figure 3. Soil map of southern China, translated into approximate equivalent soil orders of Soil Taxonomy.

Source : Adapted from Zhao Qi-guo and Shi Hua by R. Howeler.

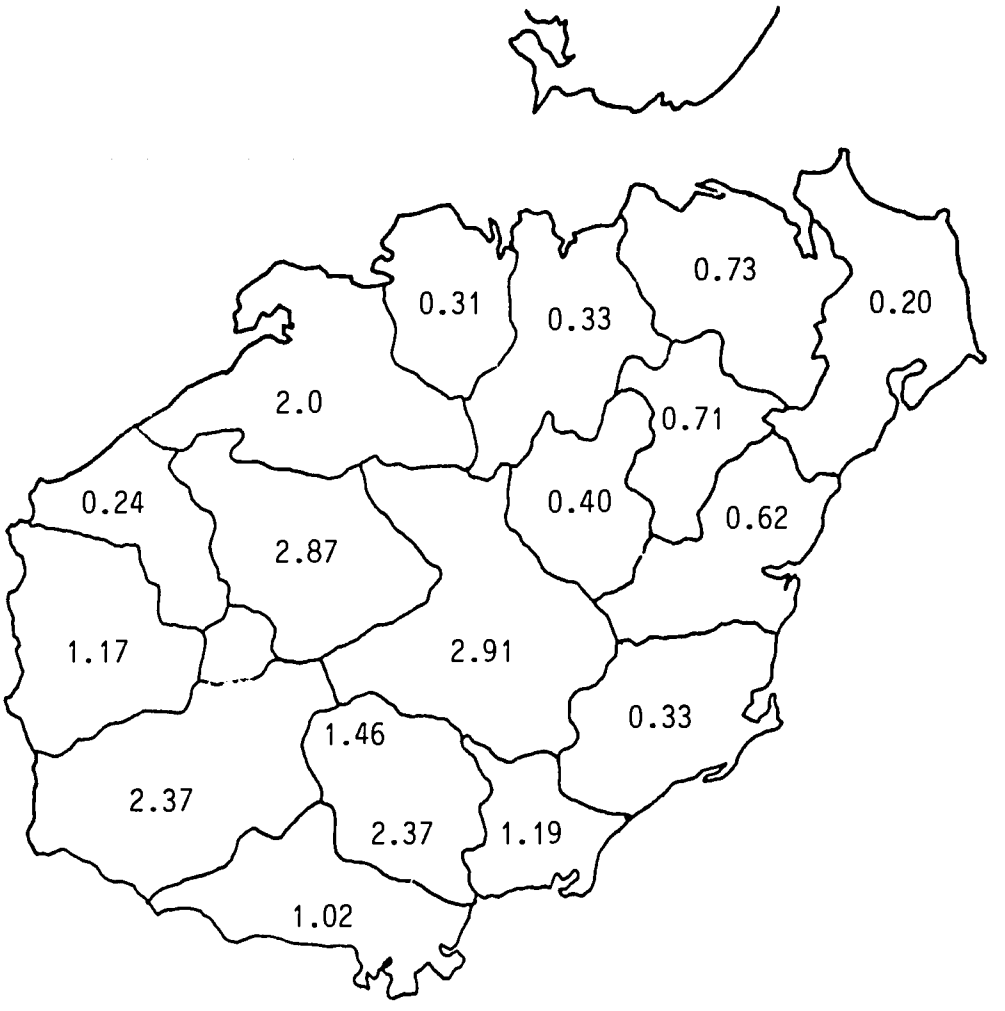

Figure 4. Cassava growing areas in Hainan island in 1987 (1000 ha).

by a low pH of 4.5 – 5.5, except the limestone derived soils, which generally have a pH of 6 – 7. Most soils have intermediate levels of organic matter (1.5 – 2.5%) and low-intermediate levels of available P and K. The texture is generally rather heavy, either clay or clay-loam. Cassava is often planted on steep slopes, with or without terracing, and erosion is a major problem in many parts of southern Guangxi. In Hainan cassava is mainly grown in the mountainous central and southern part of the island (Figure 4), where erosion may also be a serious problem due to the high rainfall intensity.

Present Status of Research on Cassava Cultivation in China

The earliest research on cassava cultivation was carried out on the Guangdong Agriculture and Silviculture Experimental Farm, where ratooning, analysis of root nutrition, NPK fertilization trials, etc., were conducted during 1914 – 1919. Similar work was done later at some other research institutions in Guangdong and Guangxi. However, a systematic and intensive investigation on cassava cultivation was first conducted in 1958 with the objective to stimulate

China's cassava production. Most of this early work was concentrated at the present South China Academy of Tropical Crops (SCATC) in Hainan island and is described in detail in an unpublished manuscript by Prof. Wun Jian, completed in 1964. Cassava agronomy research was practically suspended from 1965 to the early 1980s. With the recent flourishing of cassava based products in China, scientific research in this field is now being expanded. The following achievements and experiences can be reported :

1. Cultural Practices.

1) Land preparation : Results of the Xijiang State Farm (23°N) in Guangxi show that when cassava was planted 28 – 30 cm deep before winter and the topsoil above it was loosened to a depth of 20 cm with a plow after winter, the cassava yield was 15% higher than when cassava was cultivated only once before winter; it was also 50% higher than when the soil was cultivated to a depth of 15 cm by a bullock.

2) Ridging : Results at SCATC show that cassava planted on hill-side ridges in single and double rows gave a yield 26% and 29% higher, respectively, than that from a non-ridged field (Table 2).

Table 2. Effect of ridging and row number on cassava root yield (cv SC101)

Treatments	Planting distance (m)	No. of plants/ha	Root yield (t/ha)	%
Ridge with single row	1 × 0.83	12,048	7.58	126.4
Ridge with double row	(1.33 + 0.67) × 0.83	12,048	7.74	129.0
No ridge with single row	1 × 0.83	12,048	6.00	100.0
No ridge with double row	(1.33 + 0.67) × 0.83	12,048	7.23	120.5

Source : Wun Jian (1964).

3) Length of stakes : At SCATC, using planting stakes ranging from 3 to 30 cm in length, the following results were obtained : stakes measuring 9 – 15 cm in length gave highest yields, while stakes longer than 15 cm or shorter than 9 cm yielded considerably less (Table 3).

Table 3. The effect of different lengths of stakes on cassava root yield (cv SC101).

Year	Length of stakes (cm)									
	3	6	9	12	15	18	21	24	27	30
	t/ha									
1960	18.0	19.7	22.2	16.5	–	18.8	–	15.0	–	14.8
1961	12.7	12.3	16.2	16.3	16.4	15.1	15.5	–	–	–
1962	5.0	6.6	6.3	8.0	7.8	6.2	–	–	–	–

Source : Wun Jian (1964)

4) Planting methods : Experimental results at SCATC show that vertical planting gave deep-rooted plants which were more wind hardy and produced a yield about 20% higher

than that from horizontal planting, although the roots were more difficult to harvest; inclined planting brought about easier sprouting and a higher germination rate while the roots growing in an aggregate pattern, were easy to harvest. Besides, the latter method gave a yield about 10% higher than that from horizontal planting (Table 4). Although horizontal planting gives lower root yields, planting is simpler and root harvesting is easier, so that the method is widely used in China.

Table 4. The effect of planting methods on cassava root yield (cv SC101).

Location	Planting method					
	Horizontal		Inclined		Vertical	
	t/ha	%	t/ha	%	t/ha	%
Zhanjiang (Guangdong)	11.69	100	12.73	108	14.52	124
SCATC (Hainan)	6.98	100	9.43	135	9.25	132
Lingshan (Guangxi)	27.80	100	30.34	109	24.44.	88

Source : Wun Jian (1964).

5) Planting density : This depends on the variety and soil conditions. In general, a lower density should be used in a fertile field and a higher density for a poor one; also, a lower density for a branching variety and a higher density for a non-branching one. Test results of SCATC reveal that a density of 10,000 – 15,000 stakes/ha is suitable (Table 5).

Table 5. The effect of various planting densities on the yield of cassava, variety SC203 (slightly branched).

Spacing (m)	Stakes/ha	ton/ha	%
0.6 × 0.6	27,777	11.3	76.9
1 × 0.6	16,666	13.3	91.1
1 × 0.75	13,333	15.0	103.1
*1 × 1	10,000	14.6	100.0
1.6 × 0.6	10,416	13.[illegible]	89.7
1.3 × 1	7,692	12.5	85.1

Source : Wun Jian (1964).

6) Harvesting time : The yield and dry matter content of the roots of cassava usually increase with time after planting (Table 6). The proper harvesting time is between November and February. But cassava in the south subtropical zone is harvested before the arrival of a cold current, usually around December, while in the tropical zone the harvest occurs any time between December and February.

Table 6. The effect of various harvesting times on the yield and dry matter content of cassava, variety SC203.

Harvesting time	Yield (ton/ha)	%	Dry matter content (%)
Oct.	31.9	100	33.0
Nov.	33.7	105.6	36.1
Dec.	35.2	110.3	36.7
Jan.	37.7	118.2	40.5
Feb.	–	–	–

Note : The crop was planted in March.

Source : Wun Jian (1964).

7) Storage of stem cuttings : The method of storage varies with location. For instance, stems can be kept in the open air in the tropical zone, where they are only bundled and placed in the shade of trees and then covered with sugarcane leaves or hay to reduce moisture loss. In the south subtropical zone, stems are normally kept in trenches or shallow pits, while in the middle subtropical zone, where the frost period is longer, they are stored in deep trenches, covered with straw and at least 20 cm of soil.

2. Fertilization :

Experiments on the effects of N, P and K on cassava have been conducted by SCATC. The results show that the application of N, P and K fertilizers brought about yield increases of 24, 103 and 7%, respectively (compared to control), indicating that the three elements, especially P, have a positive effect on the production of cassava roots. Best results were obtained when P and N were used together, which gave a yield increase of 157% over control (Table 7). The trial was conducted in Nada, Danxian County, Hainan Island, where the soil was derived from granite with a relatively high K content but lower P and N contents. This explains the remarkable results of P and N application.

Table 7. The effect of N, P, K fertilization on cassava root yield (t/ha).

Basal fertilization*		← Treatments →							
		N	P	K	NP	NK	PK	NPK	Control
	t/ha	15.30	20.47	9.07	26.18	11.03	13.05	15.15	10.44
+	%	147.0	196.0	87.0	251.0	105.0	125.0	145.0	100.0
	t/ha	7.74	16.28	10.35	20.48	7.31	12.60	15.0	7.68
–	%	101.0	212.0	135.0	267.0	95.0	164.0	195.0	100.0
	t/ha	11.27	18.39	9.71	23.33	9.17	12.82	15.08	9.06
Average	%	124.0	203.0	107.0	257.0	101.0	142.0	166.0	100.0

***Basal fertilization** : 15 t/ha of "burned soil" (slowly burned mixture of soil and plant residues).

Source : Wun Jian (1964).

3. Systems of intercropping, interplanting and rotation.

Various cropping systems have been tested by SCATC with the following results :

1) When cassava is intercropped with low growing legumes (e.g. mung bean), it can provide more income, while the soil and water are better conserved and soil fertility increased. Results suggest that intercropping cassava with grain legumes often results in higher profits. Peanut intercropping was found to be the most profitable.

2) Intercropping cassava + peanuts with *Leucaena leucocephala* showed little difference in root yield over control (monoculture of cassava), but it resulted in better soil and water conservation and soil fertility maintenance with the soil's organic matter content 8.2% higher than control.

3) Investigations on interplanting cassava between rows of young China fir *(Cunninghamia lanceolata)*, which is a common practice in China, can promote the growth of the trees so that they can be cut 2 – 3 years earlier with the prospective crop of cassava as an additional source of income. Cassava can also be planted between rows of young rubber trees to provide some extra income, but this is rarely practised because the root crop would heavily reduce the soil's fertility if management is inadequate.

4) Various crops can be used for rotation with cassava and the preferable combinations can be : cassava ——► (after plowing-in the intercropped jack bean) upland rice; cassava ——► peanut + autumn sweet potatoes; sugarcane ——► sugarcane ——► cassava; cassava ——► tree crops, etc.

4. Cultivation of cassava in Northern Subtropical China

Large-scale trial cultivation was carried out by SCATC during 1961 – 62 in the areas south of 40°N in China. The results show that cassava can be cultivated in the areas around the reaches of the Yangzhi River, i.e. around the areas south of the Huaihe River and the Qinling Mountain (south of 32°N), where the mean annual temperature is over 16°C and the frostfree period during the year is over 240 days. A precocious variety can produce 12 – 20 tons of roots per hectare per year.

Prospects of Cassava Cultivation Research in China

According to the characteristics and present status of China's cassava enterprise, stress should be placed on research in applied technology that will be suited to China's specific conditions. Thus the orientation and subject matter of China's research on efficient cassava cultivation can be as follows :

1. Popularizing the use of improved varieties as well as integrated cultural practices in order to obtain high yields.

2. Continuing work on the screening of intercrops and determining the optimal patterns of intercropping, inter-planting, rotation and multi-storey cultivation in cassava so as to make full use of land and crop resources and raise the index of multiple cropping for better economic results.

3. Furthering the study on the storage of cassava planting material during the winter.

4. Continuing the investigation on plant and soil nutrients so as to determine the most judicious fertilization.

5. Searching for low-input and high-benefit cultural practices that will be readily accepted by farmers.

6. Evaluating intensive cultural practices that call for a moderate input but can turn out good economic results.

International Cooperation

1. Exchanging documents and literature on cassava cultural practices with CIAT and other cassava producing countries or regions so as to introduce advanced know-how from abroad for further development of China's cassava enterprise.

2. Intensifying international cooperation in the study of soil erosion, plant and soil nutrition, types of intercrops and systems of farming and cultivation in cassava growing areas. Contacts and academic exchanges among cassava scientists throughout the world should also be strengthened.

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CASSAVA AGRONOMY RESEARCH IN MALAYSIA

Tan Swee Lian [1]

Introduction

Cassava in Peninsular Malaysia is grown mainly as a smallholder crop geared for the starch extraction industry, with a small percentage entering the livestock feed industry. The area of cassava cultivation has decreased significantly in recent years with increased law enforcement resulting in the ousting of many illegal holdings (i.e. cultivation on state land such as forest and mining reserves), to make way for more lucrative crops.

The main area of cassava cultivation remains in the State of Perak, where most of the starch factories are located. A few attempts at plantation-scale production were made in the past, but most have not been successful. At present there is only one cassava plantation (about 400 ha in size) known to the author, which has been in operation for the past 30 years. This company has its own starch factory which engages in extracting starch from sago palm as well. The factory also buys roots from small farmers in the surrounding areas as its own field production is insufficient to meet the factory capacity.

Unlike many other short-term crops, cassava was found to adapt quite well to cultivation on peat, an organic soil characterized by low pH, high water table and deficient levels of several micronutrients such as Cu and Fe. Large tracts of peat are available both in Peninsular Malaysia as well as in Sarawak, totalling about 2.4 million ha. Up till now, only small areas of peat have been developed (felling of virgin jungle, drainage and building of roads) for the cultivation of pineapple, vegetables and oil palm. This then is a potential area for future expansion of cassava cultivation.

Review of Past Agronomic Research

1. Mineral inorganic soils

Research on agronomic requirements for the successful cultivation of cassava on mineral soils started even before the inception of MARDI, during the days when the Department of Agriculture held research functions. Over the past two to three decades, cultural practices for cassava on such soils have been developed quite adequately. The following practices are now recommended.

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Planting materials : Cuttings taken from mature woody stem portions, preferably from plants at least 7 months old.

Stake length : 20 – 23 cm.

Plant spacing : 1.0 × 1.0 m, equivalent to 10,000 plants per ha

Planting orientation : Horizontal, entirely buried.

Weed control : Pre-emergence control with a mixture of 2 liters alachlor + 2 kg fluometuron per ha; Post-emergence control by handweeding, or directed spray of 2 liters/ha of paraquat; Pre-harvest control by 2 liters/ha of paraquat.

Nutritional studies on various soil types and textures, in several locations in the country, and on a long-term basis (under monoculture of cassava) have established the importance of K nutrition. Insufficient K, resulting from inadequate fertilizer supply, depresses both root yield and starch content of the roots. This is especially grave in situations of continued production without adequate fertilizer inputs.

By contrast, P application has not resulted in a significant increase in cassava yield, and this has been explained in part by the role mycorrhizas play in supplying P to the cassava plant. N is usually required not in substantial quatities. A general fertilizer recommendation for cassava grown on mineral soils might be :

60 N : 30 P_2O_5 : 160 K_2O in kg/ha

Mg and Zn deficiency symptoms are sometimes observed in a cassava crop, but they tend to be scattered in occurrence and can easliy be corrected by applications of 15 kg/ha of Mg in the form of kieserite and 10 kg/ha of $ZnSO_4 . 7H_2O$ respectively.

2. Peat (organic) soils

Cultural practices for cassava cultivation on peat vary slightly. In addition to planting 20 cm long stakes in a horizontal orientation, it is also feasible to plant 60 cm long stakes upright. Root yields have been shown to increase significantly when long stakes planted vertically are used instead of the shorter stakes entirely buried in a horizontal position. Since peat has a light friable texture, vertical planting does not make the harvesting operation much more difficult than the usual practice of horizontal planting. On mineral soils, however, the harvesting of plants grown from vertical long stakes is considerably more difficult, rendering this practice oftentimes impractical.

It has been observed that pre-emergence weed control in cassava on peat is more effective with 4 liters/ha of alachlor than the cocktail mix of alachlor and fluometuron used at the rates recommended for mineral soils.

The high C/N ratio of peat renders almost all N in the soil unavailable to crops, and the complete N requirement must be supplied through fertilizer applications. Responses to N have been found to applications as high as 350 kg/ha. K nutrition remains an important feature, while P is again relatively less important. A general fertilizer recommendation for cassava grown on peat might be :

200 N : 50 P_2O_5 : 160 K_2O in kg/ha.

Peat is inherently deficient in Cu and this deficiency is detrimental to high root yields. Supply of Cu to the crop can be achieved through soil application (10 – 15 kg/ha $CuSO_4.5\ H_2O$), foliar application (0.05% solution of $CuSO_4.5H_2O$) or dipping the cuttings in 2.0% $CuSO_4.5H_2O$ solution prior to planting. Soil application of Cu has a residual effect lasting at least three years.

Although cassava is tolerant of low pH, correcting the extreme soil acidity of peat soils by lime applications is required to ensure optimum performance of the crop. The pH of peat can be as low as 3.2, and maximal root yields have been achieved when lime was applied to raise pH to around 4.0. The effects of liming have been found to last for four to five years.

Current Research

Current research focusses on developing production technology for cultivating cassava on peat. Among the pressing problems to be addressed are :

- water table control for optimum crop performance;
- soil fertility management under long-term cropping;
- increasing the profitability of cassava cultivation.

1. Effects of water table : A preliminary study was conducted using lysimeters where the water table was maintained at fixed levels varying from 15 to 75 cm from the soil surface. Currently, a field study is underway in which attempts are made to maintain the water table at 30, 60 and 90 cm from the soil surface through the use of sluices. Crop performance will be related to the three water tables, as well as to fluctuations within a water table regime and over the cropping season.

2. Nutrition and soil fertility management : A factorial experiment testing three levels each of N, P, K and lime is now in its fifth season of cropping. Attempts will be made to relate root yield and starch content with the nutrient status of the plant (leaf and stem analyses) and the soil.

3. Increasing profitability of cassava cultivation : Short-term returns from cassava cultivation can be realized through intercropping with shorter season crops. Two sets of trials are in progress, testing intercropping of cassava at two spacings (square planting at 0.90 × 0.90 m, and double-row cassava with 1.80 m wide interrows) with peanut and with sweet corn. Controls include monocropped plots of cassava, peanut and sweet corn.

Increasingly, cassava cultivation on mineral soils has been forced into more marginal areas. These include sloping areas prone to erosion, and land previously used for tin mining (tin-tailings). The former is an urgent problem already faced by growers of cassava, and practical means of soil conservation need to be developed to overcome this constraint.

High costs of production for cassava is a dominant reason for the declining interest to cultivate the crop, especially in the face of cheaper imports from Thailand. Cost-reducing technology, such as the close monitoring of fertilizer requirements through the development of diagnostic techniques, which will replace blanket recommendations that oftentimes lead to luxury consumption of certain nutrients while maintaining an inadequate supply of others.

Another means of reducing costs is technology for minimal or zero tillage. Current land preparation practices comprise one to two rounds of plowing, followed by one round of harrowing or rototilling, sometimes followed by ridging. Compared to seed crops, the stakes used in planting cassava are large and can well withstand a larger soil aggregate size, with little detriment to establishment. Furthermore, it is suspected that overtilling can lead to problems of soil compaction and wheel slip when field operations are carried out with heavy machinery.

This brings us to the development of technology for mechanized production of cassava on a large scale. Labor is a major cost item in cassava production, not only because of high requirements but also because the cost of hiring farm labor in Malaysia is high. Labor-reducing production systems would imply the use of machines for major field operations such as planting, fertilizer application, herbicide spraying and harvesting, in addition to land preparation.

Tin-tailings have been used by farmers to grow cassava with associated inputs of organic manure, especially farmyard manure. However, little research has been carried out to determine means to improve such soils for profitable cassava production. Some work by a local university shows the possibility of using wastes from palm oil mills for the cultivation of sweet potato on tin tailings, and it is likely that the same may be practised for growing cassava on such soils.

AGRONOMIC PRACTICES FOR CASSAVA PRODUCTION IN ASIA

Reinhardt Howeler[1]

Introduction

According to FAO statistics, during 1986 cassava was cultivated in 3.81 million ha in 11 countries of tropical or subtropical Asia with a total production of 44.25 million tons fresh roots. This represents about 32% of world production, compared with 44% in Africa and 23% in Latin America (Figure 1). While rice is by far the most important food crop in tropical Asia, cassava is the second most important crop, in terms of total production. But unlike Africa and Latin America, where cassava is mainly used for direct human consumption or animal feed,

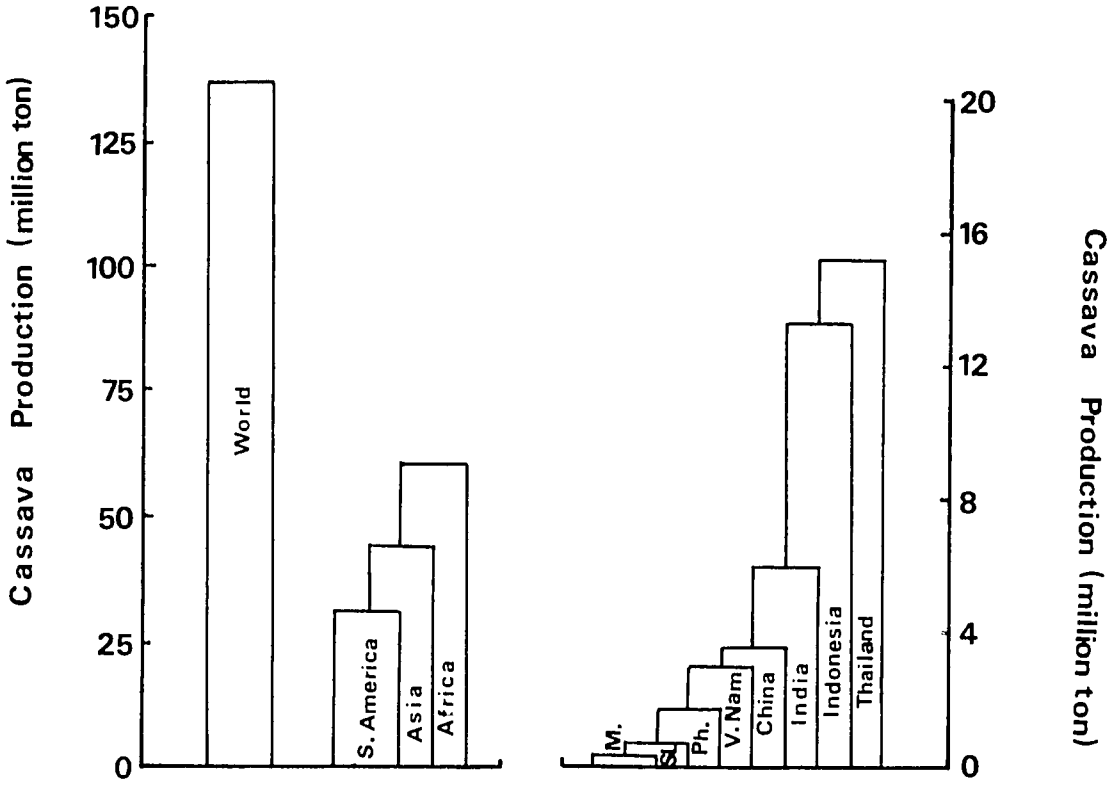

Figure 1. Cassava production in the world, the continents and the major cassava producing countries in Asia in 1986.

Source : FAO, 1987.

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Table 1. Trends of cassava area and production in Asia.

	Cassava area (000 ha)							
	61 – 65	74 – 76	79 – 81	1982	1983	1984	1985	1986
China	–	197	231	249	245	245	244	236
India	245	383	345	310	302	319	308	304
Indonesia	1572	1424	1413	1324	1242	1350	1292	1214
Malaysia	23	28	34	27	36	35	36	36
Philippines	90	118	203	224	225	209	216	218
Sri Lanka	44	66	54	59	55	57	53	54
Thailand	113	538	1063	1087	1018	1335	1376	1204
Vietnam	155	181	460	480	485	500	500	500
Others	1	13	32	22	20	23	34	35
Total	2264	3048	3836	3782	3629	4073	4059	3801

	Cassava production (000 t)							
	61 – 65	74 – 76	79 – 81	1982	1983	1984	1985	1986
China	–	2416	3290	3718	3880	3868	3658	3570
India	2295	6462	5921	5292	5341	5886	5569	6000
Indonesia	11833	12589	13608	12988	12229	14159	14057	13329
Malaysia	218	347	347	335	370	380	384	385
Philippines	562	815	2262	1987	2000	1337	1551	1727
Sri Lanka	328	745	520	573	722	683	580	650
Thailand	1789	7855	15128	17788	18989	19985	19263	15255
Vietnam	1147	1372	3300	2665	2700	2900	3000	3000
Others	5	106	256	199	228	227	319	333
Total	18179	32713	44632	45545	46459	49425	48382	44250

Source : FAO 1976 – 87

in Asia about 14% is used for starch production and 29% for export, with direct human consumption being an important use only in Indonesia, the Philippines, Sri Lanka and Kerala State of India.

In Asia, Thailand is the largest cassave producer with a production in 1986 of 15.2 million tons, followed by Indonesia, India, China, Vietnam, Philippines, Sri Lanka and Malaysia (Figure 1). Table 1 indicates that cassava production in Asia during the last decade has increased in nearly all countries with the exception of India and Sri Lanka. This production increase is due to a 22% increase in cassava area and a 10% increase in yield, from 10.7 t/ha in 1974 – 76 to 11.6 t/ha in 1986. Cassava yields in Asia are slightly lower than those in Latin America and 47% higher than those in Africa (Figure 2). In Asia highest yields are obtained in India, followed by China, Thailand, Sri Lanka, Indonesia, Malaysia, Philippines and Vietnam.

Thus, cassava in Asia remains an extremely important crop, especially for small farmers, which usually grow cassava on poor soils and under adverse climatic conditions. For example, in the Northeast of Thailand, which regularly suffers from prolonged droughts, cassava is a popular crop among farmers, because it is almost risk-free, always producing something, even on very poor soils and with a minimum amount of rainfall. On the other hand, crops like

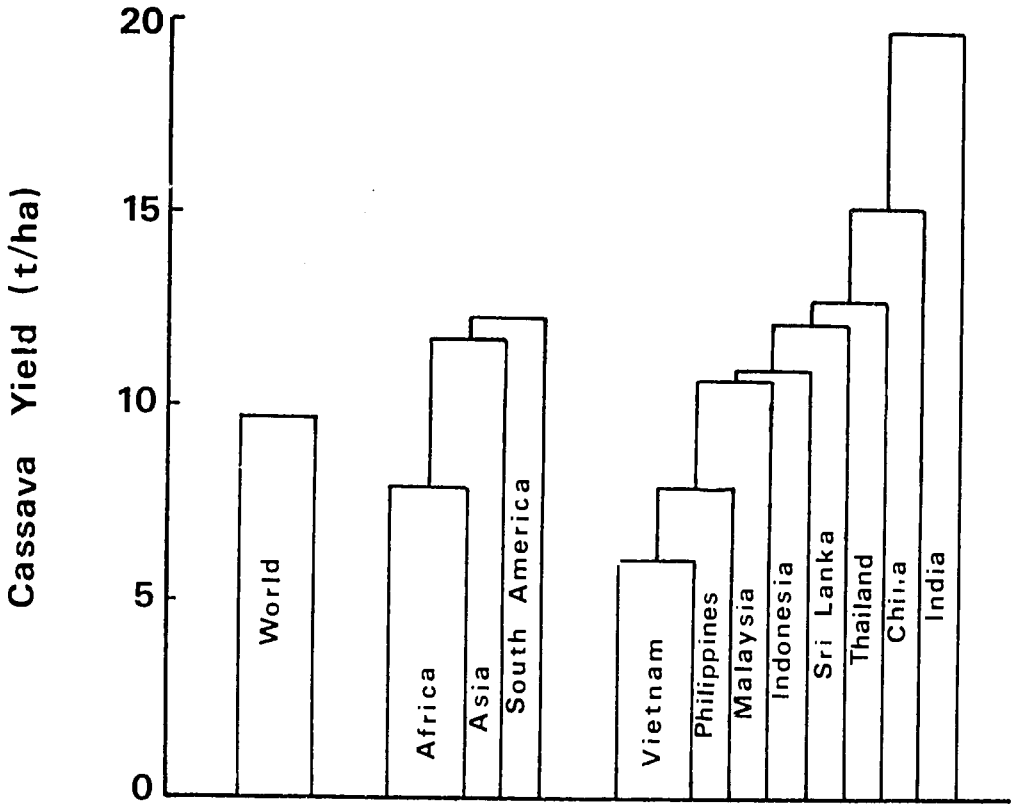


Figure 2. Yield of fresh cassava roots in the world, the continents, and the major cassava growing countries of Asia in 1986.

Source : FAO, 1987.

maize or rice may suffer complete crop failure during prolonged droughts. Cassava is also popular with small farmers because it can be grown with a minimum of purchased inputs, such as fertilizers and pesticides, requiring mainly labor, which is often in abundant supply.

Cassava Production Zones.

Figure 3 shows that in Asia cassava is grown from about 10° south to 26° north in the subtropics of India and China. Unlike in Latin America and Africa, in Asia cassava is grown exclusively in the lowlands, and seldom at elevations above 500 masl. For that reason cassava in Asia is a relatively short duration crop with a growth cycle of only 8 – 12 months. Even in the subtropical areas of northern Guangxi or Guangdong provinces of China, cassava is always harvested within one year. Figure 3 shows that cassava production is most intensive in the Central Plain and North East of Thailand, in East and Central Java, and in Kerala State of India. In China cassava is grown mainly in Guangdong and Guangxi provinces but the exact distribution is not clear; likewise, much cassava is grown in Vietnam but we know little about its distribution.

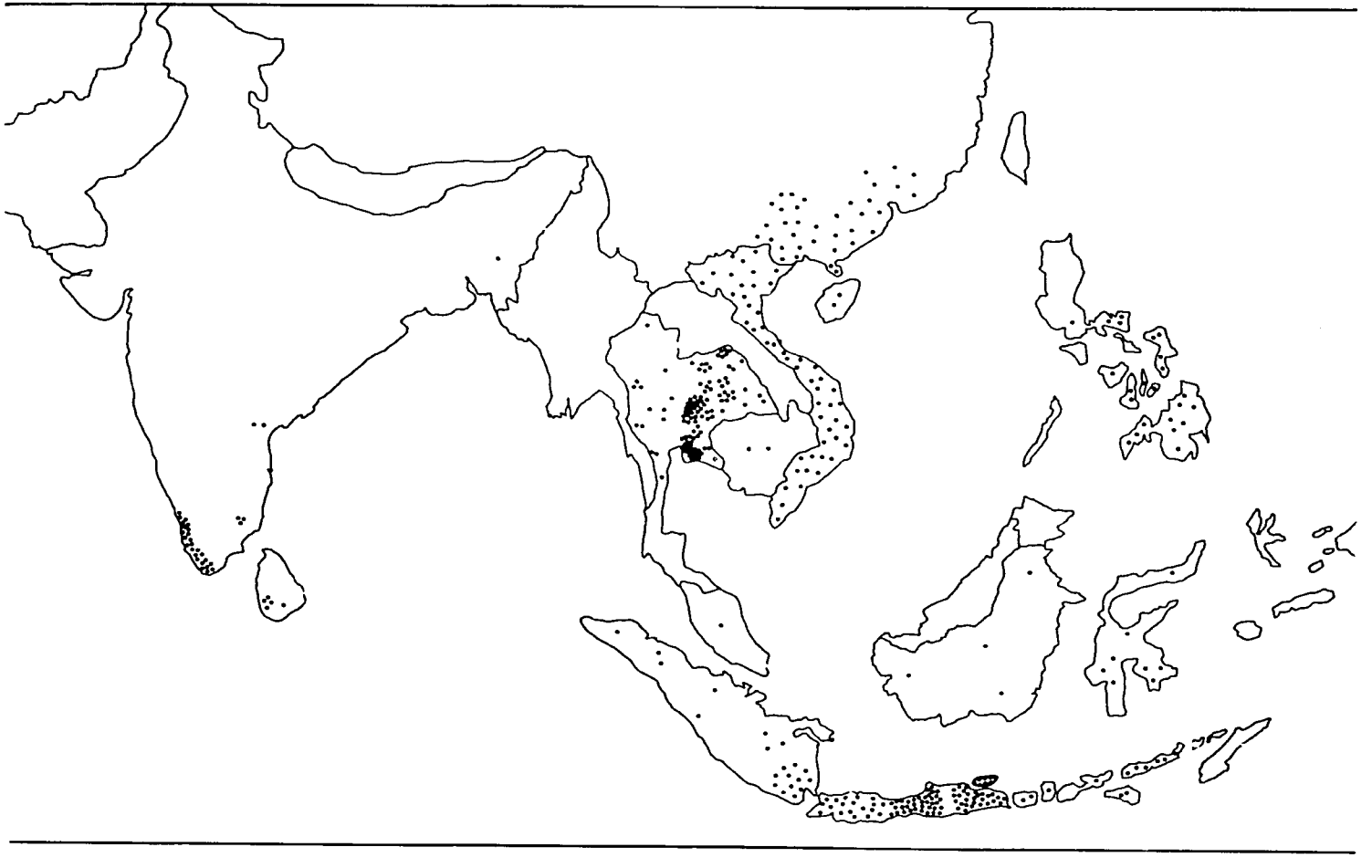


Figure 3. Principal Cassava Production Zone in Asia (a first approximation). Each dot represent 10.000 ha of cassava in 1985/86.

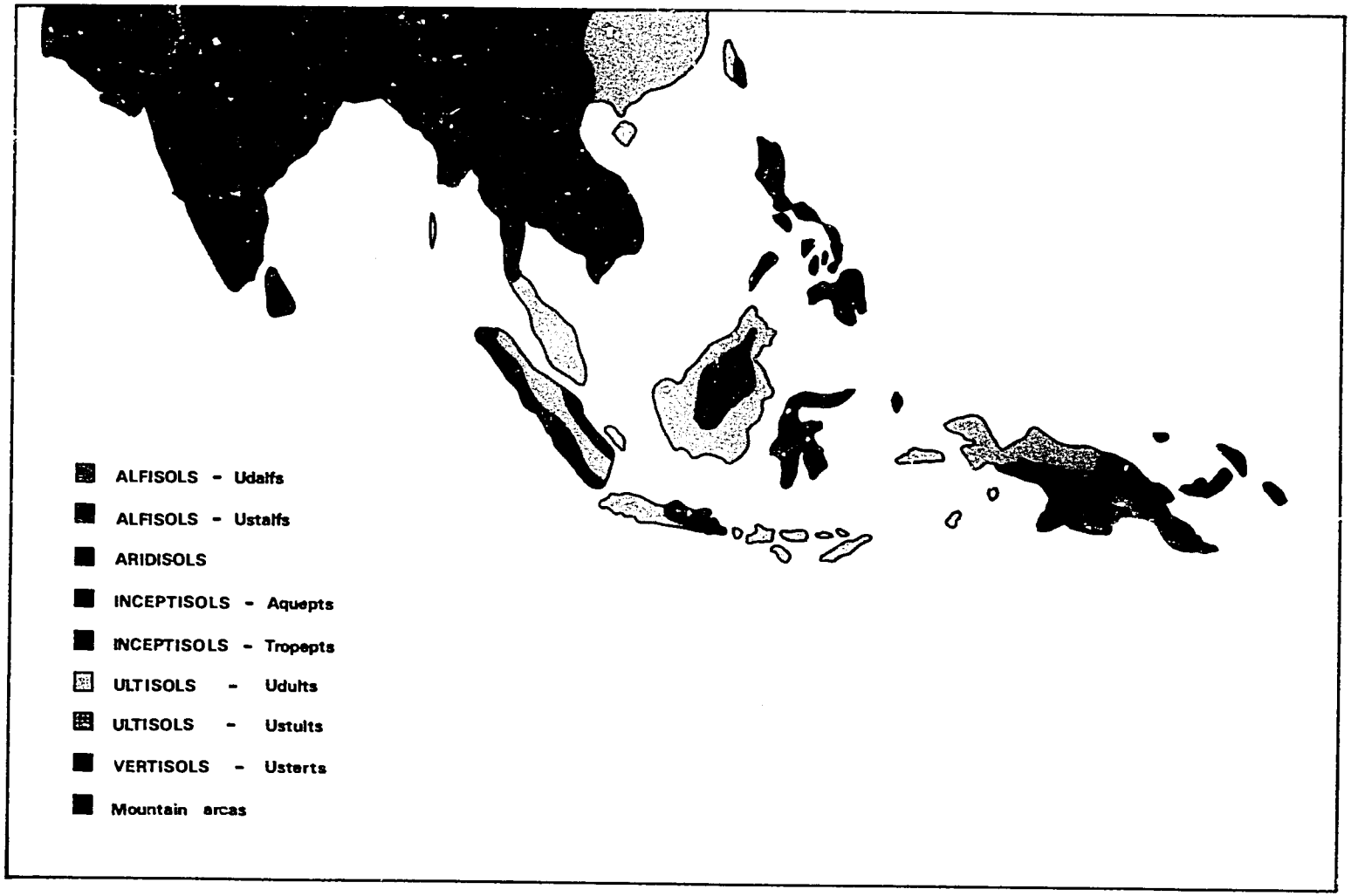


Figure 4. Soils of Southern Asia.

Source: U.S. Dept. of Agriculture, 1971. Soils of the Tropics.

Soil Characteristics of Cassava Zones

Figure 4 gives a very rough distribution of the soil orders and suborders in tropical Asia, and Table 2 gives the main characteristics of cassava soils. Unlike Latin America and Africa, where Oxisols and Ultisols are the dominant soil orders, in Asia there are relatively few areas of Oxisols (only in Kerala state of India and Hainan island of China) and the predominant soils are Ultisols and Inceptisols in the humid tropics and Alfisols and Vertisols in the semi-arid tropics. Cassava is grown mainly on Ultisols in Thailand, in West Java and Sumatra, in Southern China and in large parts of the Philippines; on Inceptisols in parts of Java; on Entisols in East

Table 2. Cassava soils in Asia.

	Topography	Soil classification	pH	Fertility	Texture
China:					
Hainan island	undulating	Oxisols, Ultisols	4.5 – 5.5	low	clay
Guangxi	terraced – steep	Ultisols, Alfisols	5.0 – 6.5	low	clay
India:					
Kerala	undulating – steep	Inceptisols, Oxisols	4.5 – 5.5	low	clay
Tamil Nadu	level	Vertisol, Alfisol	6.0 – 7.5	medium	clay
Indonesia:					
W. Java	level-undulating	Ultisols, Inceptisols	4.5 – 5.5	low	clay
E. Java	terraced-steep	Alfisols, Entisols	5.5 – 6.5	low-medium	clay
S. Sumatra	level-undulating	Ultisols, Inceptisols	4.5 – 5.5	low	clay
Philippines:					
Leyte	undulating-steep	Ultisols	5.0 – 7.0	low-medium	clay
Bohol	undulating	Ultisols	5.0 – 6.5	medium	clay
Thailand:					
Central Plain	undulating	Ultisols, Entisols	5.0 – 6.5	low	loamy sand
Northeast	level-undulating	Ultisols	5.0 – 6.0	low	sandy loam
Sri Lanka	undulating	Ultisols	5.0 – 6.0	low	

Java and Southeast Thailand, and on Alfisols in the limestone derived soils of East and Central Java. In Malaysia there is a large potential for cassava production on peat soils (Histosols). Nearly all these soils are acid with in some cases pH-values as low as 4.5, but more often in the range of 5.0 – 6.0. Aluminum toxicity is seldom a problem and there is nowhere evidence of a lime response in cassava, except on the peat soils of Malaysia. Deficiencies of calcium or magnesium have only been observed in isolated cases in Trivandrum, Kerala, in Kalasin in Thailand and in Guangzhou, China. Most cassava soils are low in P and some are low in K, but these nutritional problems are not nearly as severe as in Latin America. However, while in Latin America N deficiency is seldom a major problem, it is a very common and a major problem in Asia. Most Asian soils are very low in organic matter, possibly reflecting their long history of cultivation. Minor element deficiencies have not been commonly observed except for Fe and Zn deficiency in Tamil Nadu state of India, Cu deficiency in the peat soils of Malaysia, and Fe and Zn deficiency on old termite hills in Thailand. Thus, in Asia, the main problem of cassava nutrition is that of maintenance of soil fertility through the judicious use of fertilizers

and organic manures, as well as through alternative sources such as intercropped legumes, alley cropping or green manuring.

Table 3 shows the soil analyses data for several cassava research stations in Asia. Most experimental fields are high in P due to continuous use of P-containing fertilizers, while farmers fields tend to be low in P. This may be the cause of high yields obtained in many cassava experiments, compared with low yields under farmer's conditions. Moreover, cassava varieties may be evaluated under conditions that are not representative, and the selected material may not be well adapted to lower levels of soil fertility normally encountered in farmer's fields. This problem is especially serious in Thailand, Philippines, China and Lampung.

Table 3. Soil analyses of cassava research stations in Asia.

	pH	% OM.	ppm P (Bray II)	me/100 gm Ca	Mg	K	Texture
China:							
SCATC (Hainan isl.)	5.0	0.97	18.1	–	–	0.22	clay
India:							
CTCRI (Kerala)	5.0	1.3	8.3	8.73	4.34	0.14	gravelly sandy clay
Bhubaneswar (Orisa)	5.1	1.5	12.5	–	–	0.10	sandy loam
Indonesia :							
Umas Jaya (Lampung)	4.9	2.7	54.5	2.00	0.52	0.22	clay
Tamonbogo (Lampung)	4.5	1.8	19.3	0.42	0.17	0.07	clay
Jatikerta (Malang)	5.5	1.5	2.8	4.90	2.80	1.43	clay
Philippines:							
VISCA (Leyte)	6.4	1.6	29.8	20.90	7.60	0.80	clay loam
Thailand:							
Rayong	5.0	1.4	53.2	1.57	0.51	0.34	sandy clay
Banmai - Samrong	6.8	0.9	36.2	4.74	0.97	0.42	clay loam
Khon Kaen	4.8	0.6	30.3	0.49	0.18	0.08	sandy loam
Kalasin	5.2	0.5	75.0	1.65	0.05	0.08	sandy loam
Roi Et	5.4	0.5	78.0	0.68	0.09	0.08	sandy loam
Mahasarakham	5.8	0.5	19.6	0.76	0.18	0.08	sandy loam

Cassava is often blamed for "degrading" the soil, which is partially due to nutrient extraction without fertilization leading to soil exhaustion, and partly due to erosion. Table 2 shows that cassava in Asia is usually grown in areas with undulating or hilly topography, which are less suitable for production of rice. In most areas paddy rice is grown on the flat and fertile valley bottoms, while cassava and other upland crops (usually maize, sugar cane, sweet potato and grain legumes) are located on the surrounding slopes, usually on less fertile upland soils. Because of its ability to grow relatively well under adverse soil conditions, cassava is usually concentrated on the poorest of these soils and in those areas with already a high degree of erosion, where other crops will not produce at all. Grown under these conditions cassava is then blamed for "causing" soil degradation and erosion.

When poorly managed, cassava can indeed cause severe erosion, but recent experiments show that soil losses can be drastically reduced by better crop management. The best management

practices that reduce run-off and erosion are very site-specific and should be determined locally by simple erosion-control trials. Erosion is a particularly serious problem in the sandy loams or loamy sands of Thailand, in the hillside agriculture of Java and Kerala, as well as in parts of the Philippines and China. While cassava is often incorrectly blamed for causing extremely high levels of erosion, much research is needed to develop better practices that can maintain soil losses due to erosion within acceptable levels.

Climatic Characteristics of Cassava Zones

Table 4 shows that cassava in Asia is grown at almost uniform temperatures of about 26 – 27°C, with very little variation during the year. Only in northern Guangxi and Guangdong provinces of China and in the northeast of India is cassava grown in a subtropical climate with cool winters and possibilities of frost during 1 – 2 months.

Table 4. Climatic conditions of cassava growing areas of Asia.

	Mean temp °C	Annual precip. mm/year	No. dry months (PE > P)*	Onset of rainy season
China:				
Hainan island	24	1800 – 2500	3 – 4	March
Guangxi	20 – 24	1200 – 1800	3 – 4	March
India:				
Kerala	27 – 28	1800 – 2000	5 – 6	April, Oct
Tamil Nadu	27 – 28	900 – 1000	9 – 10	May
Indonesia:				
W. Java	26 – 27	2000 – 3000	0 – 4	Sept
E. Java	26 – 27	1500 – 2000	5 – 8	Oct
S. Sumatra	26 – 27	2000 – 3000	0 – 4	Sept
Malaysia	26	2000 – 3000	1 – 2	Oct
Philippines:				
Leyte		2000 – 3000	2 – 3	May, Nov
Sri Lanka:				
Southwest		2000 – 3000	5 – 6	March, Oct
Thailand:				
Central Plain	27	1100 – 1500	6 – 7	April
Northeast	27	900 – 1400	7 – 8	April

*PE = potential evapotranspiration; P = precipitation.

While most of the cassava growing regions are influenced by a monsoon climate, the rainfall varies from about 900 mm in Salem district of Tamil Nadu to levels of 2000 – 3000 mm in Malaysia, parts of Indonesia, Sri Lanka and Philippines. Figure 5 shows the length of the dry season, as defined by Thornthwaite as those months in which potential evapotranspiration is greater than precipitation. According to that definition cassava is grown in areas of only 1 – 2 dry months in Malaysia, Sumatra, Borneo, West Java and the Eastern Visayas of the Philippines, while it is also grown in areas of as much as 8 – 10 dry months in Tamil Nadu and Andhra Pradesh States of India, as well as in the Northeast and Central parts of Thailand, and in parts

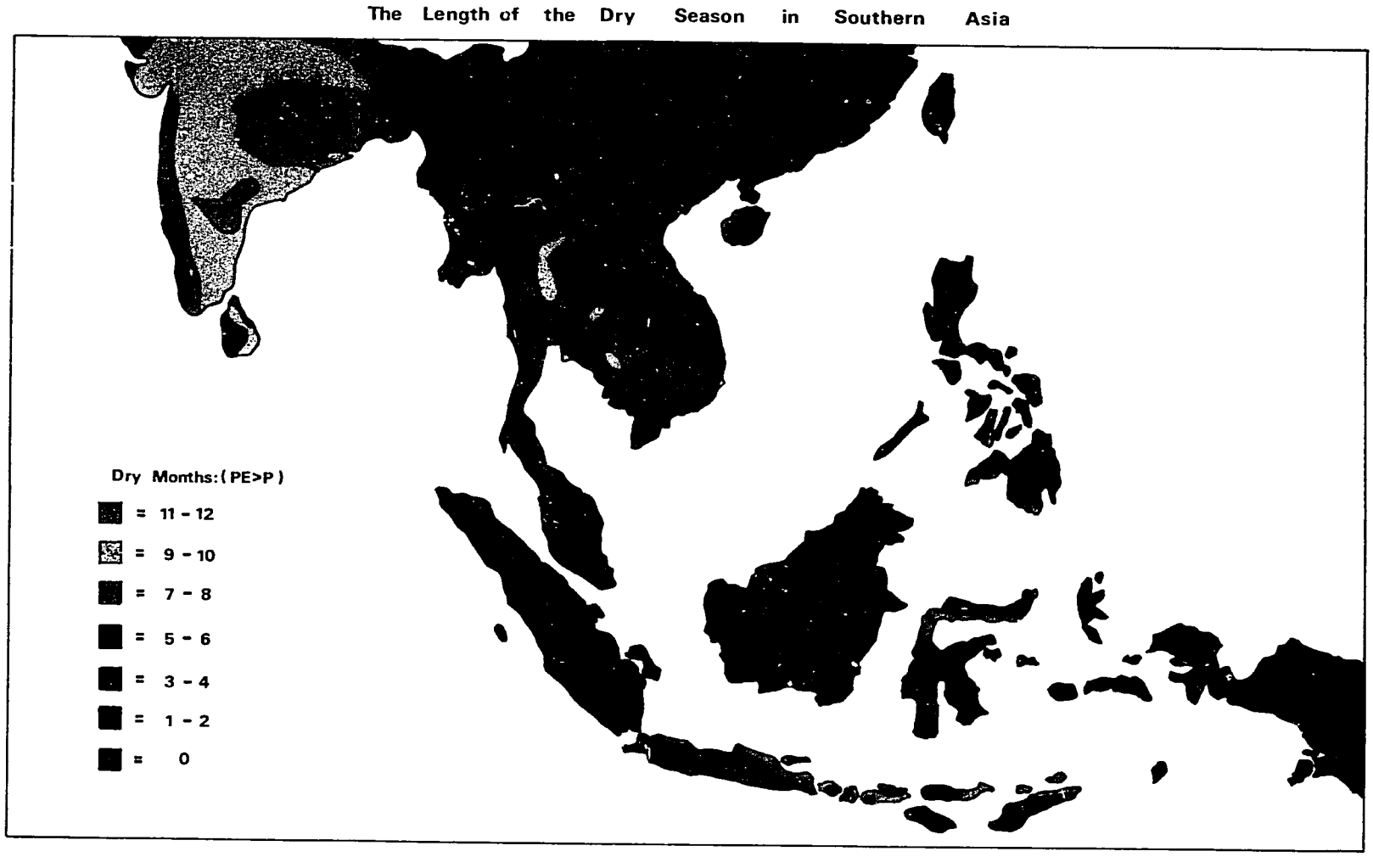
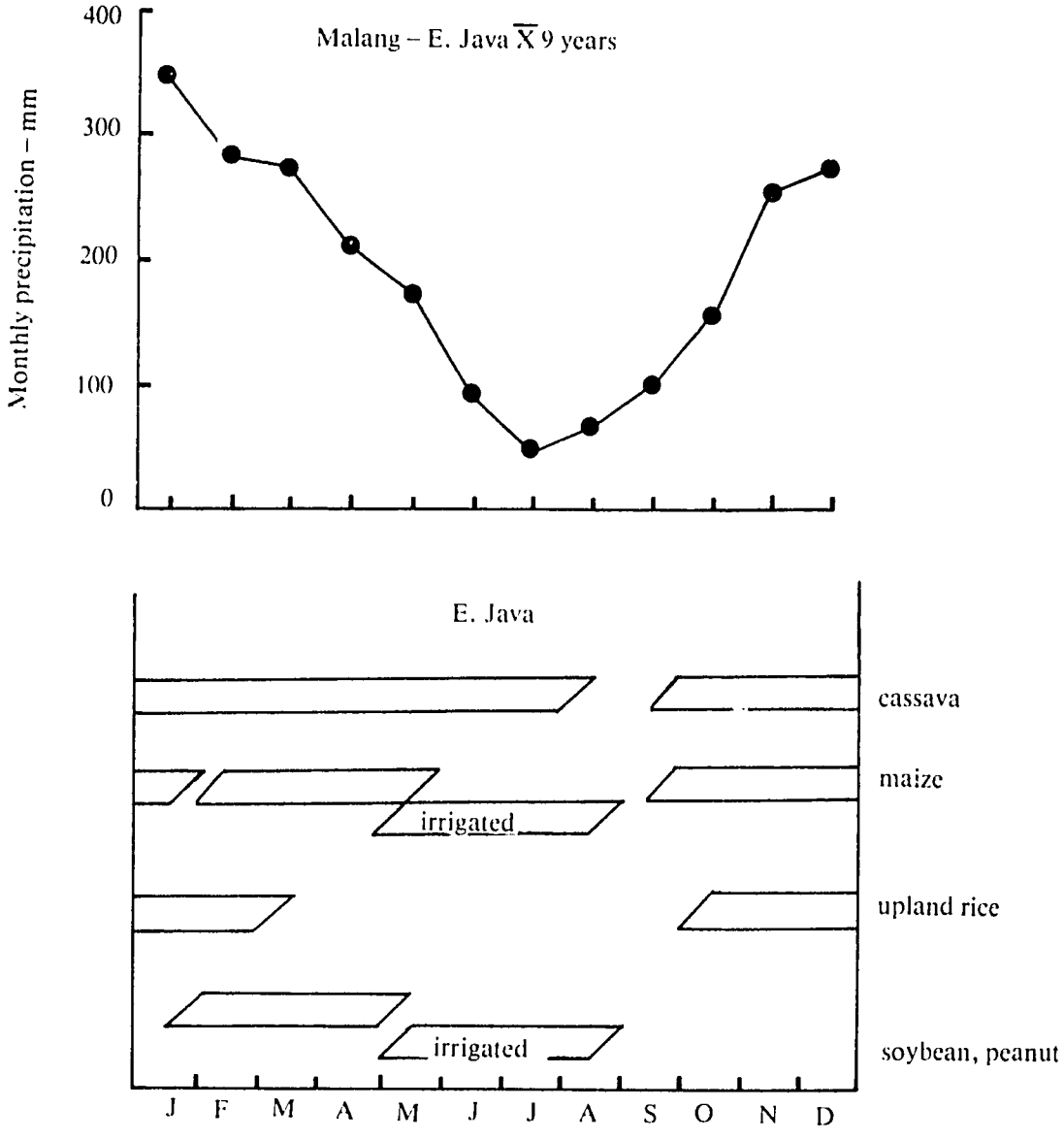


Figure 5 : Length of the dry season in Southern Asia. Dry months are defined as those with potential evapotranspiration greater than precipitation.

Source : Adapted from Huke, 1982, by R. Howeler.

of East Java. Actually, the areas of most intensive cassava production, such as Thailand and East Java, tend to have a long dry season, in which cassava has a relative advantage over other crops, because of its drought tolerance and low water requirement. For example, in Salem district of Tamil Nadu irrigation water is supplied from deep hand-dug wells; because cassava requires less frequent irrigations than rice or sugarcane it can compete with these latter crops in areas where the water supply is very limited. With irrigation and heavy applications of fertilizers cassava farmers in this district obtain some of the highest commercial yields of 30 – 33 t/ha. However, also without irrigation, yields in this district tend to be high, varying from 15 – 18 t/ha, inspite of the long dry season.

In northeast and east Thailand, where soils are sandy and very poor and the dry season may be as long as 7 – 9 months, farmers grow cassava because of lack of other alternatives.



Figuer 6. Rainfall distribution and cropping patterns in East Java (adapted from Hirose, 1985).

Due to its tolerance to drought and to acid infertile soils cassava can still produce 15 – 16 t/ha under these conditions. In East Java, under similar climatic conditions, cassava yields are lower, about 10 – 11 t/ha, because cassava cultivation is extremely intensive and cassava is usually intercropped with one or two successive crops of maize, upland rice, peanut or soybeans. Figure 6 shows that these intercrops are planted with cassava at the beginning of the wet season, followed by a second intercrop in the late wet season, which is harvested in the beginning of the dry season, while cassava is harvested in the middle of the dry season. Thus, cassava fits in a specific cropping pattern that makes maximum use of the land and the available soil moisture.

In wetter areas, however, of Kerala State, in Malaysia and the Philippines, cassava has to compete with more valuable plantation crops like rubber, oilpalm, coconut or sugarcane, and depending on world prices of these commodities and available markets for cassava or cassava-based products, cassava may not be able to compete.

Cultural Practices in Cassava-Based Cropping Systems

Cassava-based cropping systems in Asia are extremely varied due to different socio-economic as well as edapho-climatic conditions in each country or region, and the cultural practices used are also determined by these conditions. Southeast Asia has some of the highest population densities in the world, while in many countries 70 – 80% of that population is rural. Consequently, population pressure tends to be very high and the farm size very small, but this can be highly variable throughout Asia. Table 5 shows the land-labor ratio in the different countries or regions. This ratio is very low in most of India and Indonesia, it is intermediate in the Philippines and Thailand and highest in Malaysia. In regions with low land-labor ratios cassava production is very intensive and cassava is often intercropped, with little mechanization and high labor requirements. Areas with high land-labor ratios, on the other hand, have to reduce their labor requirements through mechanization and monocropping. Also, where cassava is grown as a plantation crop, usually for a starch factory, such as in southern Sumatra, in Mindanao, in Malaysia and on the state farms of China, cassava production is highly mechanized and fertilizer inputs tend to be high.

Table 5. Land-Labor ratios and average farm size for various Asian countries.

Country	Land-labor ratio 1/ (ha/person)	Average farm size (ha/farm)
Malaysia	0.65	2.19 2/
Thailand	0.51	3.72
Philippines	0.44	3.59
Indonesia	0.22	1.05
Java	NA	0.4
India (Kerala)	0.12	0.49

1/ Arable land and land in permanent crops divided by rural population, 1980.
2/ Does not include estates which make up 31% of cultivated area.

Source: FAO, 1981; agricultural censuses of different countries.

Table 6. Cropping systems of cassava in Asia.

China	intercropped with peanut, some under rubber
India:	
Kerala	monoculture or intercropped under coconut
Tamil Nadu	monoculture or intercropped with peanut or vegetables
Indonesia:	
Java	intercropped with maize, upland rice, peanut, or soybean
Sumatra	monoculture or intercropped with maize, rice, peanut or soybean
Malaysia	monoculture
Philippines	monoculture or intercropped under coconut
Sri Lanka	intercropped with pineapple or under coconut
Thailand	monoculture, some under coconut or rubber

Table 6 shows that in Thailand, Malaysia and on large plantations in Sumatra cassava is mainly grown in monoculture; in Kerala, in much of the Philippines and in small areas of Thailand and Java it is grown under coconut or in rubber plantations, while in Java, China and Tamil Nadu state of India it is intensively intercropped with maize, rice, peanuts or vegetables. In China and Java cassava plots are often rotated with sugarcane or other food crops. Only in Tamil Nadu cassava is irrigated (in about 60% of the cassava area); in the rest of Asia cassava is rainfed.

1. Land preparation :

Land preparation is done either manually with a hoe, with a bullock or waterbuffalo-drawn plow, or with a tractor mounted implement, usually a plow, disc plow or harrow. Table 7 shows that manual preparation is most common in India (especially Kerala) and in Java, while bullocks are used in Tamil Nadu, in China, Philippines and by small farmers in Thailand. In some parts of East Java land preparation is done with bullocks followed by hand ridging with hoe. In much of Thailand and Malaysia, on cassava plantations in Sumatra and Mindanao, and on state-farms of China, cassava fields are prepared by tractor, usually 1 – 2 passes with a plow, followed by a disc harrow and occasionally by a ridger.

Table 7. Land preparation for cassava in Asia.

China: state farms	tractor
peasant farms	hand preparation or bullocks
India: Kerala	hand preparation
Tamil Nadu	bullocks
Indonesia: Java	hand preparation or bullocks
Sumatra	tractor or bullocks
Malaysia	tractor
Philippines	bullocks
Sri Lanka	hand preparation
Thailand	tractor (by contractor) or bullocks

2. Stake preparation :

Nowhere in Asia are cassava stakes grown commercially and farmers obtain their planting material either from their own fields or from neighbors. Before or during the cassava harvest long stems are cut from mother plants that are selected for their vigor or high root yield. These mother plants should be 8 – 12 months old and free of symptoms of diseases or pests. The stems are either main stems or primary branches. If these stems are harvested several weeks or months before the next planting season they are usually piled up horizontally or vertically in the field, preferrably under shade or covered with leaves. In northern Guangxi and Guangdong provinces of China the stems are cut before danger of frost occurs, and they are stored in shallow or deep holes in the ground and then covered with straw and soil to protect them from frost damage. At time of planting, cassava stems are cut into stakes of 15 – 20 cm length with either a sharp knive or saw. If stems had been stored for a long time, the dehydrated or sprouted ends are disgarded. Selected stakes are usually 1.5 – 2 cm in diameter and should have at least 5 – 7 nodes. However, if planting material is scarce, farmers plant with much shorter or thinner stakes, which oftentimes leads to poor sprouting and poor stands. Nowhere in Asia are cassava stakes treated with fungicides or insecticides, and the near-absence of deseases or pests (except for occasional scale insects) makes this practice probably unnecessary.

3. Time of planting and harvest :

Table 8 shows that in most countries cassava is planted at the beginning of the rainy season. In China this also corresponds with the onset of spring in March-April. In East Java about 75% of cassava is planted in the early wet season, between Oct and Jan, while in India most cassava in Trivandrum is planted in the early rainy season in April or May and harvested during the dry season in Jan or Feb. In Thailand also most cassava is planted with the first monsoon rains in April or May, but a large proportion is also planted at the end of the rainy season in Oct—Nov, and even throughout the dry season from Dec—Mar, especially in the sandy soils which retain some moisture and do not harden excessively upon drying. Although plant

Table 8. Principal months of planting and harvesting cassava in Asia.

	Time of planting	Time of harvest
China	March – April	Dec – Jan
India:		
Kerala	Apr – May or Sept – Oct	Jan – Feb or Jul – Aug
Tamil Nadu (rainfed)	Oct – Nov	Oct
Tamil Nadu (irrig.)	Jan – Apr	Dec – March
Indonesia:		
E. Java	Oct – Nov	Jul – Aug
W. Java	all except June – Aug	almost year – round
Sumatra	all except June – Aug	almost year – round
Malaysia	year – round	year – round
Philippines	June or Nov	Jan – Feb or Jul – Aug
Sri Lanka	year – round, mainly Oct – Nov	year – round
Thailand	May or Oct	Jan – Mar or Oct

stands are often poor when planted in the dry season, requiring partial replanting, the advantage of dry season planting is a continuous use of land, less weed problems, a rapid canopy closure after the first rains, reducing erosion, and an off-season harvest, when demand for cassava is high.

In Salem district of Tamil Nadu cassava fields with irrigation facilities are planted at the height of the dry season in Jan-April. The crop is irrigated innitially weekly and later monthly until the onset of rains in June, after which it is essentially a rainfed crop. This allows a harvest in Dec-Mar, while the rainfed crop, planted in Nov, is harvested in Sept or Oct. Thus, starch factories can operate from September through March.

4. Method of planting :

Table 9 shows that planting methods are quite variable in Asia. In most countries cassava is planted vertically except in China, Malaysia and the Philippines, where it is planted horizontally. In India farmers plant the stakes either on hand-made mounds, spaced 90 × 90 cm or on levies surrounding areas of mounds. The levies and staggered mounds help to control erosion on the hillsides. In Thailand most cassava is planted on the flat, although some farmers, especially when planting in the early rainy season, plant on ridges or ridge-up with the first weeding. The latter is also a common practice in the Philippines and China, especially if weeding is done with bullocks. In Java cassava is usually planted on the flat or on slightly raised levies bordering terraces. Contour ridges on slopes have been observed on cassava plantations in Sumatra. In Thailand cassava is sometimes planted horizontally when planting occurs during the dry season. Similarly, in China cassava may be planted horizontally and rather deep in Oct or Nov to prevent frost damage during winter and enable early growth in the spring.

Table 9. Method of planting cassava in Asia

		Stake position	Field configuration	Popalation per ha
China		horizontal	flat or ridged-up	12000 – 15000
India	Kerala	vertical	on raised mounds or levies	12000 – 17000
	Tamil Nadu	vertical	flat or on ridges	10000 – 15000
Indonesia		vertical	flat or on levies	8000 – 12000
Malaysia		horizontal	on ridges	10000 – 12000
Philippines		horizontal	flat or ridged-up	10000 – 20000
Sri Lanka		vert./slanted	mounds	10000 – 15000
Thailand		vertical	flat or on ridges	10000 – 15000

5. Fertilization :

Table 10 shows that fertilizer use is highly variable, but in general tends to be very low. High levels of fertilizers are used only in the irrigated areas of Tamil Nadu, in cassava plantations in Sumatra, Malaysia and Mindanao, as well as in some areas of good soils in Java and on state-farms in China. Fertilizer use is relatively higher in Indonesia and Malaysia, due to heavy government subsidies, and is very low in Thailand because of high fertilizer prices. Although fertilizer responses for cassava in Thailand have been amply demonstrated, and government officials worry about soil exhaustion and declining yields, the fact is that high fertilizer applications are seldom economically justified, because of low prices for cassava roots and high

Table 10. Fertilizer use for cassave production in Asia.

	Chemical $N + P_2O_5 + K_2O$ kg/ha	Organic t/ha
China	little	some
India : Kerala	19	high
Tamil Nadu	200	18
Indonesia: Java	22	0 – 9
Malaysia	198	none
Philippines	none	none
Sri Lanka	none	some
Thailand	7	none

Source: Uthamalingam, 1980; Roche, 1982; Tunku Mahud, 1979; Thailand, 1982.

fertilizer costs. In India, China and Java considerable amounts of nutrients are applied annually in the form of farm yard manure (FYM) or ash, but in Thailand little animal manure is available and labor costs are too high for their transport and application.

Since most cassava farmers do not have the resources to buy large amounts of fertilizers, it is extremely important to find cheaper sources of plant nutrients and to develop application methods that make maximum use of small applications and reduce losses from NH_4-volatilization and NO_3- or K-leaching. Intercropping with other foodcrops or with tree legumes (alley cropping) may help reduce leaching losses by recycling leached nutrients. Intercropping with grain legumes, as practiced in Java, China and parts of India, can make a positive contribution to the N-supply through N-fixation. Similar effects can be obtained with hedges of tree legumes or intercropped annual legumes, which are pruned regularly and their foliage used as green manure mulch. The effectiveness of these systems is highly site-specific (usually more effective in humid climates and in well-drained soils) and the exact combination of species and their management have to be determined locally, so as to maximize their usefulness. Many of these systems will improve soil structure, and increase the water and nutrient holding capacity through an increase in soil organic matter By covering the soil and improving infiltration these systems also tend to reduce run-off and erosion.

6. Weeding :

Weeds can cause serious competition for cassava and inadequate weed control may be the cause of low yields in several countries, especially in the wetter regions such as the Philippines. Table 11 shows that in most countries weeds are controlled by 2 or 3 hand weedings with a hoe, sometimes in combination with a bullock-drawn plow. Only in Malaysia and in some large farms in Thailand are weeds controlled with herbicides. Man-days used for weeding are extremely high in Salem district of Tamil Nadu, where weeds are a serious problem and weeding is usually done by women working relatively short days, and are very low in the Philippines. The use of the "bolo" or curved knife for weeding in the Philippines also does not appear very efficient and probably leads to inadequate weed control. The introduction of more efficient weeding

Table 11. Weeding practices for cassava in Asia.

	Man – days for weeding	Weeding practices
China	high	bullocks or handweeding with hoe
India: Kerala	27	hand weeding with hoe, solely by men
Tamil Nadu	92	hand weeding with short hoe, mainly by women
Indonesia: Java	high	hand weeding with hoe
Sumatra	high	hand weeding, some pre-emergent herbicides
Malaysia	13	hand weeding with hoe, some pre-emergent herbicides
Philippines	9	bullocks and hand weeding with "bolo"
Sri Lanka		hand weeding with hoe
Thailand	25	bullocks and hand weeding with hoe, some herbicides

Source: Uthamalingam, 1980; Ninan, 1986; CTCRI 1987.

tools such as a cultivator-ridger as an animal drawn implement, or a sharp hoe with long handle, which allows people to stand straight while weeding, can probably make a major contribution in increasing the efficiency of weeding and thus in reducing weeding costs.

7. Pest and disease control :

Cassava production in Asia is characterized by the near absence of pests and diseases and no special control measures are taken except for the use of tolerant varieties and selection of healthy planting material. In India cassava mosaic virus is a serious disease, which is controlled by roqueing, use of clean planting material and tolerant varieties. In Hainan island of southern China and in the Philippines and Thailand cassava bacterial blight (CBB) can be serious and varieties are being selected for CBB tolerance.

8. Harvest :

In most of Asia cassava is harvested by hand-pulling, sometimes using simple tools as a lever. In Malaysia experiments are under way testing a tractor-mounted cassava-harvester. In most countries tops are re-incorporated into the soil, while in India and Java the tender tops are fed to cattle. Stems are often used as firewood in China, India and Indonesia.

Labor Utilization and Production Costs

The use of labor for cassava production varies greatly among countries and depends mainly on the land-labor ratio and labor costs. Thus, in India and Indonesia labor use is extremely high, ranging from 150 – 350 man-days/ha, in Thailand labor use is intermediate, while in Malaysia and the Philippines it is relatively low (Table 12). In Thailand and the Philippines most labor is required for land preparation (30 – 35%) followed by harvesting (25 – 30%) and weeding (18 – 26%). In Tamil Nadu about 50 – 60% of labor is used for weeding, which is mostly done by women (Table 13).

Table 14 shows that costs of production are highest in Malaysia due to high labor costs. This accounts for 62% of total variable costs eventhough labor input is relatively low. In India

and Indonesia labor costs are as high as 85% of total costs due to high labor input, while in Thailand labor costs are relatively low, accounting for 60% of total variable costs. Although yield levels are high in Malaysia, their production costs are also high, resulting in a high cost of US$22 per ton fresh roots. In India cassava production costs are also rather high at $17 per ton in terms of variable costs, and $33 for total costs; the latter is very high due to high land costs. In Indonesia (Lampung) production costs are relatively low, but so are yields, resulting in an intermediate cost of $13 per ton. Lowest production costs are obtained in Thailand due to a combination of relatively low land and labor costs and high yields. This results in a low per ton cost of $12, enabling Thailand to compete very successfully on the world market.

Table 12. Labor use for cassava production in Asia.

	mandays/ha
India – Kerala	116
– Tamil Nadu	139 – 265
Indonesia	230 – 350
Malaysia	62
Philippines	53
Thailand	96

Source : Lynam, 1987

Table 13. Cassava production, area and labor use in India, Philippines, Thailand, and Malaysia.

	India Kerala 1977	India Tamil Nadu 1979 1/	India Tamil Nadu 1979 2/	Malaysia Perak 1979	Philippines 1979	Thailand 1984
Cassava area (ha)		–	–	–	0.6	4.0
Farm size (ha)	0.5	–	–	–	3.0	8.9
Yield (t/ha)	15	23	15	28	4	15
Labor (man-days/ha):						
Land preparation	54	27	12	1	20	30
planting	10	19	12	8	8	12
fertilizing	– 3/	5	7	3	–	–
weeding	27	97	92	13	10	25
irrigation	–	25	–	–	–	–
harvesting + transport	22	31	28	37	14	28
peeling and drying	–	–	–	–	1	–
miscellaneous	2	2	2	–	–	1
Total	115	206	153	62	53	96

1/ irrigated
2/ rainfed
3/ included in weeding

Source : Ninan, 1986; Uthamalingam, 1980; Tunku Mahud, 1979; Mejia *et al.*, 1979; Thailand, 1984.

Table 14. Labor use and cost structure in cassava production in Asia[1/]

Country Location Period	Malaysia Perak 1983	Thailand 1984	India Salem 1979 (rainfed)	India Kerala 1977	Indonesia Lampung 1980	Indonesia E. Java 1980
Labor input (man – days/ha)	84	96	153	116	–	–
Land costs (US$/ha)	40	28	171	64	11	53
Variable Cost (US$/ha)						
Labor	304	111	162	95	108	67
Land preparation	114	52	22	–	–	–
Fertilizer	59	6	–	38	19	17
Pesticides	–	2	–	–	–	–
Seed	11	14	–	51	–	–
Total variable cost	488	185	185	184	127	84
Yield	22	15.0	10.7	12.6	9.4	10.2
Variable cost (US$/ton)	22.2	12.3	17.3	14.6	13.5	8.3

1/ Domestic currency converted to US dollars at existing exchange rate.

Source : Chan *et al.*, 1983; Achmad Suryana, 1980; Thailand, 1984; Uthamalingam, 1980; Ninan, 1986.

Cassava Utilization

Table 15 shows the cassava production and utilization data, most of it rather old. Still, it shows some clear patterns of utilization which are still valid today.

Fresh cassava consumption by humans is mainly important in Indonesia, Sri Lanka,

Table 15. Production and utilization of cassava (fresh root weight equivalent) in principal producing countries.

Country	Production (000t)	Export (000t)	Domestic utilization: Human consumption: Fresh (000t)	Dried (000t)	Starch (000t)	Animal Feed (000t)	Waste (000t)
India (1977):	5688	22	2610	619	1784	–	653
Kerala	4189	22	2437	619	499	–	503
Tamil Nadu	1310	–	126	–	1162	–	131
Indonesia (1978):	12083	924	3130	3252	4141	–	636
Java	8576	294	1928	2759	3064	–	530
Off-Java	3507	630	1202	493	1077	–	105
Malaysia (1977)	432	66	–	–	302	43	21
Philippines (1977)	1011	–	865	–	104	42	–
Thailand (1977)	13,554	9,996	–	–	745	16	2,797
China (1980)	3,300	336	1,466	–	105	1,294	99
Sri Lanka (1981)	526	–	368	–	–	–	158

Source : Unnevehr, 1982; Titapiwatanakun, 1979; CIAT data files; FAO; Jayawardena, 1986; Lynam, 1987.

Philippines and in Kerala State of India. In Java consumption of dried cassava (gaplek) is also very important. Thus, human consumption accounts for over 55% of total production in Java and 60% on the outer islands. In Kerala cassava is consumed mainly as fresh roots, accounting for 73% of total production; likewise, in the Philippines it may account for as much as 85% and in Sri Lanka for 70% of production, respectively.

Production of starch and starch-based products such as glucose and high fructose/glucose syrups (HFGS), monosodium glutamate (MSG), and alcohol is important in Salem district of Tamil Nadu, and in Malaysia, where it accounts for nearly 90% and 70% of production, respectively. It is also traditionally very important in Indonesia, where it accounts for 28% of production. Some of this production has now expanded to large cassava starch factories/plantations in Lampung, Sumatra. Cassava starch in Indonesia is mainly used for production of MSG and "krupuk", while an HFGS plant is recently in operation. In China starch and MSG factories are often part of the state farms and probably more than 30% of cassava production is now used for starch production.

China is probably the only country where significant amounts (probably more than 50% of production) is used as animal feed, mainly for swine, after hand chipping, drying and milling of the cassava roots.

Export of cassava chips and pellets is the main utilization of cassava in Thailand, where it accounts for over 70% of production. Due to relatively cheap cassava production and a highly efficient large-scale processing and transport system, Thailand is now the world's primary exporter of cassava, mainly as pellets but also in the form of starch. Increasing demand for cassava chips and pellets for animal feed, both for export and for domestic use, make this the growth market of greatest future potential for increasing cassava production in Asia.

Production and Utilization Constraints

Table 16 shows the primary and secondary markets for cassava and the major production and/or utilization constraints faced by each country. These were identified after intensive study of cassava production and marketing systems in Asia by the CIAT Cassava-Economy program and are discussed in detail in a recent publication on Cassava Demand in Asia (Lynam, 1987). In some countries, notably Thailand, Philippines and on the outer-islands of Indonesia, the principal constraints for increased cassava production are lack of growth markets, i.e. demand side constraints. These countries have to identify additional markets in which cassava can compete economically with corn in the animal feed and starch markets and with sugarcane and corn in the HFGS markets. In many countries this can be done only through increased cassava yields and/or decreased production costs by the use of higher yielding varieties and more efficient agronomic practices. It can also be accomplished by shifting cassava from areas with serious land constraints, where it has to compete with other, more valuable products, to areas where cassava has a greater relative advantage, such as the drier areas of Tamil Nadu and Andhra Pradesh of India or the outer-islands of Indonesia. In these areas cassava could be produced more cheaply through advantage of scale and lower land prices.

In other countries, notably India, Malaysia, Java and probably China the constraints are on the supply side, limited by small farm size, need for intercropping, competition with

Table 16. Cassava utilization in Asia and principal constraints to expansion of production and utilization.

	Major market	Secondary market	Principal constraints
China	feed-dry chips	starch	short growing season, access to fertilizers
India:			
Kerala	food-fresh roots	starch	farm size, competition with tree crops
Tamil Nadu	starch	food-fresh roots	farm size, competition with sugar cane, rice
Indonesia:			
Java	food-fresh roots	food-gaplek	farm size, soil degradation
Sumatra	starch	food-fresh roots	competition with tree crops, infrastructure
Malaysia	starch	animal feed	land use policy, competition with imported maize and cassava
Philippines:			
Mindanao	starch	food-fresh roots	lack of integration between production and processing
Other islands	food-fresh roots	starch	farm size, marginal land, poor practices
Sri Lanka	food-fresh roots	feed-dry chips	farm size, competititon from maize
Thailand	export-pellets	starch	soil degradation, high fertilizer costs price distortions by EEC policies

tree crops, or the use of low-yielding varieties or poor cultural practices. In Malaysia the present land-use policies limit cassava production by giving priority to export plantation crops. In this case cassava production can increase by identification of better varieties and cultural practices, especially more productive intercropping systems, and by intensification of technology transfer to farmers.

Research Needs

In Asia most cassava research programs are relatively young (with the exception of CTCRI in India) but have developed rapidly during the past 10 – 15 years. They have been quite successful in selecting or breeding new, higher-yielding varieties and to develop packages of recommended cultural practices. Tables 17, 18, 19, 20 and 21 summarize the recommended varieties and cultural practices in India, Indonesia, the Philippines, Thailand and Malaysia. In countries like China and Sri Lanka, the recommended practices may not be as well defined, while in Malaysia the recommended practices for mineral soils are now being adapted to fit production on peat soils.

In several countries an increasing amount of cassava is produced under coconut, or among young rubber trees, as well as in areas of recent reforestation. Research is needed to identify varieties with shade tolerance or practices that reduce competition for light as well as underground competition for water and nutrients. This research is highly site-specific, the

Table 17. Recommended cultural practices for cassava production in India.

Varieties:	H 97	: high starch, good cooking quality, 10 months duration
	H 165	: early (7 months) variety, desease and pest resistent
	H 226	: good cooking quality
	H 1687	: good cooking quality, high yield
	H 2304	: high yield, drought resistent, high starch content
Planting time:		April May or Sept Oct
Land preparation:		mounds of 25 30 cm high, or contour ridges of 25 30 cm high
Planting material:		select plants free of CMV, cut mature stems, 15 20 cm stakes
Planting method:		vertical, 5 cm deep; 90 × 90 for branching varieties, 75 × 75 for non-branching types; replant as soon as possible.
Fertilization:		10 15 t/ha of FYM, incorporated; 100 kg N, 100 P_2O_5, 100 K_2O/ha; P all at planting, N and K split at 0 and 45 60 days; only 25 P_2O_5 if soil is high in P.
Sprout removal:		retain only two shoots, removing excess sprouts at 30 45 days.
Weeding and earthing up:		at 45 60 days and 1 2 months later
Intercrop:		peanut, french bean, cowpea
Harvest:		at 8 10 months, depending on variety

Table 18. Recommended cultural practices for cassava production in Indonesia.

Varieties:	Adira 1	: low HCN, high starch content, early maturity
	Adira 2	: high HCN, high yield, medium starch content, CBB tolerant
	Adira 4	: high yield, CBB tolerant, medium HCN
	Faroka	: high yield, high HCN; adapted to drier areas
	Ndoro	: low HCN, good eating quality, low yield
Planting time:		Oct Nov or in Jan Feb as a monocrop after maize or peanut
Land preparation:		plowing with bullocks followed by ridging
Planting material:		stakes from basal part of stem, 20 25 cm long and 2.25 2.5 cm in diameter. Long stems can be stored in open field for up to 20 days.
Planting method:		1) Ordinary system with stakes planted vertically at a spacing of 100 cm between rows and 75 cm between plants. Maize or peanut are planted between plants in the row. 2) Mukibat at a spacing of 100 × 100, or 100 × 125
Fertilization:		100 kg N, 50 P_2O_5, 100 K_2O/ha for ordinary system, 200 kg N, 50 P_2O_5 and 150 K_2O for Mukibat system.
Weeding:		2 3 hand weedings with hoe.
Harvest:		after 10 12 months for ordinary system, or 12 15 months for Mukibat system.
Intercropping:		with maize or peanut, followed by peanut or soybean.

Table 19. Recommended cultural practices for cassava production in the Philippines.

Varieties:	PR-C 13 (Kadabao) PR-C 24 (Golden Yellow) : high starch, early variety PR-C 62 (Colombia) : high yield
Planting time:	at onset of rainy season or 3 – 5 months before dry season
Land preparation:	one plowing and harrowing to 20 cm depth (2 – 3 plowings in areas fallowed for long time). Ridging or mounds in areas subject to water logging.
Planting material:	select desease free 10 – 12 months old plants, use mature stems, cut stakes of 20 – 25 cm length; stems stored up to 1 month under shade; for long-term (>2 months) storage, bury basal part of stem in soil to allow leaf production.
Planting method:	vertical on ridges in wet areas; horizontal in furrows in dry periods and in light soils; deeper (>15 cm) if soil is dry. Population of 10.000 plants/ha in fertile soils, 20.000 in infertile soils.
Fertilization:	generally 90 kg N, 60 P_2O_5, 60 K_2O/ha, but depends on soil fertility; half at planting, half side-dressed at 30 days.
Weeding:	off-barring at 2 weeks, hilling up at 5 and 7 weeks, plus hand weeding between plants.
Harvest:	at 10 – 12 months
Intercropping:	cassava may be intercropped or rotated with peanuts, soybean, mungbean, cowpea, pigeonpea or bush beans.

Table 20. Recommended cultural practices for cassava production in Thailand.

Varieties:	Rayong 1: high yield, high yield stability, bitter Rayong 2: good eating quality Rayong 3: high starch content, bitter Rayong 60: high yield, relatively high starch content, bitter
Planting time:	May – June or Oct – Nov
Land preparation:	plowing once or twice at 15 – 20 depth with tractor or oxen, followed by disc – harrowing once or twice; ridging by oxen.
Planting material:	select healthy 10 – 12 months plants, cut mature stems, store in shade (less than 30 days), cut stakes of 15 – 25 cm length.
Planting method:	ridge planting if soil will be wet; flat planting when low soil moisture; plant vertical at 5 – 10 cm depth; spacing at 70 – 100 cm row width, 60 – 100 cm between plants.
Fertilization:	50 kg N, 50 P_2O_5, 50 K_2O/ha (or 100 – 100 – 100 in poor soils), half at planting, half side dressed after first weeding.
Weeding:	2 – 3 times manually, at 30 – 45 days and 2 – 3 months later.
Harvest:	at 10 – 12 months.
Intercropping:	Cassava may be intercropped with two rows of peanut or mungbean, 20 cm between rows, 10 cm between plants.

Table 21. Recommended cultural practices for cassava production in Malaysia.

Varieties:	Black Twig : high starch, high yield, wide adaplability, bitter C – 5 : high starch, high yield, early Medan : good eating quality CM 982 – 7 : high yield, adapted to peat soils, low starch
Planting time:	almost year – round
Land preparation:	1 – 2 plowings with tractor followed by harrow or rototiller, sometimes ridging.
Planting material:	20 – 23 cm long stakes, cut from woody mature stem taken from healthy plants, at least 7 months old.
Planting method:	horizontal planting, completely buried; spacing at 1 × 1 meter; on peat soils also vertical planting with 60 cm long stakes.
Fertilization:	For mineral soils: 60 kg N/ha, 30 P_2O_5, 160 K_2O/ha; sometimes 15 kg Mg and 2 kg Zn/ha. For peat soils: 200 kg N/ha, 50 P_2O_5, 160 K_2O, 2.5 Cu/ha, sometimes lime. Fertilizer banded near stake at planting or at 3 – 4 weeks after planting.
Weeding:	pre-emergent herbicides: 2 liter alachlor + 2 kg fluometuron/ha; post emergent hand weeding or directed spray of 2 liter paraquat/ha; pre-harvest spray with 2 liter paraquat/ha. In peat soils: pre-emergent herbicides: 4 liter alachlor/ha.
Harvest:	9 – 12 month
Intercropping:	Cassava may be intercropped with 1 row of sweet corn or peanut at normal 1 × 1 m cassava spacing, or with 2 rows of sweet corn or 3 rows of peanut at 0.9 × 0.9 × 1.8 m cassava spacing (double row).

results depending on the tree species involved (Ghosh *et al.*, 1987), as well as the soil and climatic conditions.

Besides the research objective of increasing cassava yields, there is a second objective of increasing the stability and sustainability of yields. Yield stability can be increased by selection of germplasm that is adapted to drought as well as occasional flooding, to wind damage by typhoons, or to cold spells in the subtropics. Tolerance to diseases or insect pests will also increase yield stability as these problems may be endemic or only occur sporadically. Yield sustainability is extremely important in Asia where few land frontiers remain, and cassava production will have to continue on the same land for many more years. Long-term productivity can only be maintained by preventing soil exhaustion, through the judicious use of fertilizers, organic manures, green manures, or intercropping with grain or tree legumes, and by preventing soil erosion or degradation through loss of organic matter. As these aspects have not been studied much in the past, there is a need for intensive research in these areas in the future. Notwithstanding the improvement in varieties and cultural practices in Thailand, cassava yields have declined recently, because of continuous monocropping without fertilization and inadequate erosion control. A strong effort should be made to reverse this trend. For similar reasons, Indonesian government officials are reluctant to support cassava research for fear of stimulating a crop which eventually may degrade the soil. A research effort is required to develop cultural practices that not only increase cassava yields but also permit the sustainability of cassava production.

On-Farm Research

In most countries of Asia cassava research is conducted by researchers on experiment stations. The transfer of technology is the responsability of the Extension Service. Due to institutional separation the researchers may have little knowledge about real farmer's needs and conditions, and may get little feed back about the applicability of their recommendations. Likewise, the extension agents are not up-to-date on the latest research results and may be recommending practices that are not optimum for their particular conditions. To reduce this problem researchers should work in close cooperation with extention agents and be well acquainted with the agronomic as well as the socio-economic constraints of farmers in their area. Also more research should be conducted on farmer's fields, ideally in close cooperation with farmers, so as to test the technology under the real-world conditions of the farmer.

India has been quite successful in promoting new high-yielding varieties, selection of planting material, intercropping and the use of fertilizers in their Lab-to-Land program in Southern Kerala. Undoubtedly, this program has also helped CTCRI in focussing their research on practical farmers problems, which hopefully lead to greater adoption of recommended practices. Also, the success of the highly productive irrigated cassava in Salem district, is at least partly due to a close cooperation between the research and extension services.

In Malang district in East Java an On-Farm Research (OFR) program has been initiated in the lime-stone derived soils of southern Malang, where cassava is intercropped with maize and grain legumes. A better understanding of these very complicated cropping systems, and of the contraints faced by the farmers, is essential for the development of new technology. Thus, the OFR program includes exploratory surveys to describe the physical and socio-economic conditions in the area and to diagnose the problems and their causes. This is then followed up by on-farm testing of certain technologies to define the best varieties, the optimum spacings or fertilizer levels etc. The obtained results or problems encountered feed back to the development of more practical solutions. Finally a production package is developed and tested in verification trials, in which the recommended practices are compared with farmer's practices and the economic costs and benefits are calculated. If the OFR is conducted in an area that is representative for a much larger "recommendation domain" and the research is done in collaboration with the extension service, then the recommended technologies can quickly lead to farmers' adoption and increasing yields, with the associated social benefits, both for the farmers and the consumers of cassava and cassava-based products.

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RAPPORTEUR'S SUMMARY OF DISCUSSION ON RESEARCH PRIORITIES IN CASSAVA AGRONOMY

Piya Duangpatra[1/]

In order to increase cassava production in Asia, research priorities in agronomy have been set for the principal cassava producing countries. (Table 1). These include the Peoples Republic of China, India, Indonesia, Malaysia, Philippines, Sri Lanka and Thailand. The Chinese agronomists considered stake storage during the cold season as the most important topic for research. In addition, they considered of high priority research on weed control and soil fertility improvement, particularly research on control of soil erosion, intercropping, and NPK fertilization. For India, the five topics of highest priority included soil erosion control, intercropping (especially under tree crops) stake storage in dry season, irrigation, and green manuring. Similarly, the research topic of highest priority for Indonesia was also considered to be erosion control. The importance of some other research aspects such as intercropping and on-farm research was also discussed. For Malaysia topics of highest priority included erosion control, reduced tillage, mechanization and intercropping, whilst the Philippine agronomists indicated research needs on on-farm trials, cultural management under tree, and research on nitrogen fixing bacteria, in addition to the two most important topics of erosion control and NPK fertilization. For Sri Lanka, the topics of weed control, intercropping, reduced tillage, and on-farm research were considered of most importance. Thailand listed the following topics of greatest priority: research on soil fertility maintenance, particularly through studies on soil erosion, NPK fertilization and green manuring; also, research on weed control and on-farm trials were considered important topics.

Nearly all countries (except Sri Lanka) were in agreement that erosion control is the most important topic for research. Another topic considered of high priority is that of maintenance or improvement of soil fertility through NPK fertilization, intercropping or green manuring. Research on weed control, particularly on integrated weed control, intercropping and on-farm trials were also rated of high priority by most countries. Note that very high research priorities on stake storage proposed by the Chinese and Indian agronomists are primarily due to their existing climatic conditions, which are quite different from those of other countries.

A collaborative research net work should be established among these seven Asian countries so that pertinent activities such as inter-regional trials on some research topics of mutual interest could be performed in different countries. For instance, some of the collaborative research topics considered of greastest importance are soil erosion and maybe integrated weed control. Particularly, research on erosion control is badly needed, and the results obtained could be of great significance in alleviating this common production problem existing in most cassava-growing countries in Asia.

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Table 1. Priority of research topics in cassava agronomy, identified by national program scientists in Asia.

Research topic	China	India	Indon.	Malays.	Philip.	Sri L.	Thail.	Ave.
1. Soil fertility maintenance								
erosion control	9	10	10	10	10	5	10	9.1
NPK fertilization (long term)	6		5	4	9		8	4.6
green manures		6	2				9	2.4
alley cropping	2		3		2	4		1.6
intercropping	8		8	3	3	9	6	5.3
2. Weed control								
efficient-manual control						6		0.9
chemical control	5			2				1.0
integrated weed control	7	4	1			10	7	4.1
3. Land preparation								
reduced tillage		5	4	9		8	1	3.9
4. Stake storage								
in dry season		8						1.1
in cold season	10							1.4
5. Intercropping								
spacing and arrangement			2	7		6	4	2.7
fertilization			7	6	4	3		2.9
spacing under trees	3	9			5			2.4
6. Time of planting and harvest	4	1				2	2	1.3
7. Irrigation								
frequency, quantity method		7				1		1.1
8. On-farm research	1	2	6	1	8	7	5	4.3
9. Water management on peat				5				0.7
10. Cultural management under trees					7			1.0
11. Development inoculants of N fixing bacteria					6			0.9
12. Pruning as a form of storage					1			
13. Mechanization				8				1.1
14. Techniques for field establishment of stakes		3						0.4
15. Test production package in each region							3	0.4

1 = low priority
10 = high priority

Collaborative network research in cassava agronomy could be of great value provided that an appropriate international organization or institute such as CIAT helps to coordinate this Inter-Asian cassava program. Additionally, CIAT should provide some research funding, in order that national institutes are able to conduct this collaborative network research. Through the assistance of CIAT, some reasonable number of international or inter-Asian travel grants should be provided, so that the agronomists can have a chance to visit and observe pertinent cassava research conducted in other countries. In addition inter-Asian or international seminars or workshop should be organized periodically to discuss the latest research results.

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