SUSTAINABLE SOIL AND CROP MANAGEMENT OF CASSAVA IN ASIA

A REFERENCE MANUAL

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NHÀ XUẤT BẢN THÔNG TẤN

SUSTAINABLE SOIL AND CROP MANAGEMENT OF CASSAVA IN ASIA

A REFERENCE MANUAL

by Reinhardt Howeler

For the International Center for Tropical Agriculture (CIAT)
and The Nippon Foundation in Tokyo, Japan

With financial support from The Nippon Foundation, Tokyo, Japan

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AGROVOC Descriptors:
1. *Manihot esculenta.* 2. Cassava. 3. Varieties. 4. Adaptation. 5. Growth. 6. Soils. 7. Soil fertility. 8. Soil degradation. 9. Erosion. 10. Fertilizers. 11. Organic fertilizers. 12. Trace elements. 13. Plant nutrition. 14. Agricultural practices. 15. Sustainable agriculture. 16. Yields. 17. Farmer participation. 18. Asia.

Local Descriptors:
1. Cassava. 2. Micronutrients. 3. Planted area.

Descriptores AGROVOC:
1. *Manihot esculenta.* 2. Yuca. 3. Variedades. 4. Adaptación. 5. Crecimiento. 6. Suelos. 7. Fertilidad del suelo. 8. Degradación del suelo. 9. Erosión. 10. Abonos. 11. Abonos orgánicos. 12. Micronutrientes. 13. Nutrición de las plantas. 14. Prácticas agrícolas. 15. Agricultura sostenible. 16. Rendimiento. 17. Participación de agricultores. 18. Asia.

Descriptores Locales:
1. Yuca. 2. Micronutrientes. 3. Área sembrada.

AGRIS Subject Category: A50 Agricultural research
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Cover photos: Neil Palmer: (top) Thai cassava farmer with simple but efficient harvesting tool,
(bottom) Researchers in Luang Prabang, Lao PDR, checking the growth of their cassava varieties.

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FOREWORD

Cassava is now widely adopted in Southeast Asian countries as the raw material for the production of food, snacks, and many industrial products. More than two decades ago, when CIAT and The Nippon Foundation started a joint endeavor, the situation was quite different from now. Dr. Kazuo Kawano, CIAT cassava breeder, had been relocated from Colombia to the Field Crops Research Institute (FCRI) of the Department of Agriculture in Thailand with the objective to develop improved cassava varieties in collaboration with cassava breeders in various Asian countries. In 1992, Dr. Kawano sent a request to The Nippon Foundation to widen the project activities to include the important issue of production technology development and extension. Dr. Reinhardt Howeler was then invited to coordinate this collaborative project between CIAT and The Nippon Foundation, initially working in Thailand, Vietnam, China, and Indonesia, and then expanding later to other Southeast Asian countries, such as Cambodia, Lao PDR, and Myanmar.

Dr. Howeler applied both practical agricultural and social science approaches to develop a unique method of cassava production technology and extension, which is called farmer participatory research (FPR). FPR is unique in that it makes an extra effort to involve farmers directly in the development of location-specific production technologies as well as extension. Dr. Howeler knew that many agricultural extension efforts in the world were facing the challenge of low adoption rates of newly developed technologies. In those days, many agricultural extension programs were involved in so-called technology transfer. In this case, the developed technologies were considered "ready-made," and could be directly transferred and adopted by farmers.

The FPR methodology, previously developed by social scientists at CIAT, was adapted to the specific local conditions in each country. Working in collaboration with national research and extension institutions, the project encouraged farmers of a particular village to diagnose their main problems; project staff then presented various options to solve these problems and asked farmers to evaluate and select those that they considered most useful for their own conditions. Farmers were then assisted in testing these potential solutions as treatments in simple FPR trials in their own fields. In so doing, farmers developed specific technologies, such as the best varieties and agronomic practices that are adapted to their own biophysical and socioeconomic environment, as well as their interest and needs. As a result of the project, farmers participating in the project showed a high rate of adoption of new technologies, and they transformed their farming practices from the knowledge they had generated together.

A cassava network was also created to encourage active collaboration among cassava researchers and research institutions and extension institutions in all cassava-growing countries in Asia. Regional cassava workshops were organized every three years during the project period in order to exchange information and experiences among cassava researchers from different countries. By friendly dialogue and working together, Dr. Howeler also learned and gained useful information from many research colleagues, extension workers, and farmers. This cassava reference manual compiles important data and discusses aspects of cassava production that will provide comprehensive guidance to all researchers, extension workers, and agricultural policy makers. As more and more attention is paid to cassava as a very useful industrial crop, more private companies are also becoming involved in cassava production. Staff and researchers of these private companies can learn important points and issues from this reference book in order to apply more appropriate approaches for sustainable cassava production.

The Nippon Foundation enjoyed very effective collaboration with CIAT over 20 years, and we are grateful to reach out to more partners through this book.

Toshiro Mado, Senior Manager, The Nippon Foundation

PREFACE

This book is another collaborative effort between CIAT and The Nippon Foundation to review and summarize the results of many years of research on cassava, especially that conducted in Asia by CIAT in collaboration with national programs in the various cassava-growing countries. Much of the earlier research was conducted with funding from the Japanese government, while The Nippon Foundation provided most of the financial support during the past 20 years. The main objective was not only to continue the development of new technological options to improve cassava yield while protecting the soil from degradation but also to enhance the adoption of these technologies by cassava farmers.

CIAT received in 1972 the world mandate to conduct basic research on all aspects of cassava production and to help improve cassava yield and production mainly in Latin America and Asia, while another center, the International Institute for Tropical Agriculture (IITA), based in Nigeria, received the mandate to improve cassava production mainly in Africa. During the 1970s, most of the cassava research conducted by CIAT focused on Latin America and was mostly conducted in Colombia, its host country. However, cassava production in Asia was changing rapidly from an important food crop to an industrial crop, used mainly for processing the roots into dry chips for animal feeding and into starch used in many food products as well as in the paper, textile, and pharmaceutical industries.

Thailand and India were at the forefront of this development and had already established a well-functioning cassava research program in the early 1970s. After several researchers, mainly from Thailand and Malaysia, spent many months for training at CIAT headquarters in the late 1970s, it became clear that progress in developing new higher-yielding cassava varieties in Asia was constrained by the limited genetic variability in the crop present on that continent. For that reason, CIAT decided to station one of its cassava breeders, Dr. Kazuo Kawano, in Asia, not only to help cassava breeders in national programs develop new higher-yielding varieties but also to increase substantially the genetic potential of the crop by the introduction of large amounts of sexual seed from CIAT's breeding program into Asia. Thus, the CIAT Regional Cassava Office for Asia was established in 1983 at the Field Crops Research Institute (FCRI) of the Department of Agriculture in Bangkok, Thailand.

Between 1983 and until his retirement from CIAT in 1998, Dr. Kawano introduced close to half a million sexual seeds from Latin America into Asia, which were used by the national cassava breeding programs to develop at least 40 new higher-yielding varieties. It is estimated that these new varieties are now planted on 55−60% of the cassava-growing areas in Asia, which has markedly contributed to the increase in average yield.

Because yield is determined not only by the yield potential of varieties but also by the management of those varieties, I joined the Asian cassava program in 1986 after having worked with CIAT in Colombia since 1970. I was tasked with the coordination of the agronomic aspects of cassava, especially in the area of soil management, until my retirement in 2009.

Over the past 30 years, the CIAT cassava scientists in Asia worked hand in hand with researchers in Cambodia, China, East Timor, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Sri Lanka, Thailand, and Vietnam, and contributed in India mainly with the introduction of new cassava germplasm resistant to the Indian and Sri Lankan cassava mosaic disease.

CIAT also established and coordinated the Asian Cassava Research Network and has organized so far nine regional workshops, held every three years in different countries of the region. During these workshops, the results of research during the past three years were presented by representatives from each country, and these were published in the various workshop proceedings. In addition, three special topic workshops were held and the papers published in the corresponding proceedings. These proceedings contain a wealth of information about a wide range of aspects of cassava research, from cassava biotechnology to the use of cassava roots and leaves in animal feeding and the production of cassava-based ethanol. However, these proceedings are basically snapshots in time about the research conducted during the previous three years. This current book is an attempt to review those snapshots and string them together into a running account of what happened over time, especially with respect to the effect of continuous cassava production on soil health and fertility characteristics.

Cassava production is often blamed for degrading the soil, and many long-term trials with cassava have shown that yield will decline when the crop is grown for many years in the same fields. However, this is true for many other crops as well, due to the removal of nutrients in the harvested products. Nonetheless, many long-term fertilizer trials have shown that this is not necessarily the case if cassava is fertilized with the right amount and balance of nutrients, but the research also showed the need to reincorporate cassava crop residues into the soil before each new planting. Alternatively, the organic matter content of the soil can also be maintained or increased by the application of animal manure, by the mulching or incorporation of crop residues of intercrops or the prunings from hedgerows of leguminous shrubs or trees, or by the use of green manures. The research also found that soil erosion can be a major problem when cassava is grown on slopes—even very gentle slopes—but that simple soil conservation and crop management practices can markedly reduce soil loss from erosion. The most important message of the book is that continuous cassava production does not necessarily degrade the soil and that high yield can be maintained, if not increased, by the judicious use of chemical fertilizers combined with various sources of organic matter to supply secondary nutrients and micronutrients as well as organic matter to maintain soil health and good soil physical conditions.

Another important lesson learned is that research by itself will not increase yield, and will not have any impact until the new varieties and technologies developed are adopted by farmers. Research institutes, including the international agricultural research centers, should work much more closely together with extension institutes to help take the new varieties and practices to farmers, not as a fixed package of recommendations but as a range of options that farmers can test, adapt, and then select those varieties and practices that produce the best results under their local conditions, and best fit into their current production practices. Farmers are also not necessarily interested in improving their soil or obtaining high yield, but they are interested in improving their income. As such, agronomists and extension agents should show not only the higher yield obtained but also the gross income obtained with that higher yield, the cost of the practices used, and the net income that farmers can obtain by adopting those improved practices. Through the use of a simplified farmer participatory research (FPR) approach, developed over the past 20 years, the project was able to work with thousands of farmers in more than a hundred villages, while further spreading the news through field days, pamphlets, posters, newspaper articles, as well as radio and television programs, to millions of other farmers. This has markedly increased the adoption of new varieties and improved soil and crop management practices—especially by those farmers directly involved in the testing of new technologies—and has resulted in marked increases in cassava yield in Asia, from about 12.7 t/ha in 1984 to nearly 20 t/ha in 2012, especially during the past 10−15 years. It was estimated that this increase in yield between 1984 and 2012 resulted in an annual increase in gross income of cassava farmers in Asia by 1.5−2.0 billion US dollars.

One advantage of the international centers is that their staff can work together with any national institute in any country and thus stimulate collaboration between the various national institutions, as well as among countries. The bringing together of university professors, researchers, and extension workers from different countries and the sharing of information will not only enhance the efficiency and effectiveness of future research but also create friendships that will further enhance future collaboration. Furthermore, scientists from international centers have the opportunity to travel to different countries, and can share information and practices learned in one country with colleagues in other countries. We can even learn a lot from working with farmers, as farmers oftentimes develop practical solutions to problems that even the best engineers have not come up with. A good example is the cassava harvesting tool developed by Thai farmers, which markedly increased the efficiency of harvesting cassava roots, and which is now used in many different countries. Other examples are the weeding tool constructed from bicycle parts by farmers in southern Vietnam, which facilitates weeding between cassava rows; and the use of plastic mulch developed by farmers in China to allow earlier planting of cassava in the spring.

I hope that the information provided in this book will be useful and will contribute to the design and implementation of better research by a new generation of cassava researchers and extension workers, who face many new challenges for improving cassava yield and production, not only in Asia, but throughout the world. Cassava is an ideal vehicle for initiating rural development, and the crop, when well-managed, can contribute to markedly increasing farmers' income and reducing hunger, while not damaging the soil.

Finally, I want to thank CIAT for giving me the opportunity to work for so many years on a very interesting, although undervalued, crop, and to thank The Nippon Foundation for its generous financial support, and especially the personal interest in the project shown by Mr. Shuichi Ohno, executive director, and Mr. Takeju Ogata, the president of The Nippon Foundation.

Reinhardt Howeler
CIAT emeritus, consultant
October 2013

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Color photos

CHAPTER 1

WHAT IS CASSAVA, WHERE IS IT GROWN, AND WHAT IS IT USED FOR?

Cassava (*Manihot esculenta* Crantz) is a small perennial shrub, usually 2−3 m tall, that produces thickened roots that are mostly filled with starch. This crop is widely grown in tropical and subtropical countries in Latin America, Africa, and Asia. **Table 1** shows that cassava is currently the world's seventh most important food crop in terms of area planted, far behind wheat, maize, and rice, but having a slightly greater planted area (19.6 million ha) than potato (19.2 million ha). The area under cassava increased by 44% from 13.6 million ha in 1980 to 19.6 million ha in 2011. The cassava-growing area expanded faster than that of any other food crop. Since 1980, total cassava production has increased more than 100%, somewhat less than maize, but more than any of the other crops **(Figure 1)**.

Table 1. Area, production, and yield of the ten most important food crops in the world from 1980 to 2011, as well as the percent change over that 31-year period.

Crop	Area harvested (million ha)			Total production (million tons)			Yield (t/ha)		
	1980	2011	% change	1980	2011	% change	1980	2011	% change
Wheat	237.3	220.4	−7	440.2	704.1	+60	1.86	3.19	+72
Maize	125.8	170.4	+36	396.6	883.5	+123	3.15	5.18	+64
Paddy rice	144.4	164.1	+14	396.9	722.8	+82	2.75	4.40	+60
Barley	78.4	48.6	−38	156.7	134.3	−14	2.00	2.76	+38
Sorghum	44.0	35.5	−19	57.2	54.2	−5	1.30	1.53	+18
Millet	38.4	31.9	−17	24.8	27.7	+11	0.65	0.87	+34
Cassava	**13.6**	**19.6**	**+44**	**124.1**	**252.2**	**+103**	**9.13**	**12.84**	**+41**
Potato	18.8	19.2	+2	240.5	374.4	+56	12.82	19.45	+52
Oats	24.7	9.7	−61	41.4	22.5	−46	1.68	2.33	+38
Sweet potato	10.8	8.0	−26	137.9	104.3	−24	12.81	13.11	+2

Source: *FAOSTAT, 2013.*

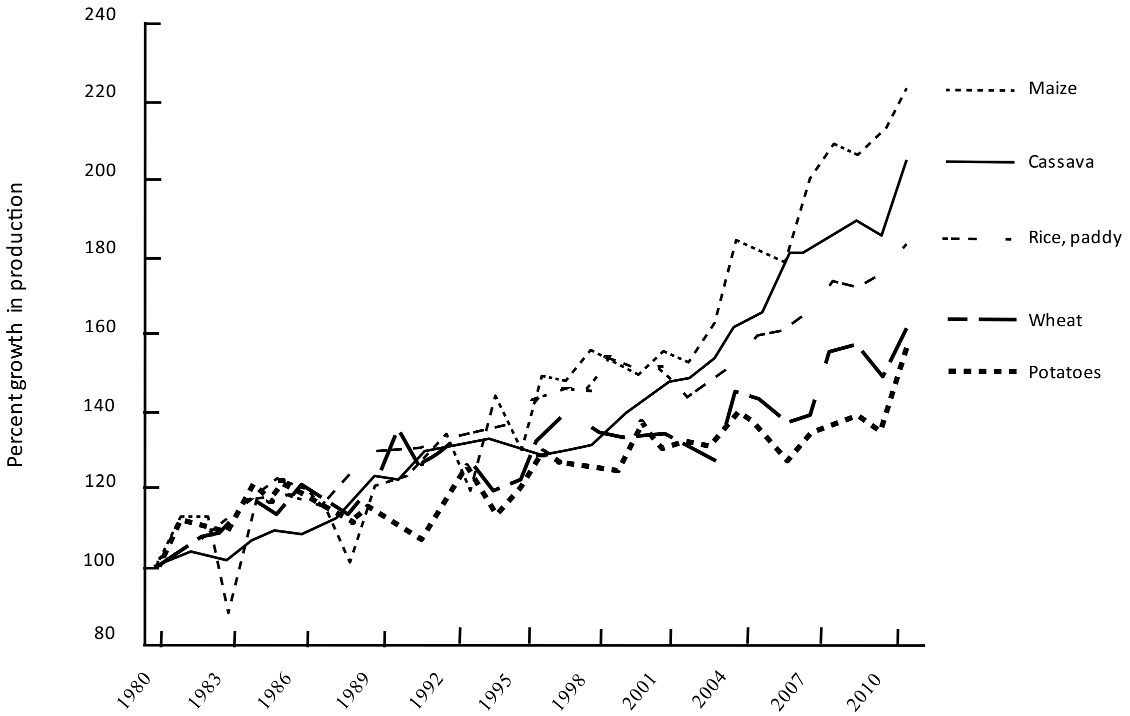

Figure 1. *Percent growth in annual production of the major staple food crops in the world from 1980 to 2011. Index: 1980 = 100%.*

Source: *FAOSTAT, 2013.*

Cassava production expanded most rapidly in Africa, by 192%, followed by Asia at 67% and Latin America by 16% **(Table 2)**. The expansion of production in Africa was mainly due to a rapid expansion in planted area of 85% as well as a marked increase in yield of 58%. In contrast, the increase in production in Asia of 67% was due only to a remarkable increase in yield as the planted area hardly changed at all. The relatively small increase in production in Latin America of 16% was the result of a modest increase in yield of 15% and a very slight increase in area of about 1%. In 2011, about 56% of cassava was produced in Africa, 30% in Asia, and only 14% in Latin America, its center of origin.

Table 2. Area, production, and yield of cassava on the three cassava-producing continents in 1980 and 2011, as well as the percent change over that 31-year period.

Continent	Area harvested (million ha)			Total production (million tons)			Yield (t/ha)		
	1980	2011	% change	1980	2011	% change	1980	2011	% change
Africa	7.05	13.05	+85.1	48.34	140.97	+191.6	6.85	10.80	+57.7
Americas	2.65	2.67	+0.8	29.70	34.36	+15.7	11.23	12.88	+14.7
Asia	3.89	3.91	+0.5	45.94	76.68	+66.9	11.82	19.60	+65.8

Source: *FAOSTAT, 2013.*

The main cassava-producing countries are Nigeria, Brazil, Indonesia, Thailand, and DR Congo. In Nigeria and DR Congo, cassava is a very important food crop; in Brazil and Indonesia, it is an important food crop in some areas and an important industrial crop in others, while in Thailand it is hardly ever eaten directly, but is a very important industrial crop, mainly for the production of dry chips and starch, for both domestic use and export. In several countries in Asia, cassava is now also used for the production of bioethanol that can be mixed with gasoline as a fuel, mainly for cars.

In many countries in Africa, such as Congo, DR Congo, Ghana, Mozambique, Angola, the Central African Republic, and Cameroon, cassava is the main source of calories in people's diets. In many other countries in sub-Saharan Africa, it is the second most important source of calories, usually after maize, rice, or plantain **(Table 3)**. In some countries, such as Angola, China, Vietnam, Malawi, Nigeria, Brazil, and Paraguay, cassava is used mainly for animal feeding, while in others, such as Thailand, Cambodia, and Malaysia, cassava is mainly used for processing into dry chips, starch, ethanol, and a host of starch-derived products **(Table 4).**

Table 3. Food staples in their order of contribution to the daily per capita calorie intake (Kcal/day) from cassava in countries where cassava was among the most important food crops in 2009.

Country	Crop	Kcal/d	Crop	Kcal/d	Crop	Kcal/d	Crop	Kcal/d
Congo	**Cassava**	758	Wheat	400	Palm oil	186	Sugar	159
Ghana	**Cassava**	649	Yams	400	Rice	258	Maize	227
Mozambique	**Cassava**	637	Maize	430	Rice	186	Wheat	186
Benin	Maize	455	**Cassava**	441	Yams	418	Rice	344
Angola	**Cassava**	415	Maize	340	Wheat	254	S. potato	125
C. Afr. Rep.	**Cassava**	370	Maize	316	Yams	224	Peanut oil	215
Cameroon	**Cassava**	329	Maize	305	Rice	304	Sorghum	208
Cote d'Ivoire	Rice	610	Yams	496	**Cassava**	318		
Paraguay	Maize	509	**Cassava**	304	Sugar	246	Wheat	216
Madagascar	Rice	1,074	**Cassava**	301	Maize	155		
Guinea	Rice	1,068	Veg. oils	332	**Cassava**	301	Sugar	142
Uganda	Plantain	340	**Cassava**	288	S. potato	191	Maize	190
Rwanda	Plantain	330	**Cassava**	269	Beans	269	Potato	201
Zambia	Maize	928	**Cassava**	261	Wheat	102		
Tanzania	Maize	455	**Cassava**	225	Rice	195	Beans	131

Source: *FAOSTAT, 2013.*

Table 5 indicates that in 2011 about 30% of world cassava production was in Asia. The major producing countries were Indonesia, Thailand, Vietnam, and India. However, the area under production has recently been decreasing in Thailand and India, while increasing markedly in Cambodia and Lao PDR. **Figure 2** shows the important production zones within each country.

The major cassava-growing areas in Asia continue to be located in the eastern and northeastern part of Thailand, on the island of Java and in Lampung Province of Sumatra in Indonesia, and in Kerala and Tamil Nadu States of India. The cassava planted area in Kerala has been decreasing while that in Tamil Nadu and Andhra Pradesh has been increasing. In China, cassava is grown throughout much of Guangxi, Guangdong, and Hainan Provinces, but most intensively in the hilly regions along the border between

Table 4. Cassava total domestic supply and food supply (in fresh root equivalents, 000 t) and its domestic use (%), as well as the per capita supply as food and its energy contribution to the diet in 13 cassava-producing countries in Asia in 2009.

Country	Popula -tion (mil.)	Total domestic supply (000 t)	Domestic use (%)				Total food supply (000 t)	Per capita food supply (kg/year)	Per capita food con-sumption (Kcal/d)
			Food	Feed	Other uses	Waste[1]			
Asia (13)	**4,050**	**89,242**	**30.4**	**30.8**	**32.5**	**6.4**	**27,135**	**6.7**	**18.0**
Thailand	69	12,257	6.5	18.0	63.2	12.3	800	11.6	37.0
Indonesia	238	22,134	47.9	2.0	37.1	12.9	10,600	44.6	126.0
India	1,205	9,637	95.0	-	-	5.0	9,156	7.6	17.0
Vietnam	87	6,405	10.1	83.2	-	6.7	650	7.5	21.0
China	1,352	28,057	9.2	68.6	21.8	0.5	2,568	1.9	6.0
Cambodia	14	3,485	10.1	0	84.8	5.0	352	25.2	70.0
Philippines	92	2,411	79.7	5.1	15.2	-	1,921	20.9	58.0
Malaysia	28	1,285	31.1	1.7	65.5	1.7	399	14.3	39.0
Myanmar	48	358	90.2	-	9.8	-	323	6.8	19.0
Sri Lanka	21	291	64.6	23.7	6.9	4.8	188	9.1	38.0
Lao PDR	6	113	73.0	13.5	-	13.5	83	13.5	37.0
Timor-Leste	1	37	97.3	-	-	2.7	36	32.9	80.0
Bangladesh	210	152	13.8	-	86.2	-	21	0.1	0

[1] Much of the "waste" (peels, solid residue from starch extraction, etc.) is used for industrial purposes or animal feed.
Source: *FAOSTAT, 2013.*

Table 5. Cassava production, area, and yield in the world, on three continents, and in various countries in Asia in 2011.

	Production (000 tons)	Area (000 ha)	Yield (t/ha)
World	**252,204**	**19,644**	**12.84**
Africa	140,966 (56%)	13,047	10.80
Americas	34,363 (14%)	2,668	12.87
Asia	76,681 (30%)	3,913	19.60
-Cambodia	4,368	205	21.29
-China	4,515	276	16.37
-India	8,076	221	36.48
-Indonesia	24,010	1,183	20.30
-Lao PDR	743	31	23.87
-Malaysia	39	3	13.43
-Myanmar	615	47	13.09
-Philippines	2,210	221	9.99
-Sri Lanka	293	24	12.10
-Thailand	21,912	1,135	19.30
-Timor-Leste	22	6	3.84
-Vietnam	9,876	560	17.63

Source: *FAOSTAT, 2013.*

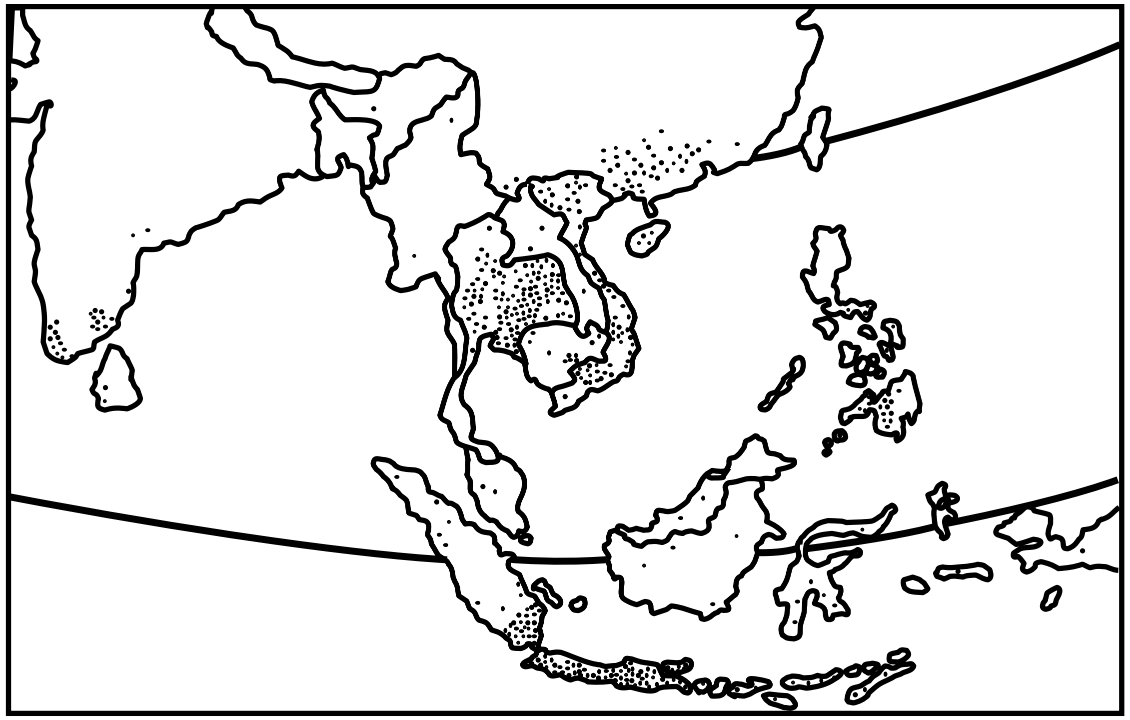

Figure 2. *Cassava production zones in Asia in 2007. Each dot represents 10,000 ha of cassava.*

Guangdong and Guangxi and between 22° and 24° N latitude. Over the past decades, cassava production in Guangdong has decreased markedly, while that in Guangxi, Fujian, Jiangxi, and Yunnan has increased. In Vietnam, cassava is grown throughout the country but most intensively in the southeastern region, in the Central Highlands, and in the south-central coastal region. Little cassava is grown in the Red River and Mekong River deltas. In Cambodia, cassava remains an important crop in Kampong Cham Province in the northeast, but is increasing rapidly in areas along the border with Thailand in the west and with Vietnam in the east.

Figure 3 shows the distribution of edapho-climatic zones in southern Asia, while **Table 6** shows the definition of the various edapho-climatic classes. Unlike Latin America where a large proportion of cassava is grown under subtropical conditions, sometimes with frost during winter, in Asia this is only about 13%, mostly in southern China and northern Vietnam. In Latin America and Africa about 20% of cassava is grown in the highlands with year-round cool temperatures, while in Asia practically no cassava is grown at elevations above 1000 meters above sealevel (masl). Most cassava in Asia is grown in the lowland humid and sub-humid tropics, mainly in Indonesia, Thailand, Cambodia, the southern part of Vietnam, India and Lao PDR; little cassava is grown in the semi-arid tropics according to this classification.

Figure 4 shows the distribution of soil orders in southern Asia. It is clear that tropical and subtropical Asia are dominated by Ultisols in those areas that have a relatively high rainfall, while Alfisols and Vertisols tend to dominate in the dryer regions of India and islands of southeast Indonesia. Inceptisols are often found on the upper and middle slopes of mountainous areas, as well as along river beds or in river deltas. Entisols are most common along the coast or along the major rivers. Histosols (peat soils) are found mainly in low-lying coastal areas of Sumatra, Borneo, West Irian, and Malaysia.

Table 6. Edapho-climatic classification of cassava production areas in southern Asia.

	Edapho-climatic zone	Mean temperature (°C)	No. of months dry season [1)]	Annual temp. range [2)] (°C)	Soil pH
1	Lowland humid	>22	0-3	<10	
2	Lowland acid sub-humid	>22	4-6	<10	<5.3
3	Lowland non-acid sub-humid	>22	4-6	<10	>5.3
4	Lowland semi-arid	>22	7-9	<10	
5	Tropical highlands	18<t<22		<10	
6	Subtropical lowlands	>22		>10	
7	Subtropical highlands	18<t<22		>10	
8	Arid or too cold	<18	10-12		

1) Dry month: rainfall <60 mm;

2) Difference between the hottest and coldest month

Source: *P.G. Jones. Personal communication, 2013.*

Previous data (Howeler, 1992) indicate that approximately 55% of cassava in Asia was grown on Ultisols, 18% on Alfisols, 9% on Entisols, and only 7% on Vertisols, Oxisols, Histosols, and Mollisols combined **(Table 7)**. Thus, cassava is predominantly grown on low-fertility Ultisols, but these soils are not nearly as infertile as many of the Oxisols on which about 20% of cassava is grown in Latin America. Still, most Ultisols have low organic matter and very low reserves of P, K, Ca, and Mg. Also, most of the Ultisols are associated with an undulating or hilly topography, which makes them quite susceptible to erosion. Thus, continued cassava production on these soils is likely to lead to soil degradation due to loss of topsoil by erosion and exhaustion of the limited nutrient reserves by the harvesting of cassava roots. Particular emphasis should therefore be placed on developing cultural practices that reduce soil erosion and that maintain soil nutrient reserves.

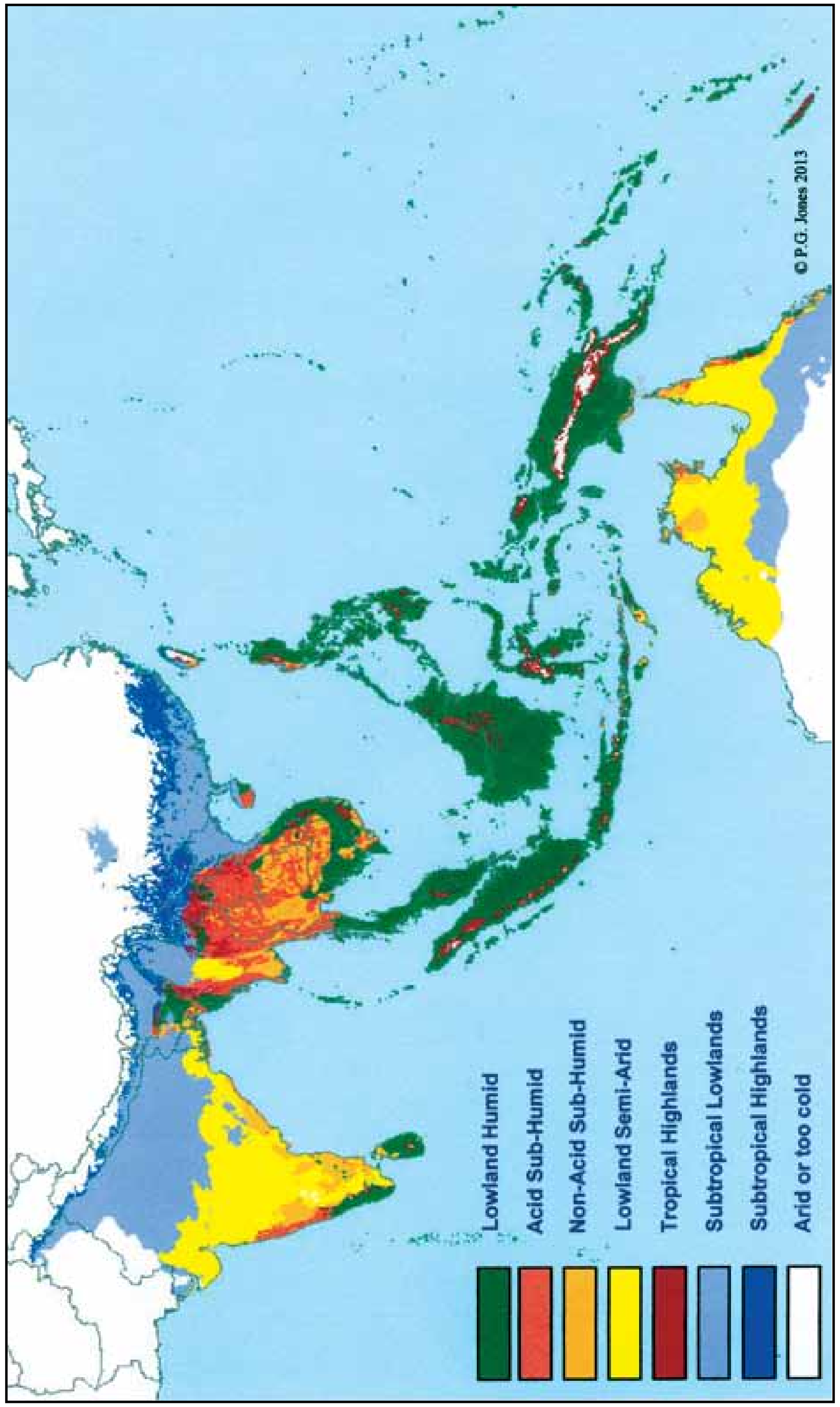

Figure 3. *Edapho-climatic classification of cassava production areas in southern Asia.*

Source: *P.G. Jones, personal communication. 2013; Map based on FAO/IIASA/ISRIC/ISSCAS/JRS, 2012; Hijmans et al., 2005.*

Figure 4. *Soils of southern Asia. Adapted from FAO-UNESCO Soil Map of the World (FAO, 1979).*

***Source:** Howeler, 1992.*

Table 7. Estimate of area (000 ha) planted with cassava on various soil orders in Asia in 1992, and the planted area in each country in 2011.

Country	ULT [1]	INC	ENT	ALF	VER	OXI	HIS	MOL	Total [2]	1992 [3]	2011 [3]
Cambodia	**6**	**4**	**1**	**2**	**2**	**1**	**-**	**-**	**16**	**16**	**205**
China	**347**	**98**	**-**	**11**	**4**	**-**	**-**	**-**	**460**	**234**	**276**
-Guangdong	121	51	-	9	-	-	-	-	181		
-Guangxi	173	38	-	-	-	-	-	-	211		
-Fujian	27	6	-	-	3	-	-	-	36		
-Hainan	18	3	-	-	-	-	-	-	21		
-Yunnan	8	-	-	2	1	-	-	-	11		
India	**221**	**8**	**41**	**32**	**6**	**-**	**-**	**-**	**308**	**251**	**221**
-Kerala	196	-	34	3	-	-	-	-	233		
-Tamil N.+ others	25	8	7	29	6	-	-	-	75		
Indonesia	**291**	**254**	**266**	**322**	**107**	**9**	**26**	**75**	**1,350**	**1,351**	**1,183**
-Java	132	166	188	253	95	-	-	74	908		
-Sumatra	95	34	45	-	-	-	20	-	194		
-Bali+Nusa T.	3	43	10	56	10	1	-	-	123		
-Sulawesi	47	3	12	11	2	-	-	1	76		
-Kalimantan	12	3	9	1	-	7	4	-	36		
-Maluka+Irian J.	2	5	2	1	-	1	2	-	13		
Lao PDR	**6**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**6**	**5**	**31**
Malaysia	**8**	**-**	**-**	**-**	**1**				**9**	**30**	**3**
Myanmar	**3**	**3**	**-**	**-**	**-**	**-**	**-**	**-**	**6**	**4**	**47**
Philippines	**122**	**56**	**3**	**23**	**14**	**-**	**-**	**-**	**218**	**204**	**221**
-Mindanao	21	27	2	8	2	-	-	-	60		
-Basilan+Sulu	35	4	-	-	-	-	-	-	39		
-Bohol	26	-	-	9	2	-	-	-	37		
-Other islands	40	25	1	6	10	-	-	-	82		
Sri Lanka	**24**	**1**	**1**	**27**	**-**	**1**	**-**	**-**	**54**	**34**	**24**
Thailand	**1,154**	**301**	**65**	**63**	**10**	**-**	**-**	**-**	**1,593**	**1,450**	**1,136**
-Northeast	719	239	-	30	-	-	-	-	988		
-East	292	41	10	-	-	-	-	-	343		
-North	110	-	34	-	-	-	-	-	144		
-Centr. Plain+West	33	21	21	33	10	-	-	-	118		
Vietnam	**199**	**52**	**6**	**12**	**10**	**20**	**-**	**-**	**299**	**284**	**560**
-North	120	17	5	10	-	-	-	-	152		
-South	79	35	1	2	10	20	-	-	147		
Asia (000 ha)	**2,381**	**777**	**383**	**492**	**154**	**31**	**26**	**75**	**4,319**	**3,877**	**3,913**
(%)	**55**	**18**	**9**	**11**	**3**	**<1**	**<1**	**2**	**100**		

1) ULT = Ultisol, INC = Inceptisol, ENT = Entisol, ALF = Alfisol, VER = Vertisol, OXI = Oxisol, HIS =Histosol, MOL = Mollisol.
2) Based on 1992 local data.
3) Based on FAO planted area data for 1992 and 2011 (FAOSTAT, 2013).
***Source:** Adapted from Howeler, 1992.*

CHAPTER 2

HOW IS CASSAVA GROWN?

Cassava is usually multiplied vegetatively by planting a 15-20 cm long stem cutting (also called a “stake” or “set”), cut from the mature and woody stem of an 8-12 month old mother plant. On average, each mother plant can produce about 10 stem cuttings, so the multiplication rate of cassava is about 1:10, which is very low. That of maize is about 1:300.

1. Crop growth and development

After clearing the field and preparing the land to loosen the soil and eliminate weeds, these cuttings are planted by pushing them into the soil, either vertically or inclined (slanted), to a depth of 10−12 cm. Cuttings can also be planted by burying them horizontally in the soil at a depth of 5−10 cm. Planting vertically or inclined is slightly more complicated as the cuttings have to be planted with the buds facing up, but this method results in faster sprouting and early growth. Depending on the variety, the freshness of the cuttings, and the temperature, the buds will sprout in 5−10 days; for horizontally planted stakes, it usually takes 15−30 days before the young sprouts emerge from the soil. Since the cuttings still don’t have any roots at this very early stage, they depend on the reserves of starch and nutrients present in the stakes. For that reason, thicker and more mature stakes tend to sprout faster than thin and immature stakes. After about 2 weeks, the stakes will produce adventitious or fibrous roots, which will penetrate the soil; these roots will absorb water and, after about 1 month, also soil nutrients. In addition, the young leaves open and start photosynthesizing, producing sugars and starch that allow the plant to grow. From the second to sixth month, the plants grow fast, reaching their full height and canopy spread during the fourth to sixth month after planting (MAP). At this stage, the crop canopy will usually close and weeds will be shaded out. Whether or not this is the case will depend to a large extent on the variety, planting distance, soil fertility, and climatic conditions, mainly temperature, solar radiation, and rainfall.

At higher elevations, the temperature is lower year-round, while at higher latitudes the winter can be too cold for cassava to grow. In general, cassava grows best at temperatures between 25 and 29°C, but the crop will tolerate high temperatures up to 38°C, while growth stops when the temperature drops below 15°C. Similarly, cassava is very tolerant of drought, but the crop grows best when soil moisture is around field capacity; this is the soil moisture content about a day after a good rain storm has stopped and the water in the larger soil pores has moved down the soil profile. At that point, roots can still access water left in the micropores, as well as air for respiration in the larger pores. During long periods of drought, these micropores also lose their water, but cassava roots will be able to grow deeper down the soil profile to absorb water. At the same time, the plant will close its stomata during much of the day to reduce transpiration, and new leaf production stops while older leaves may drop off. These are all mechanisms to reduce water loss and conserve soil moisture. Thus, unlike many other crops, cassava will seldom die because of drought, but the plants will stop growing and become more or less dormant until the rains come back. When soil moisture has been restored, plants start sprouting new leaves and begin to grow again.

Between the second and third month, some of the fibrous cassava roots start filling with starch. Sugars being produced through photosynthesis in the leaves are being translocated through the xylem down the plant to the roots, and are deposited as starch in some roots; these swell up to become the tuberous or storage roots that will eventually be harvested.

At about 4 months after planting, some of the older leaves start to fall off and this continues throughout the rest of the growth cycle. Leaf fall is accelerated during periods of drought. The increased penetration of light during the later stages of the crop cycle will generally lead to increased weed growth, but this seldom has an effect on final root yield.

Because of its rather slow early growth, cassava is a rather poor competitor with weeds or other crops growing nearby. Weeds tend to grow faster and will seriously compete with cassava for light, water, and nutrients, resulting in reduced cassava growth. For that reason, it is important that fields be weeded two to three times during the first 3−4 months, before the cassava canopy closes. Weeding after the fourth or fifth month is generally not necessary. At this later stage of the growth cycle, weeding will generally not increase yield.

Once the stem cuttings are planted in a moist soil, they will absorb water and some of the axillary buds on the cutting will sprout. When cuttings are planted vertically or inclined, only one or two buds near the upper end of the cutting will sprout, while the other buds will remain dormant; this is due to apical dominance. When cuttings are planted horizontally, completely underground, 2−4 buds may sprout, resulting in a greater number of stems per plant. Depending on the variety, these main stems may grow erect or may fork into 2−3 branches. An inflorescence, having both male and female flowers, may appear in the branching point. The female flowers generally open 1−2 weeks before the male flowers in the same inflorescence, thus preventing self-pollination. Cross-pollination with pollen from male flowers of nearby plants occurs naturally, mainly by insects visiting both the male and female flowers. Once fertilized with pollen, the female flowers produce a fruiting body, which grows bigger as the fruit matures. After about 3 months, the fruits spring open, ejecting 2−3 sexual seeds from each fruit. Since the male parent is generally not known, plants grown from sexual seeds collected from one variety are half-sibs of the same family, and each plant is genetically different, with distinct morphological characteristics. Farmers generally do not plant sexual seeds of cassava because the young plants produced are weak and require special care to survive. The crop will also not be uniform and will tend to have a lower yield than a crop grown from stem cuttings taken from a high-yielding variety. Sexual seeds are mainly used by plant breeders to produce new varieties with higher yield, higher starch content, or other favorable characteristics such as disease or pest resistance.

The optimum spacing of plants in the field depends on the branching habit of the variety as well as on soil fertility and climatic conditions. Highly branched varieties occupy more space than more erect varieties, while plants growing in a fertile soil or well-fertilized soil will also need more space than those growing in an infertile soil. In a hot and humid climate, cassava tends to grow faster and taller than in a cool or dry climate. Smaller or more erect plants are generally planted at a close plant spacing of 75×75 cm to 90×90 cm, while larger or more branched varieties produce high yields at a wider spacing of about 100×100 cm. Thus, plant populations may vary from about 10,000 to 20,000 plants per ha. Increasing the plant population will result in more plants per area, but the yield of each plant will decline due to more severe competition from neighboring plants. When cassava is planted as a sole crop in monoculture, farmers usually prefer planting in a square planting arrangement, such as 1×1 m. But, if cassava is intercropped, generally with cereals or grain legumes, farmers tend to use a wider between-row cassava spacing to allow the planting of 1−3 rows of intercrops, while decreasing the plant spacing within the row to maintain the same cassava population per ha as in monoculture. In most intercropping systems, the yield of cassava decreases somewhat due to the competition from the intercrops, but the total gross income per ha may increase due to the additional income from the intercrops. In areas where farm size is small and labor abundant, farmers tend to grow cassava in intensive intercropping systems, whereas, in areas with larger farms and limited labor availability, the crop is generally grown in monoculture.

Although cassava is tolerant of very acid and low-fertility soils, the crop does respond well to increased soil fertility. In very infertile soils, cassava may still produce 5−10 t/ha of roots, while many other crops may not produce at all; but, in more fertile soils or with adequate and well-balanced fertilization, cassava can produce 30−40 t/ha, and, under exceptionally good conditions and with irrigation, even 40−60 t/ha. Thus, good soil management, including the use of chemical fertilizers in combination with biological means to increase organic matter, improve soil structure, and reduce erosion losses, will markedly increase cassava yields while maintaining or improving the soil's productive capacity into the future. That is the main objective of this book.

2. Production systems in Asia

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

Farm size in Asia tends to be very small, with areas under cassava ranging from 0.2 to 0.8 ha/family in China, Vietnam, Kerala State of India, and Java island in Indonesia to 2−3 ha/family in Thailand (**Table 1**).

The crop is often grown in association with maize, upland rice, and grain legumes in Indonesia, with peanut or black beans (cowpea) in northern Vietnam, with peanut or watermelon in Guangxi Province and with young rubber trees in Hainan Province of China, and under coconut trees in the Philippines and Kerala, India. It is primarily grown in monoculture in Thailand, Cambodia, Malaysia, and southern Vietnam.

The land is usually prepared by hand (hoe) in Kerala, India, on Java island of Indonesia, and in Lao PDR and Myanmar; by cattle or buffalo in northern Vietnam, China, Tamil Nadu State of India, and in Lampung Province of Indonesia; and by tractor in Thailand, southern Vietnam, Malaysia, and Cambodia.

In India, Indonesia, and Thailand, cassava stakes are mostly planted vertically, while in China, Vietnam, and Cambodia, they are mostly planted horizontally or inclined.

Fertilizers or animal manures are commonly used on cassava, but not necessarily in adequate amounts or in the right proportions of N, P, and K. Usually, responses to animal manures can be greatly enhanced by additional application of chemical fertilizers high in N and K.

Cassava is generally weeded by hand (hoe) two to three times during the first 3–4 months, but herbicides are now commonly used in Thailand, China, and Malaysia **(Table 1).**

Production costs vary significantly across the region. Production costs for cassava farmers in China, India, Indonesia, and Lao PDR are higher than in Thailand, the Philippines, and Cambodia, which in turn are higher than in Vietnam. When calculated per ton of fresh roots, production costs in Thailand are slightly higher than in Vietnam, but much lower than in the Philippines, Lao PDR, Indonesia, and China. It is clear that cassava products from Vietnam and Thailand remain competitive in the world market as farmers have increased their yields through the use of improved varieties and better production practices (Howeler, 2001b; 2005; 2010a). Cassava yields in India are by far the highest in the world, but labor use is also very high because of manual land preparation in Kerala and the need for frequent weeding in irrigated cassava fields in Tamil Nadu. This results in high production costs, so the cost per ton of cassava produced is still fairly high, making it difficult for cassava from India to compete in the world market **(Table 1)**.

Table 1. Characteristics of cassava production and use practices in eight countries in Asia in 2009.

	Cambodia [1]	China [2]	India [3]	Indonesia [4]	Lao PDR [5]	Philippines	Thailand [6]	Vietnam [7]
Cassava production (000 t)	3,497	4,506	9,623	22,039	153	2,044	30,088	8,557
Cassava harv. area (000 ha)	157	277	280	1,176	10	216	1,327	509
Cassava yield (t/ha)	22.3	16.3	34.4	18.7	14.7	9.5	22.7	16.8
Use -main	dry chips -exp/dom	starch -domestic	human consumption	human consuption	human consumption	human consumption	dry chips (50%) -export/domestic	starch exp. (70%)/ dom, (30%)
-secondary	starch -exp/dom	animal feed ethanol-dom.	starch -domestic	starch -domestic	starch dry chips	starch-dom. ethanol-dom.	starch (50%) -exp.(65%)/ dom. (35%)	dry chips-export animal feed
Farm size (ha/farm)	2-7	0.7-1.0	0.4-2.0	1.0--3.0	2-3	3-4	3-5	0.8-1.5
Cassava area (ha/farm)	1-4	0.2-0.7	0.2-1.0	0.2-0.5	0.3-0.4	0.2-1.0	2-3	0.2-0.8
Topography	flat-sloping	flat-steep	flat-sloping	sloping/flat	gentle-steep	flat-sloping	flat-sloping	flat-steep
Soil texture	loam-sandy	loam-clay	loam	clay/sandy loam	clayey-loamy	clay-loam	sandy loam	sandy-rocky
Soil fertility	medium-high	medium	low-high	medium/low	medium	medium	low-medium	low-medium
Rainfall (mm)	~1,200-1,400	~1,200-1,700	~800-1,400	~1,200-1,600	~1,200-1,400	~1,200-1,400	~1,200-1,400	~1,200-1,400
Crop. system(%)-monocrop	95	40	70	40	66	60	95	65
-intercrop	5	60	30	60	34	40	5	35
Land preparation	tractor	oxen/hoe	hoe/oxen	hoe/oxen	hoe or no-till	hoe/oxen	tractor	oxen/hoe/tractor
Soil preparation	flat or ridges	flat	mounds/flat	ridges/flat	flat	flat/ridges	flat/ridges	flat/ridges
Time of planting	April-May	March	April-May	Oct-Nov	April-June	April-May	Feb-May	March/Sept
Stake planting position	slanted	horizontal	vertical	vertical	horizontal	horizontal	vertical	slanted/vertical
Weeding	by hoe	hoe/herbicides	hoe	hoe	hoe or knife	hoe or knife	hoe/herbicide	Hoe
Fertilizer -chemical	38% of farmers	low-very high	medium-high	low (mainly N)	none	none-little	75% of area	~80% of farmers
- organic	little	medium	some	some	some	some	some	medium-high
Irrigation	no	no	no/furrow irr.	no	no	no	no/some drip	No
Harvest	by hand	by hand	by hand	by hand	by hand	by hand	by hand/tractor	by hand
Labor cost (US$/person-day) [8]	2.93	5.80	4.35	3.87	3.50	3.33	4.41	2.50
Labor use (person-days/ha) [8]	100	75	210	84	78	66	65	125
Production costs (US$/ha) [8]	965	1,130	1,298	1,455	1,192	881	801	517
Production costs (US$/ton) [8]	43	69	38	78	81	93	35	31

1) *El Sotheary, 2010.*
2) *Henry and Howeler, 1994.*
3) First entry refers to Kerala, second to Tamil Nadu.
4) First entry refers to Java, second to Lampung.
5) *Boupha et al., 2010.*
6) *Office of Agricultural Economics, 2010.*
7) *Pham Van Bien et al., 1996.*
8) *Howeler, 2010a.*

CHAPTER 3

WHAT ARE THE MAJOR CONSTRAINTS TO HIGH YIELDS?

Cassava is a very hardy crop that can grow reasonably well in areas of infertile or very acid soils, under conditions of low or unpredictable rainfall, and with minimum care and inputs. For that reason, it is a crop preferred by subsistence farmers who often live in isolated areas of poor soils or with a mountainous topography. Under those difficult conditions, most other crops may fail completely. Still, cassava can suffer from a host of disease and pest problems, and yields can also be seriously affected by weed competition. Although plants may survive and produce some yield when the crop is grown on poor or degraded soils, high yields are obtained only in fertile or well-fertilized soils, and only when the crop is well managed, weeds are controlled, and insect and disease problems are minimized. The effect of these constraints on yield will vary from place to place, depending on the intensity of the problem and the area affected by it.

In 1994, the Economics Section of the CIAT Cassava Program attempted to estimate the yield gain that could be achieved by eliminating each constraint in the areas affected, as well as the percent of the total planted area affected by each constraint. **Table 1** summarizes the results of this analysis for the cassava-growing areas of Africa, the Americas, and Asia. Interestingly, improved soil management, which includes the elimination of soil fertility problems, soil erosion, salinity, and either low- or high soil temperature, could increase cassava yields in Africa by about 27%, in the Americas by 28%, and in Asia by 35%. In addition, better crop management, including better land preparation, the use of high-quality planting material, correct plant spacing, and optimum weed control, could increase yields by 34% in Africa, by 29% in the Americas, and by 21% in Asia. Improvements in these two groups of constraints (i.e., soil and crop management) could increase yields by 55−60% in most cassava-growing areas in the world. This is more than for any of the other identified groups of constraints, such as low yield potential of planted varieties, climatic constraints, or pest and disease problems. Although pest and disease problems are highly visible and can be very serious in certain areas, the areas affected by these problems tend to be relatively small, or the problem may occur only in some years but not in others. In contrast, the effect of low soil fertility is not very visible, because cassava does not show very clear symptoms of deficiency of the three major nutrients, N, P, and K. When these nutrients are deficient, the plants will only grow less and yield will be lower, but without showing clear deficiency symptoms. This is called “hidden hunger.” The problem can be both very serious and widespread, and the elimination of this can markedly increase yield, not only for the current crop, but also in the future.

Naturally, some things have changed since this analysis was made in the mid-1990s. In Africa, the problems of green spidermites and mealybugs have declined markedly because of the release of effective biocontrol agents, and African cassava mosaic disease (ACMD) has decreased with the development and adoption of ACMD-resistant varieties. On the other hand, the problem of cassava brown streak disease (CBSD) is much more severe and more widespread than it was in the 1990s. Asia had few serious pest and disease problems during the 1990s, but the recent accidental introduction of the mealybug, *(Phenacoccus manihoti)* and the appearance of a new phytoplasma disease have markedly increased the seriousness of the biotic constraints on that continent. On the other hand, soil and crop management have markedly improved in Asia, and new higher-yielding varieties are now planted on about 50% of the cassava-growing areas (Howeler *et al., 2006*). These three aspects together have already resulted in a yield increase of about 50%, from 13.0 t/ha in 1995 to 19.6 t/ha in 2011; this compares with a possible 80% increase in yield (23.4 t/ha) if soil and crop management constraints were completely eliminated and high-yielding varieties were planted throughout the region, according to the constraint analysis conducted in 1994–95. If all constraints included in **Table 1** could be removed, average yield in Asia could be at least 25.4 t/ha.

Table 1. Cassava sector constraints by continent.

	Africa			Americas			Asia		
Constraint	% Yield gain in aff. area	% Area affected	Total % yield gain	% Yield gain in aff. area	% Area affected	Total % yield gain	% Yield gain in aff. area	% Area affected	Total % yield gain
Soil			**27**			**28**			**35**
-low soil fertility	27	81	22	27	61	17	32	68	22
-soil erosion	12	34	4	20	54	11	17	60	10
-salinity	11	2	0	1	0	0	0	0	0
-surface temperature	10	8	1	9	6	1	11	26	3
Management			**34**			**29**			**21**
- sub-optimal land preparation	9	51	5	9	33	3	8	33	3
- poor planting material	23	68	15	21	62	13	17	48	8
- incorrect spacing	7	51	4	8	50	4	8	47	4
- weeds	17	59	10	15	60	9	18	37	7
Varietal traits			**24**			**19**			**24**
- low yield potential	29	84	24	26	75	19	26	89	24
Climate			**16**			**7**			**11**
- drought	25	54	14	13	40	5	16	58	9
- waterlogging	28	9	3	53	1	0	0	0	0
- low winter temperature	0	0	0	13	15	2	0	8	1
Diseases			**29**			**16**			**2**
- root rot	14	11	2	20	27	5	6	5	0
- bacterial blight	17	53	9	16	33	5	6	19	1
- superelongation	0	0	0	7	6	0	0	0	0
- anthracnose	7	31	2	8	37	3	2	15	0
- ACMV	22	73	16	0	0	0	6	3	0
- frogskin	0	0	0	18	7	1	0	0	0
- CCMV	0	0	0	13	3	0	0	0	0
- other virus/ phytoplasmas	2	0	0	5	5	0	0	0	0
- vein mosaic	0	0	0	6	6	0	0	0	0
- brown streak	2	1	0	0	0	0	0	0	0
- leaf/stem pathogens	3	56	2	0	90	3	0	82	2
Pests			**20**			**12**			**3**
- spider mite	26	48	13	11	36	4	6	38	2
- mealybug	11	40	4	5	16	1	2	2	0
- burrowing bug	0	0	0	12	4	0	0	0	0
- burrowing bug/ mealybug	0	0	0	6	12	1	0	0	0
- thrips	0	0	0	3	12	0	0	0	0

Source: *Henry and Gottret, 1996.*

CHAPTER 4

ARE THERE BETTER VARIETIES WE CAN USE?

Every country has its own favorite varieties that were selected by farmers for their high yield, good eating quality, ease of peeling, or other attributes, such as resistance to certain pests or diseases, or special qualities required by consumers or processors. These varieties will vary from region to region and even within one region farmers may grow a wide range of varieties for different uses or different consumer preferences. Oftentimes, farmers will grow a well-known variety in most of their fields, but will try out in small areas of a field some new varieties they have obtained from neighbors or from extension agents. Farmers are usually very keen to try new varieties as new higher-yielding varieties will increase their yield at basically no extra cost.

When cassava is grown mainly for human food, a wide range of varieties may be grown for different dishes or different tastes. On Java Island of Indonesia, where cassava is grown in a mosaic of different soils and climates, farmers are growing an especially large number of different varieties that they have bred and selected over the past two to three centuries. In contrast, in Thailand, where cassava is grown mainly for industrial processing and is seldom used for human food, the range of varieties is quite limited. In fact, during the 1970s and ‘80s, about one million hectares of cassava were grown using a single variety, Rayong 1. Depending too much on a single variety is dangerous as this variety could suddenly break down due to a new disease or pest problem. For that reason, Thai researchers have developed a range of new higher-yielding varieties. These were actively distributed and promoted by the government during the early 1990s. Presently, Rayong 1 is hard to find in Thailand, as practically all farmers now plant the new higher-yielding varieties. Because of this wide distribution of these new varieties, cassava yield in Thailand increased markedly, from 13−14 t/ha in 1995 to 22 t/ha in 2009. However, not all of this yield increase was due to the adoption of new varieties.

Data in **Table 1** indicate that cassava yield increased markedly between 1990 and 2003, mainly due to the adoption of new higher-yielding varieties, but, after nearly 100% of the cassava area in Thailand was already planted with new varieties and there were no major changes in varieties used, yield still continued to increase. This was mainly due to the greater adoption of better agronomic practices. Thus, new varieties play a major role in increasing yield, but better crop management, especially the use of chemical fertilizer, better erosion control, and more intensive weeding, is almost equally important.

Table 1. Change in cassava yield in Thailand between 1990 and 2009 as a result of the adoption of new varieties and better cultural practices.

Year	Cassava area under new varieties (%)	Cassava yield (t/ha)	Observation
1990	1.1	13.9	Almost no adoption of new varieties
1995	13.0	13.0	Only some adoption of new varieties
2003	97.8	19.3	Almost 100% adoption of new varieties and some improved agronomic practices
2009	~99	22.7	No major change in varieties but major adoption of improved agronomic practices with 80% of cassava farmers using chemical fertilizer

Since the mid-1970s, cassava breeders in several national programs in Asia have developed many improved varieties with specific characteristics, such as good taste, high yield, high starch or dry matter (DM) content, early maturity, or early high yield. Others were selected for dual-purpose use, which means that they can be used both for eating and for processing into starch or ethanol. One variety in Thailand was specifically released for the production of ethanol as the starch had an unusually high conversion rate to ethanol. Most of these new varieties have some genetic background from Latin America, as they were selected mainly from crosses between local varieties and Latin American germplasm. This germplasm was introduced as sexual seed by the CIAT cassava breeder, Dr. Kazuo Kawano, who worked closely with breeders in the various national cassava breeding programs in Asia. Being the center of origin of cassava, Latin America has a much wider genetic diversity than Asia, which allowed for a more rapid improvement in many desired characteristics.

Table 2 shows the names and years that these varieties were released, as well as their main characteristics. Farmers may be able to obtain planting material from those varieties in their own country that have the specific characteristics they like, and then compare these new varieties with those they have traditionally grown. The adoption of new higher-yielding varieties is likely to further contribute to major yield increases for cassava in many countries.

Before a new variety is released, it should be thoroughly tested to make sure that it is better than any of the varieties already being planted. This means that it should have a higher yield and higher starch content, be more resistant to or tolerant of diseases or pests, or have any other positive characteristics not presently available. The new breeding line to be potentially released should be evaluated for several (2−3) years in different parts of the country in comparison with the most popular varieties currently grown. These experiments are best conducted in farmers' fields and using agronomic practices that good farmers would normally use, which is usually without irrigation and not on the most fertile soil. In general, these experiments should not be conducted on experiment stations because the soil on most stations is either better than in farmers' fields or it has been heavily fertilized after many years of experimentation. On the other hand, the official requirements for the release of new varieties should also not be so restrictive that breeders cannot release their best lines because of inadequate personnel to conduct all the experiments and/or inadequate funding to meet all the requirements.

During this prerelease testing, the new line(s) should be evaluated by farmers, processors, and consumers to make sure that they meet the requirements of the final end users. Letting farmers grow and evaluate the new lines together with their current varieties in farmer participatory research trials is a good way to involve farmers directly in the selection of the best lines. This will help in producing enough planting material for rapid post-release distribution and also enhance the adoption of the selected varieties by as many farmers as possible.

Table 2. Local and newly released cassava varieties in Asia and their most important characteristics.

Country	Variety name	Year of release	Location of hybridization	Main characteristics
Cambodia	Damlong Kor	-	Local	Good eating quality (red petioles)
	Damlong Mi	-	Local	Good eating quality (green petioles)
	Damlong narrow leaf	-	Local	High yield
	Malaysia = KU50	1)	KU	High yield, high starch content
China	Bread cassava	-	Malaysia	Low yield, high starch content, eating variety
	SC 102	-	Malaysia	Low yield, high starch content, eating variety
	SC 201	-	Malaysia	High yield, suitable for poor soils
	SC 205	-	Philippines	High yield, suitable for high fertility soils
	SC 6068	1980	CATAS	Low yield, high starch content, eating variety
	Nanzhi 188=CM321-188	1987	CIAT	High yield, poor cold tolerance
	Nanzhi 199=MPan19	1987	CIAT	High yield, high starch content
	SC 124	1988	CATAS	High yield, cold tolerant
	SC 8002	1994	CATAS	High yield
	SC 8013	1994	CATAS	High yield, typhoon resistant
	GR 891	1998	CIAT	High yield, high starch content
	GR 911	1998	CIAT	High yield
	SC 5	2000	CATAS	High yield, typhoon resistant
	SC 6	2001	RFCRC	High starch content, typhoon resistant
	SC 7	2004	CATAS	High yield
	SC 8	2004	RFCRC	High yield, high starch content
	SC 9 = yolk cassava	2005	CATAS	High yield, high starch, β-carotene, eating
	SC 10	2006	CATAS	High yield, cold tolerant
	Gui Re 3	2006	RFCRC	High yield, high starch content
	Gui Re 4	2008	CIAT	High yield
	SC 11 = MBra 900	2009	CATAS	High yield
E. Timor	Mantega	-	Local	Good eating quality; β-carotene
	Lesu	-	Local	Good eating quality
	Ai Luka 2= OMM90-03-100	2007	ILETRI	High yield, good eating quality
	Ai Luka 4 = Gading	2007	Indonesia	High yield, good eating quality
India	H-97	1971	CTCRI	High yield, high starch
	H-165	1971	CTCRI	Early maturing, erect, suitable under coconut
	H-226	1971	CTCRI	High yield, high starch, suitable for processing
	Co-1= ME-7	1976	TNAU	High starch, CMD tolerant, suitable for processing
	Sree Visakham	1977	CTCRI	Has β-carotene, suitable under coconut trees
	Sree Sahya	1977	CTCRI	High yield, drought tolerant
	Co-2	1985	TNAU	Drought, CMD and root rot tolerant
	Sree Prakash	1987	CTCRI	Early maturing, suitable in rice-based rotation
	Co-3	1992	TNAU	CMD tolerant, good cooking qual., for processing

Country	Variety name	Year of release	Location of hybridization	Main characteristics
India (continued)	Nidhi	1993	KAU	Early maturing, suitable for sandy soils along coast
	H-119	1995	TNAU	Early maturing
	Kalpaka	1996	KAU	Early maturing, good cooking quality
	Sree Harsha	1996	CTCRI	High yield, high starch, drought tolerant, processing
	Sree Jaya	1998	CTCRI	Early maturing, good cooking quality, rice-based rotations
	Sree Vijaya	1998	CTCRI	Early mat., has β-carotene, suitable in rice-based rotations
	Sree Rekha	2000	CTCRI	High yield, has β-carotene, edible, suitable for lowland and upland conditions
	Sree Prabha	2000	CTCRI	High yield, has β-carotene, suitable for lowland and upland conditions
	Vellayani Hraswa	2002	KAU	Early mat., good cooking quality, suitable for lowland in rice-based rotation, suitable under coconut
	Co-4	2002	TNAU	CMD tolerant, high starch content, erect
	Sree Padmanabha =MNga-1	2006	IITA	First CMD resistant variety, drought tolerant
	Sree Athulya	2006	CTCRI	High yield, high starch, triploid, suitable for process.
	Sree Apoorva	2006	CTCRI	High yield, high starch, triploid, suitable for process.
Indonesia	Adira 1	1978	BORIF	High yield, sweet, good cooking qualities
	Adira 2	1978	BORIF	High yield, bitter
	Adira 4	1987	BORIF	High yield, bitter
	Malang 1	1992	CIAT	High yield, bitter taste
	Malang 2	1992	CIAT	High yield, sweet taste
	Darul Hidayah	1998	Lampung	High yield, sweet, specific adaptation
	UJ 3 = Rayong 60	2000	RFCRC	High yield, early bulking
	UJ 5 = KU 50	2000	KU	High yield, high dry matter content
	Malang 4	2001	ILETRI	High yield, bitter
	Malang 6	2001	ILETRI	High yield, bitter
	LITBANG UK2	2012	ILETRI	High yield, high ethanol yield, early bulking, sweet
Malaysia	Black Twig	-	Local	Old commercial starch variety, highly adaptable
	Medan	-	Local	Popular old eating variety, good when steamed
	Sri Kanji 1	2003	RFCRC	High yield, relatively high starch content
	Sri Kanji 2	2003	RFCRC	High yield, relatively high starch content
	Sri Pontian	2003	CIAT	Edible, for snack food
Philippines	Golden Yellow	-	Local	Good eating quality, β-carotene
	Lakan	-	UPLB	High yield
	VC-1	1986	CIAT	High yield
	VC-2	1988	Brazil	High yield, edible
	VC-3	1990	CIAT	Dual purpose
	VC-4	1990	CIAT	High yield, dual purpose
	VC-5	1990	Colombia	High yield, bitter
	PSB Cv-11	1995	CIAT	Dual purpose
	PSB Cv-12	1995	CIAT	Dual purpose
	PSB Cv-15	1999	CIAT	Dual purpose
	PSB Cv-19	2000	CIAT	Mite resistance
	NSIC Cv-22= KU50	2008	KU	High yield, high starch content
	NSIC Cv-48= R 72	2013	RFCRC	High yield, drought tolerant

Country	Variety name	Year of release	Location of hybridization	Main characteristics
Thailand	Hanatee	-	Local	Low yield, good eating quality
	Rayong 1	-	Local	High yield, rather low starch content
	Rayong 3	1983	CIAT	High starch content, short, very branched
	Rayong 2	1984	CIAT	Good eating quality, for snack food
	Rayong 60	1987	RFCRC	High early yield, very bitter
	Sriracha 1	1991	KU	High dry matter content, bitter
	Rayong 90	1991	RFCRC	High starch content, relatively high yield, bitter
	Kasetsart 50 (KU50)	1992	KU	High yield, high dry matter content, bitter
	Rayong 5	1994	RFCRC	Relatively high yield, high starch content, bitter
	Rayong 72	1999	RFCRC	High yield, drought tolerant, relatively low HCN
	Huay Bong 60	2003	KU	High yield, high starch content
	Rayong 7	2005	RFCRC	High yield, high starch content
	Rayong 9	2006	RFCRC	High yield, high starch content, high ethanol yield
	Huay Bong 80	2008	KU	High yield, high starch content
	Rayong 11	2010	RFCRC	High starch content, high yield
	Rayong 86-13	2013	RFCRC	High starch content, high yield
Vietnam	Vinh Phu	-	Local	Rather high yield, eating variety
	Gon	-	Local	Rather low yield, eating variety
	La Tre = SC205	-	Local	Rather high yield, bitter
	KM 60 = Rayong 60	1993	RFCRC	High early yield
	KM 94 = KU50	1995	KU	High yield, high starch content
	SM 937-26	1995	CIAT	High yield, high starch content
	KM 95	1995	RFCRC	High yield, dual purpose
	KM 95-3	1998	RFCRC	High yield, dual purpose
	KM 98-7	1998	CIAT	High yield, dual purpose
	KM 98-1	2005	RFCRC	High yield, dual purpose
	KM 140	2010	IAS, NLU	High yield, dual purpose, early bulking
	KM 98-5 [2]	2010	IAS	High yield, dual purpose, early bulking
	Sa21-12	2012	RFCRC	High yield, high starch content
	Sa06	2012	RFCRC	High yield, high starch content
	KM 419	2013	NLU	High yield, high starch content
	HL-S10	2013	IAS	High yield, early bulking
	HL-S11	2013	IAS	High yield, high starch content, early bulking
	KM 10	2013	IAS	High yield, early bulking

1) Introduced from Vietnam in the eastern provinces and from Thailand in the west, but never officially released.

2) KM 98-5 released mainly for Tay Ninh and Dong Nai Provinces.

CHAPTER 5

DOES CASSAVA PRODUCTION DEGRADE OR IMPROVE THE SOIL?

In many countries, governments are reluctant to promote the planting of cassava because of the general belief that cassava is "bad" for the soil. Although few people would be able to pinpoint in what way the crop is bad for the soil, they often indicate that soils on which cassava is grown show clear signs of degradation. Cassava is often grown on seriously eroded soils or on extremely infertile soils that are often sandy and have very little organic matter. People may also mention that cassava produces relatively high root yields, and therefore must be extracting large amounts of nutrients, leaving the soil exhausted after the root harvest. There is some evidence for this general belief that cassava causes soil degradation. **Table 1** shows the effect of the long-term planting of rubber, cashew, sugarcane, cassava, and natural forest vegetation on the chemical characteristics of a Haplic Acrisol in southern Vietnam. Cong Doan Sat and Deturck (1998) reported that long-term cassava cultivation caused the most serious reduction in the organic C and total N contents of the soil, as well as in cation exchange capacity (CEC) and K and Mg contents. However, cassava cultivation had increased the content of available P as compared with forest and cashew, probably because some P may have been applied to cassava, as well as to sugarcane and rubber.

Cassava cultivation also resulted in a soil with a lower clay content, low aggregate stability, and low volumetric water content and infiltration rate. However, whether or not cassava cultivation caused these problems is still not clear. Heavier and more fertile soils, having a greater aggregate stability, are usually used for higher-value crops such as rubber, cashew, and sugarcane. Moreover, cassava is usually grown as an annual crop that needs regular land preparation, weeding, and harvesting, whereas the other crops used as a comparison are mainly perennial crops that do not require such intensive land preparation; sugarcane is also an annual or biennial crop, but, after the first harvest, the crop can be ratooned for two or more cycles before the land needs to be prepared again. Cassava should be compared with other annual crops because it is the regular land preparation and weeding that often lead to a rapid decline in soil organic matter and aggregate stability.

Thus, although cassava often grows on highly degraded or naturally infertile soils, this is not necessarily because the crop has "caused" this degradation. It is very well possible that cassava is grown in infertile and degraded soils because it is one of the few crops that will tolerate these difficult conditions, and still produce some yield where other crops would perish. Also, cassava is usually grown by the poorest farmers on very infertile soils, and on steep slopes, with few inputs such as fertilizer and with very little care.

Table 1. Chemical properties of various horizons of Haplic Acrisols that had been under different land use for many years in southeastern Vietnam.

	Forest	Rubber	Cashew	Sugarcane	Cassava	CV (%)
Organic C (%)	1.032 a	0.839 ab	0.579 ab	0.796 ab	0.496 b	44.7
Total N (%)	0.058 a	0.054 ab	0.032 bc	0.040 abc	0.022 c	36.7
Available P (Bray II) (ppm)						
-1st horizon	5.21 b	20.90 a	4.85 b	20.68 a	15.33 ab	37.5
-2nd horizon	2.48 b	7.03 a	3.19 b	7.92 a	5.31 ab	32.6
-3rd horizon	1.57 b	2.83 ab	1.08 ab	3.82 a	3.82 a	44.6
CEC (meq/100 g)	3.43 a	2.94 a	2.39 ab	3.24 a	1.53 b	27.1
Exch. K (meq/100 g)						
-1st horizon	0.132 a	0.127 a	0.070 ab	0.051 b	0.060 b	66.3
-2nd horizon	0.073 a	0.046 ab	0.031 ab	0.022 b	0.021 b	75.1
Exch. Mg (meq/100 g)	0.145 a	0.157 a	0.046 ab	0.055 ab	0.036 b	89.1

Values are the average of 6–10 profiles per cropping system. Within rows, numbers followed by the same letter are not significantly different at the 5% level by Tukey's Studentized Range Test.
Source: *Cong Doan Sat and Deturck, 1998.*

1. Effect of cassava cultivation on yield and nutrient removal by the crop

When poorly managed, cassava cultivation can indeed result in serious soil degradation. When cassava roots are harvested and taken off the field, the nutrients present in the roots are also removed. This may lead to nutrient depletion in the soil. When cassava is grown for many years on the same field without application of fertilizer or manure, yields will very likely go down due to nutrient depletion leading to soil exhaustion. A good example of this is shown in **Figure 1**. During 4 years of consecutive cassava cropping, root yield declined from 18.9 t/ha in the first year to 6.4 t/ha, or only 34% of the first-year yield. However, the yield of upland rice grown in the same experiment also declined, from 2.55 t/ha in the first year to no yield at all in the fourth year, indicating that cassava is not necessarily worse in this respect than other annual crops.

Does cassava actually extract more nutrients from the soil than other crops? **Table 2** shows data from the literature comparing nutrient removal in the harvest of cassava with the amounts of nutrients removed in the harvested products of many other crops. At a relatively high fresh root yield of 35.7 t/ha (or 13.53 t/ha of dry roots), these roots contained 55 kg of N, 13.2 kg of P, and 112 kg of K. This is comparable with the nutrient removal of many other crops, except that cassava removed more K than most other crops. But, when the same data are calculated on the basis of nutrients removed per ton of dry matter of the harvested product, it is clear that cassava removed less N and P than many other crops and similar amounts of K.

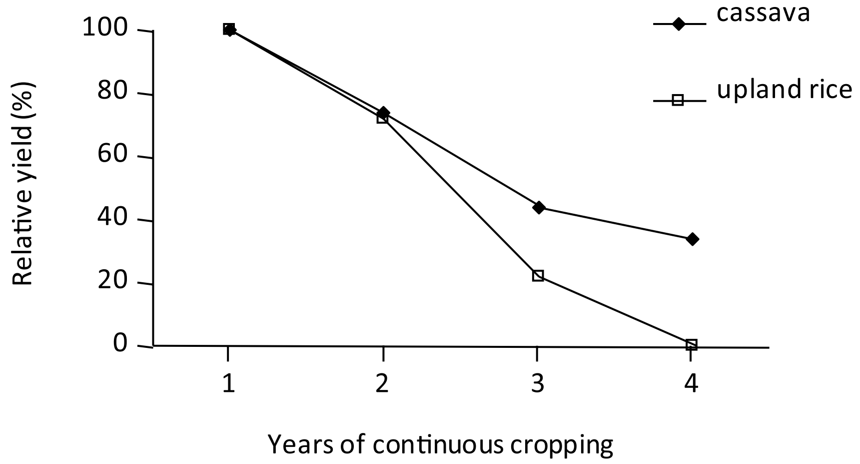

Figure 1. *Yield reduction of upland rice and cassava due to fertility decline as a result of continuous cropping without fertilizer application; 100% corresponds to 18.9 t/ha of fresh cassava roots and 2.55 t/ha of rice.*

Source: *Adapted from Nguyen Tu Siem, 1992.*

Table 2. Average nutrient removal in the harvested products of cassava and various other crops, expressed in both kg/ha and kg/t dry matter (DM) produced, as reported in the literature.

	Yield (t/ha)		(kg/ha)			(kg/t DM produced)		
Crop/plant part	fresh	dry[1)]	N	P	K	N	P	K
Cassava/fresh roots	35.7	13.53	55	13.2	112	4.5	0.83	6.6
Sweet potato/fresh roots	25.2	5.05	61	13.3	97	12.0	2.63	19.2
Maize/dry grain	6.5	5.56	96	17.4	26	17.3	3.13	4.7
Rice/dry grain	4.6	3.97	60	7.5	13	17.1	2.40	4.1
Wheat/dry grain	2.7	2.32	56	12.0	13	24.1	5.17	5.6
Sorghum/dry grain	3.6	3.10	134	29.0	29	43.3	9.40	9.4
Beans /dry grain	1.1	0.94	37	3.6	22	39.6	3.83	23.4
Soya/dry grain	1.0	0.86	60	15.3	67	69.8	17.79	77.9
Groundnut/dry pod	1.5	1.29	105	6.5	35	81.4	5.04	27.1
Sugarcane/fresh cane	75.2	19.55	43	20.2	96	2.3	0.91	4.4
Tobacco/dry leaves	2.5	2.10	52	6.1	105	24.8	2.90	50.0

[1)] Assuming cassava to have 38% DM, grain 86%, sweet potato 20%, sugarcane 26%, and dry tobacco leaves 84%.
Source: *Howeler, 1991b.*

Putthacharoen et al. (1998) reported similar data for an experiment conducted for nearly 2 years with seven different crops in Sri Racha, Thailand. **Table 3** shows that, in two consecutive crops, the total dry matter (DM) production of cassava was 14.9 t/ha while the DM in roots was 5.2 t/ha, corresponding to a fresh root yield of about 15 t/ha. Removed with the harvest of the roots were 48 kg/ha of N, 7 of P, and 60 of K, but, if the whole plant were harvested and removed, this would be 284 kg/ha of N, 39 of P, and 192 of K, indicating that most of the absorbed nutrients could be returned to the soil through the re-incorporation of the top growth, which is the normal practice in Thailand. Compared with the other crops grown in the same experiment during the same 22-month period, cassava in the harvested product (roots) removed much less N and P, and similar amounts of K, Ca, and Mg, than the other crops, whereas pineapple removed much greater quantities of all nutrients, including K.

Table 3. Total dry matter (DM) production and nutrient uptake (A), nutrients removed (B), and DM and nutrients returned to the soil (C) of seven crops grown during 22 months at the Sri Racha Research Station, Sri Racha, Thailand, from 1989 to 1991.

Crop	DM	N	P	K	Ca	Mg
A. Total dry matter produced and nutrient uptake (kg/ha)						
Cassava for roots	14,920	284	39	192	167	42
Cassava for forage	17,186	380	47	256	186	67
Maize	21,538	219	57	357	40	39
Sorghum	22,222	225	52	355	61	46
Peanut	13,489	347	31	236	93	36
Mungbean	5,990	171	21	128	60	25
Pineapple	26,761	243	46	465	136	43
F-test	**	**	**	**	**	**
CV (%)	12.24	11.21	19.10	14.69	15.66	12.20
LSD (P<0.01)	5.081	72.5	19.4	100.6	39.4	11.9
B. Dry matter and nutrients removed from the field in the harvested products (kg/ha)						
Cassava for roots	5,185	48	7	60	14	6
Cassava for forage	15,695	363	43	240	162	62
Maize	8,782	118	44	87	6	11
Sorghum	5,097	79	25	51	10	9
Peanut	4,899	213	19	53	6	8
Mungbean	2,878	117	15	62	9	11
Pineapple	7,582	83	15	190	51	19
C. Dry matter and nutrients returned to the soil in the nonharvested products (kg/ha)						
Cassava for roots	9,735	236	46	132	154	35
Cassava for forage	1,491	17	4	16	24	5
Maize	12,756	101	13	269	34	28
Sorghum	17,125	147	27	304	51	37
Peanut	8,590	133	12	183	87	28
Mungbean	3,112	54	7	66	51	14
Pineapple	19,179	160	31	176	85	24

Source: *Putthacharoen et al., 1998.*

Cassava also returned to the soil in the form of nonharvested products much larger amounts of N and P than any of the other crops, but less K than maize, sorghum, peanut and pineapple.

When cassava was grown for forage production, however, and stems and leaves were harvested at 3-month intervals during the same 22-month period, the harvested DM of both forage and roots was very high and nutrient removal was also extremely high, indicating that this management system requires high inputs of all nutrients to prevent rapid soil nutrient depletion.

Table 4 shows the nutrient content at the time of harvest in the tops, roots, and fallen leaves of both fertilized and unfertilized cassava plants grown in infertile soil in Carimagua, Colombia. It is clear that most of the N, Ca, and Mg was present in the plant tops and fallen leaves; P was rather evenly distributed between tops and roots, whereas K was present mainly in the roots. This was true for both fertilized and unfertilized plants, but the growth of the fertilized plants was more vigorous, resulting in substantially higher root yield and greater nutrient absorption by the fertilized plants. It is also clear that when both roots and tops, and even the fallen leaves, are removed from the field at the time of harvest, the removal of many nutrients can double or triple, which can lead to rapid nutrient depletion and soil degradation. To maintain soil fertility, it is important to return to the soil those nutrients that were removed in the harvested products. This can be done by the application of the right amounts and the right balance of chemical fertilizer as well as moderate amounts of animal manure to prevent nutrient exhaustion. In addition, all plant tops (except stems used as planting material) and fallen leaves should be reincorporated into the soil to maintain adequate organic matter, and improve soil structure and aggregate stability (Howeler, 2010b; 2012a).

Table 4. Dry matter and nutrient distribution in 12-month-old cassava, cv. MVen 77, grown with and without fertilization in Carimagua, Colombia, in 1983/84.

	DM (t/ha)	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		(kg/ha)										
Unfertilized												
-tops	5.11	69.1	7.4	33.6	37.4	16.2	8.2	0.07	0.03	0.45	0.33	0.26
-roots	10.75	30.3	7.5	54.9	5.4	6.5	3.3	0.08	0.02	0.38	0.02	0.10
-fallen leaves	1.55	23.7	1.5	4.0	24.7	4.0	2.5	0.04	0.01	-	0.37	0.18
Total	**17.41**	**123.1**	**16.4**	**92.5**	**67.5**	**26.7**	**14.0**	**0.19**	**0.06**	**-**	**0.72**	**0.54**
Fertilized												
-tops	6.91	99.9	11.7	74.3	55.0	15.3	9.6	0.08	0.03	0.78	0.57	0.30
-roots	13.97	67.3	16.8	102.1	15.5	8.4	7.0	0.07	0.03	0.90	0.06	0.17
-fallen leaves	1.86	30.5	2.0	7.1	31.9	4.7	2.6	0.05	0.02	-	0.46	0.19
Total	**22.74**	**197.7**	**30.5**	**183.5**	**102.4**	**28.4**	**19.3**	**0.20**	**0.08**	**-**	**1.09**	**0.66**

Source: *Howeler, 1985a.*

As cassava root yields increase due to fertilization **(Table 4)** or more favorable growing conditions, nutrient removal in both roots and total biomass also increases **(Table 5)**. Based on the data set of the 15 sources in **Table 5** that also shows DM yields, the average nutrient removal in an "average" root yield of 28.9 t/ha is 67.1 kg N, 11.2 kg P, and 88.1 kg K/ha, while that by the whole plant would be 179.5 kg N, 22.7 kg P, and 156.1 kg K/ha **(Table 6)**. This table also shows the average nutrient removal per ton of fresh and dry roots.

Table 5. Fresh and dry yield as well as nutrient content in cassava roots and in the whole plant at the time of harvest, as reported in the literature.

Plant part	Yield (t/ha) fresh	dry	Nutrient content (kg/ha) N	P	K	Ca	Mg	Source/cultivar
Roots	6.0	1.52	18	2.2	15	5	2	Putthacharoen et al., 1998,
Whole plant	-	4.37	91	12.2	55	46	15	1989–90, Rayong 1
Roots	8.7	2.68	13	0.9	4	3	2	Sittibusaya (unpublished)
Whole plant	-	4.23	39	3.2	10	21	8	unfertilized Rayong 1
Roots	~9.0	3.24	37	1.5	23	4	2	Paula et al., 1983
Whole plant	-	6.54	93	4.0	40	30	9	unfertilized Branca St. Cat.
Roots	~15.9	5.58	66	2.7	17	8	5	Paula et al., 1983
Whole plant	-	10.62	197	8.1	61	100	20	unfertilized Riqueza
Roots	16.1	3.64	30	4.7	45	9	5	Putthacharoen et al., 1998,
Whole plant	-	10.55	193	27.0	137	122	27	1990–91, Rayong 1
Roots	18.3	5.52	32	3.6	35	5	4	Sittibusaya (unpublished)
Whole plant	-	9.01	95	9.9	65	37	15	fertilized Rayong 1
Roots	21.0	-	21	9.2	44	8	10	Kanapathy, 1974
Whole plant	-	-	86	37.2	135	45	34	Malaysia, peat soil
Roots	26.0	10.75	30	8.0	55	5	7	Howeler, 1985a
Whole plant	-	17.41	123	16.0	92	67	27	unfertilized MVen 77
Roots	26.6	12.81	91	11.3	47	5	6	Cadavid, 1988
Whole plant	-	19.10	167	19.1	76	32	19	unfertilized CM523-7
Roots	~28.5	10.28	100	8.7	107	15	13	Paula et al., 1983
Whole plant	-	19.56	353	24.8	174	133	37	fertilized Riqueza
Roots	31.0	-	31	18.9	47	-	-	Sittibusaya and
Whole plant	-	-	73	31.9	72	-	-	Kurmarohita, 1978
Roots	32.3	15.39	127	19.1	71	6	5	Cadavid, 1988
Whole plant	-	25.04	243	34.4	147	56	25	fertilized CM523-7
Roots	~36.0	12.60	161	10.0	53	16	12	Paula et al., 1983
Whole plant	-	20.92	330	20.5	100	88	30	fertilized Branca St. Cat.
Roots	37.5	13.97	67	17.0	102	16	8	Howeler, 1985b
Whole plant	-	22.74	198	31.0	184	102	28	unfertilized MCol 22
Roots	45.0	-	62	10.0	164	12	22	Amarasiri and Perera, 1975
Whole plant	-	-	202	32.0	286	131	108	Sri Lanka
Roots	50.0	-	153	17.0	185	25	6	Cours, 1953
Whole plant	-	-	253	28.0	250	42	29	Madagascar
Roots	52.7	25.21	38	27.9	268	34	19	Nijholt, 1935
Whole plant	111.1	44.65	132	48.5	476	161	52	cv. Manggi
Roots	59.0	21.67	152	22.0	163	20	11	Howeler and Cadavid, 1983
Whole plant	-	30.08	315	37.0	238	77	32	fertilized MCol 22
Roots	64.7	26.59	45	28.2	317	51	18	Nijholt, 1935
Whole plant	110.6	39.99	124	45.3	487	155	43	cv. São Pedro Preto
Roots	**30.8**	**-**	**67.0**	**11.7**	**92.7**	**-**	**-**	**Average 19 sources**
Whole plant	**-**	**-**	**174.0**	**24.7**	**162.4**	**-**	**-**	

Source: *Howeler, 2002.*

Table 6. Average fresh and dry root yield as well as the amount of nutrients removed when cassava roots or the whole plant are harvested, based on data from the literature.[1)]

Plant part	Yield (t/ha) fresh	dry	Nutrient removal N	P	K	Ca	Mg
			kg/ha				
Roots	28.87	11.43	67.1	11.2	88.1	13.5	7.9
Whole plant		18.99	179.5	22.7	156.1	81.8	25.8
			kg/t fresh roots				
Roots	28.87	11.43	2.32	0.39	3.05	0.47	0.27
Whole plant		18.99	6.22	0.79	5.41	2.83	0.89
			kg/t dry roots				
Roots	28.87	11.43	5.87	0.98	7.71	1.18	0.69
Whole plant		18.99	15.70	1.99	13.66	7.16	2.26

[1)] Data are average of 15 data sets that have yields reported in dry weight in Table 5.

Source: *Howeler et al., 2001b.*

However, when the reported N, P, and K removal data are plotted against fresh root yields, we see that this is not a linear relationship **(Figure 2)**. As yields increase, because of better growing conditions, the nutrient concentrations in the plant tissues also tend to increase, resulting in a curvilinear relationship between nutrient removal and yield. Thus, at a “normal” yield of 15 t/ha, nutrient removal in the roots is only about 30 kg N, 3.5 kg P, and 25 kg K/ha rather than 34.80 kg N, 5.85 kg P, and 45.75 kg K as predicted from the average values shown in **Table 6**. Thus, at the relatively low yields that farmers usually obtain, nutrient removal in the harvested roots is actually quite low, especially of P, as long as crop residues are returned to the soil. But, when yields increase from 15 to 30 t/ha, K removal by the roots does not double, from 25 to 50 kg/ha, but increases to about 65 kg/ha. Thus, when farmers want to increase their yield, they will need to apply chemical fertilizer or manure, or they may plant green manure crops, depending on the native fertility of the soil.

The large extraction of K in each root harvest can lead to K exhaustion of the soil. Thus, Den Doop (1937) reported that, in three consecutive cassava plantings without applied K, yield decreased from 15 t/ha in the first year to 4 t/ha in the third year. Similarly, Chan (1980) reported that, in a long-term fertility trial on mineral soils in Malaysia, yield decreased from 32 to 20 t/ha in nine consecutive cassava crop cycles without fertilization; with application of 112 kg N, 68 kg P, and 156 kg K/ha, yield actually increased from 30 to 54 t/ha in the ninth crop. The yield decline without fertilization was mainly due to K exhaustion.

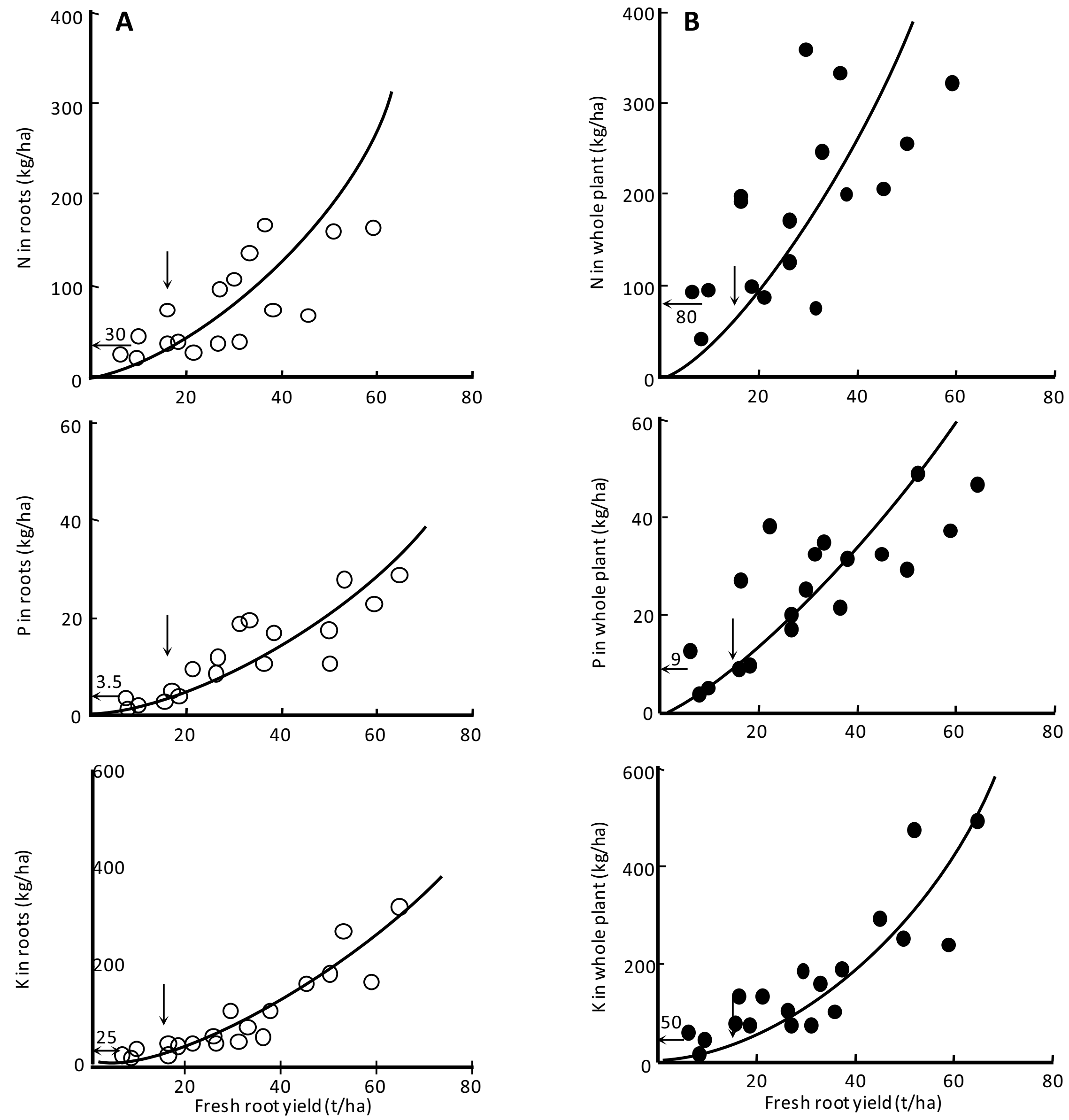

Figure 2. *Relation between the amounts of N, P, and K in cassava roots (A) or in the whole plant (B) and fresh root yield, as reported by various sources in the literature. Arrows indicate the approximate nutrient content corresponding to a fresh root yield of 15 t/ha.*

Source: *Howeler, 2002; 2004.*

Similar results were reported by Kabeerathumma et al. (1990) for a long-term NPK trial conducted in Trivandrum, Kerala, India. After 10 years of continuous cassava cropping, yield without K application had decreased from 22 t/ha in the first year to about 6 t/ha in the 10th year. In the treatment without K, the exchangeable K in the soil had decreased from an initial 0.17 meq/100g to only 0.07 meq/100g,

indicating a clear depletion of the K status of the soil due to repeated cassava cropping and harvests; with K application, the exchangeable K had increased to 0.23 meq/100 g and yield had increased to 28 t/ha (**Figure 3**).

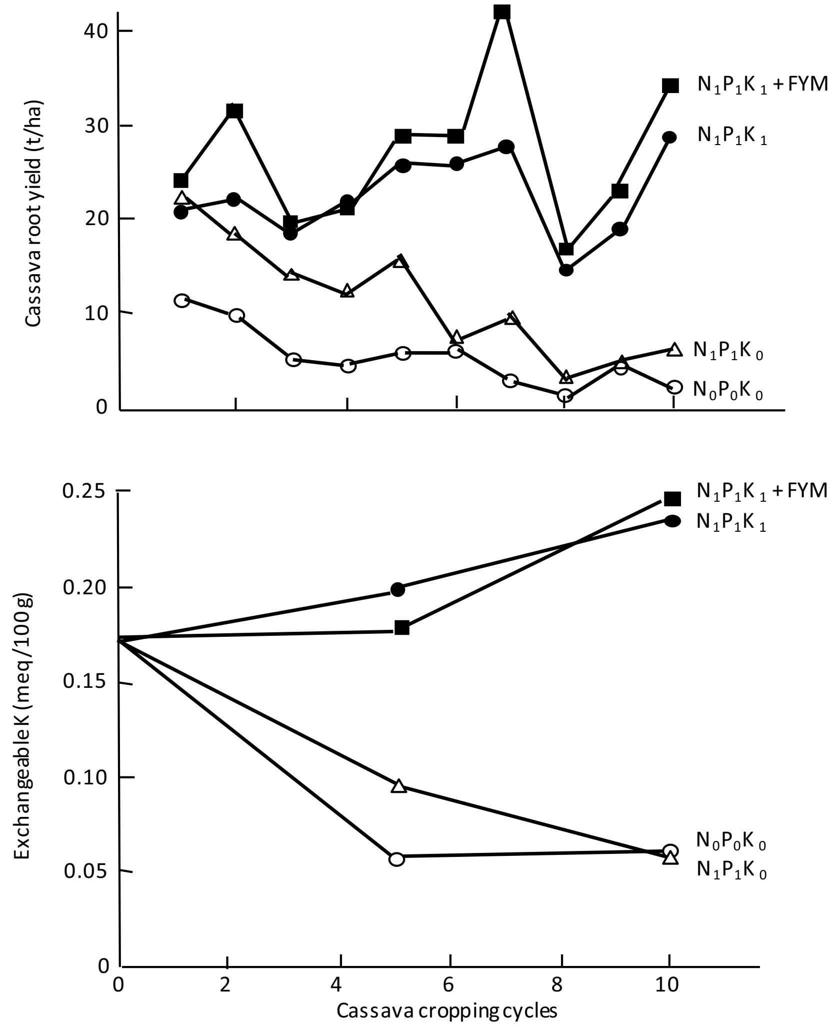

Figure 3. *Cassava yield (top) and the exchangeable K content of the soil (bottom) during 10 years of continuous cropping with various NPK treatments in Trivandrum, Kerala, India.*

Note: $N_1P_1K_1$ = 100 kg N, P_2O_5, and K_2O/ha.

Source: *Kabeerathumma et al., 1990.*

Howeler and Cadavid (1990) also reported similar results for a long-term NPK trial conducted for 8 years in Santander de Quilichao, Colombia (**Figure 4A**). Root yield of about 30 t/ha could be maintained only with the application of 150 kg K_2O/ha, which maintained the exchangeable K content of the soil at about 0.2 meq/100 g (**Figure 4B**). Without K application, yield slowly declined from 21 to 14 t/ha, while the exchangeable K content declined from 0.2 to 0.1 meq/100 g after eight cassava crop cycles.

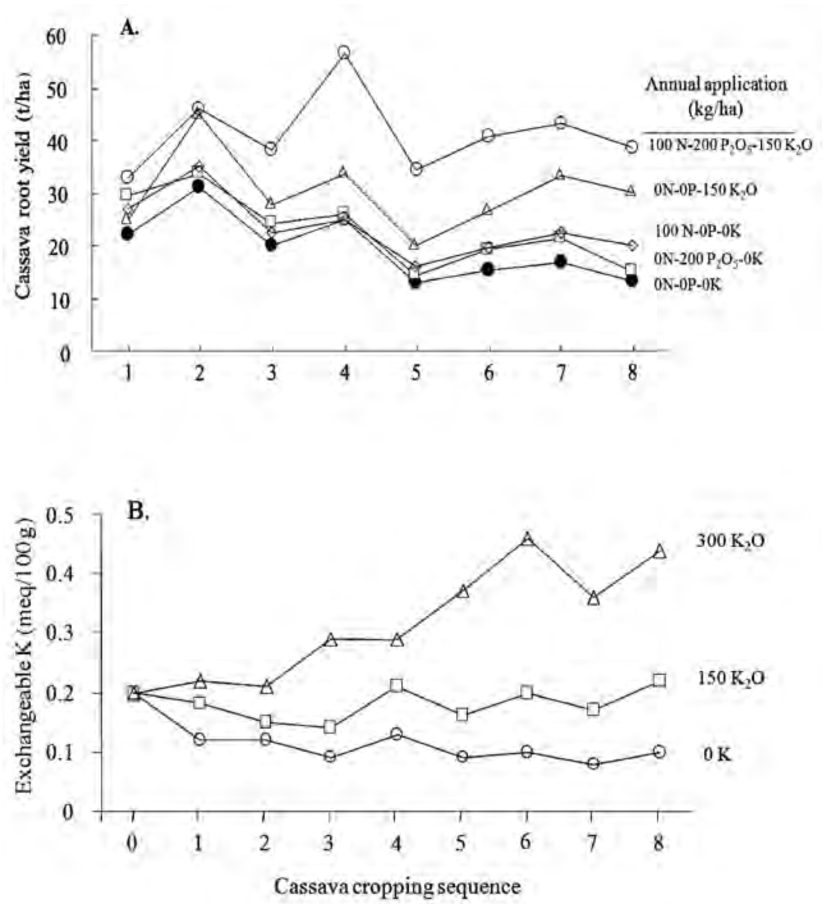

Figure 4. *Effect of various amounts of annual applications of N, P, and K on cassava root yield (A) and on the exchangeable K content of the soil (B) during eight consecutive cropping cycles in a long-term NPK trial conducted in Santander de Quilichao, Colombia.*

Source: *Howeler and Cadavid, 1990.*

2. Effect of cassava cultivation on soil erosion

The decrease over time in cassava yield shown in **Figure1** can be due to nutrient depletion as no fertilizers were applied, but can also be due to a loss of nutrients in rainfall runoff and eroded soil. Soil degradation by erosion is often more serious than that caused by nutrient removal in the crop harvest as soil erosion not only carries away plant nutrients in the soil and fertilizers but also a disproportionate amount of clay particles, organic matter, and beneficial soil microorganisms. The latter cannot be replaced by the simple application of chemical fertilizer. This is of particular concern because cassava is often grown on steep slopes in mountainous areas on acid infertile soils or in very light-textured soils with low organic matter and nutrient contents. The fact that cassava is well adapted to these adverse conditions also makes its cultivation possible and more common in areas or soils that are prone to have serious soil erosion problems.

But, even under the same conditions of slope and soil type, cassava cultivation was found to result in more serious soil losses by erosion than most other crops. Experiments conducted in Pernambuco, Brazil, showed that cassava cultivation resulted in more erosion than cotton, maize, velvet bean and *Panicum maximum* **(Table 8)**. Similar results were obtained in experiments on soil loss and runoff between different crops grown for many years in experiments on Terra Roxa soils in Brazil (Quintiliano et al., 1961). Cassava cultivation caused more soil loss and runoff than any other crop, except *Phaseolus* beans and castor bean. However, being a long-season crop, cassava requires only one land preparation per year, whereas short-season crops such as *Phaseolus* beans can be grown at least twice a year, and thus require more frequent land preparation and weeding, which results in much greater soil losses by erosion than with cassava (Howeler, 1987; CIAT, 1988b).

Table 8. Annual soil losses by erosion caused by planting various crops on 12% slope in Gloria do Goita, Pernambuco, Brazil. Data are average values for 10 years (1969–1978).

Treatment	Soil loss (t/ha)
Bare soil	59.90
Cassava	11.01
Cotton	8.35
Maize	2.97
Velvet bean (*Mucuna* sp.)	2.85
Panicum maximum	0.43

Source: *Margolis and Campos Filho, 1981.*

Soil loss by erosion depends mainly on the soil type, degree and length of slope, rainfall amount and intensity, as well as the degree of soil cover by vegetation. The latter is represented by the "C" factor in the Universal Soil Loss Equation. The degree of soil cover in turn depends on the crop's inherent characteristics as well as on its management, such as frequency and intensity of land preparation and weeding, plant spacing, fertilization, etc. Roose (1977) lists cassava as a crop causing intermediate erosion **(Table 9)**, with a "C" factor ranging from 0.2 to 0.8 depending on its management (a "C" factor of 1.0 corresponds to bare soil while 0 indicates no erosion). Cassava tends to cause more serious erosion than other crops due to its wide plant spacing and slow initial growth, which result in a slow formation of soil cover (**Figure 5**); this can be improved by intercropping with maize, peanut, or creeping crops such as watermelon, squash, or pumpkin.

Table 9. Effect of crop cover on crop management factor "C" in the Universal Soil Loss Equation.

Crop cover	C
No cover (bare soil)	1.0
Maize, sorghum	0.3–0.9
Groundnut	0.4–0.8
Cassava	**0.2–0.8**
Cotton, tobacco	0.5
Oil palm, coffee, cacao with cover crops	0.1–0.3
Rice	0.1–0.2
Rapidly growing cover crop	0.1
Savanna or pasture (without grazing)	0.01
Forest or crop with thick layer of mulch	0.001

Source: *Roose, 1977.*

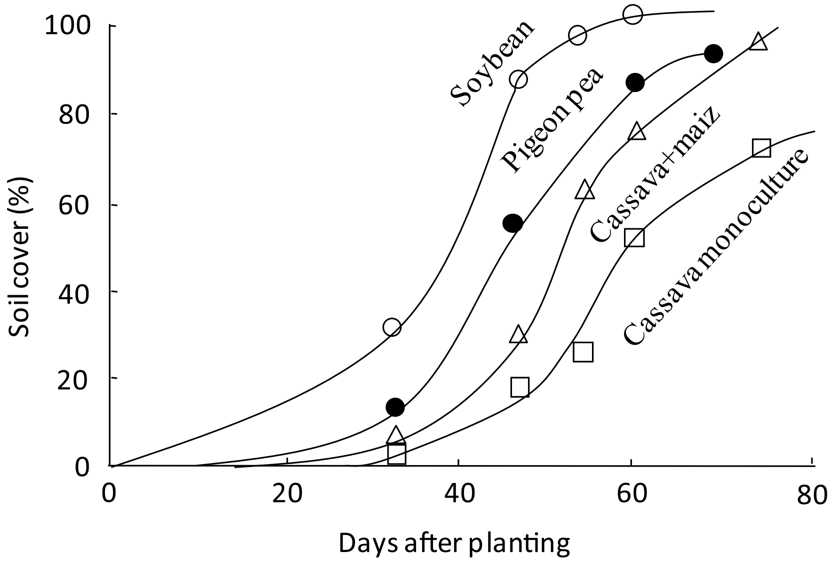

Figure 5. *Percent soil cover of various crops and cropping systems during crop establishment.*
Source: *Aina et al., 1979.*

Putthacharoen et al. (1998) reported the dry soil losses due to erosion of eight crops grown side-by-side on 7% slope in Sri Racha, Thailand, during a 4-year period; this allowed for four consecutive crops of cassava for root production; five crops of maize, sorghum, and peanut; six crops of mungbean; and two crops of cassava for forage production, pineapple, and sugarcane. **Table 10** shows that soil losses due to erosion with cassava grown for root production averaged about 75 t/ha/year as compared with 15−20 t/ha/year for maize, sorghum, and peanut, and only 13 t/ha/year for pineapple due to the ratooning of the second-cycle pineapple crop. Cassava grown for forage production was planted at a closer spacing, resulting in faster canopy cover and less erosion, but still averaging about 50 t/ha/year. Thus, the wider spacing of cassava and its slower canopy formation resulted in more soil being exposed to the impact of raindrops and thus more soil loss by erosion. These high rates of soil loss also mean high losses of soil nutrients (Howeler et al., 2001); this can be as high as, or higher than, that removed annually with the

Table 10. Total dry soil loss by erosion (t/ha) due to the cultivation of eight crops during 4 years on 7% slope with sandy loam soil in Sri Racha, Thailand, from 1989 to 1993.

Crop	No. of crop cycles	First period (22 months)	Second period (28 months)	Total (50 months)	Average (t/ha/year)
Cassava for root production	4	142.8 a	168.5 a	311.3	74.7
Cassava for forage production	2	68.8 b	138.5 ab	207.3	49.8
Maize	5	28.5 d	35.5 cd	64.0	15.4
Sorghum	5	42.9 c	46.1 cd	89.0	21.4
Peanut	5	37.6 cd	36.2 cd	73.8	17.7
Mungbean	6	70.9 b	55.3 cd	126.2	30.3
Pineapple[1)]	2	31.4 cd	21.3 d	52.7	12.6
Sugarcane[2)]	2	-	94.0 bc	-	-
F-test		**	**		
CV (%)		11.4	42.7		

[1)] Second cycle is ratoon crop
[2)] Sugarcane only during second 28-month period.
Source: *Putthacharoen et al., 1998.*

harvested roots. Nutrients lost in runoff were found to be quite low for N and P, but still substantial for K (Phommasack et al., 1996). Erosion seriously affects the fertility of the soil, oftentimes exposing very acid infertile and highly compacted subsoils, or—in limestone-derived soils—a calcareous subsoil that may cause severe micronutrient deficiencies. Cassava grown on seriously eroded soils will have low yield and may require heavy inputs of fertilizer to obtain the same yield as in noneroded soil even without applied fertilizer **(Figure 6).**

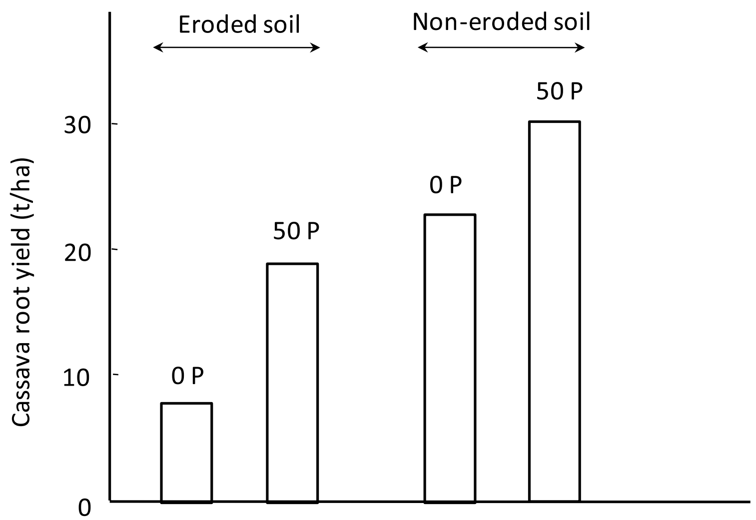

Figure 6. *Effect of soil erosion and P application on the yield of cassava cv. CMC 92 in Mondomo, Cauca, Colombia.*
Source: *Howeler, 1987.*

3. Can cassava production actually improve soils?

Cassava is one of the most important food crops in many countries in sub-Saharan Africa, but farmers seldom apply any chemical fertilizer or manure to their cassava crop. Traditionally, soil fertility is maintained through slash-and-burn systems, in which, after several years of cropping, the land is returned to bush fallow for 10−20 years to let the soil rest and replenish the nutrients that were lost during the cropping cycle. However, because of rapid population growth and the consequent increase in land pressure, the fallow cycle has steadily been shortened while the cropping cycle and intensity have increased. In many densely populated countries in East and West Africa, the fallow cycle has now declined to 1−2 years or has actually been eliminated entirely. Instead, farmers are trying to maintain the fertility of their land through the planting of "improved" fallows of fast-growing leguminous trees, alley-cropping systems, or cereal-legume crop rotations.

Farmers in Ghana and Benin in West Africa also use extensive cassava cropping as a "substitute fallow" as they have observed that this system seems to restore soil productivity; the maize crop planted after cassava grows better than maize planted after maize, or even after many legume crops. Cassava cropping in many countries in West Africa is called "jachère manioc," which literally means "cassava fallow" (Saïdou, 2006; Adjei-Nsiah et al., 2007). Similarly, the bush-fallow cycle in many countries in East Africa has nearly disappeared, and many farmers are now rotating maize with cassava so that cassava can "rest" the soil and improve soil fertility for the following maize crop (Fermont, 2009).

In an experiment in Ghana, the yield of maize planted after either cassava or Mucuna *(Mucuna pruriens)* indeed was higher than when maize followed cowpea, maize, or a speargrass *(Imperata cylindrica)* fallow **(Figure 7)**.

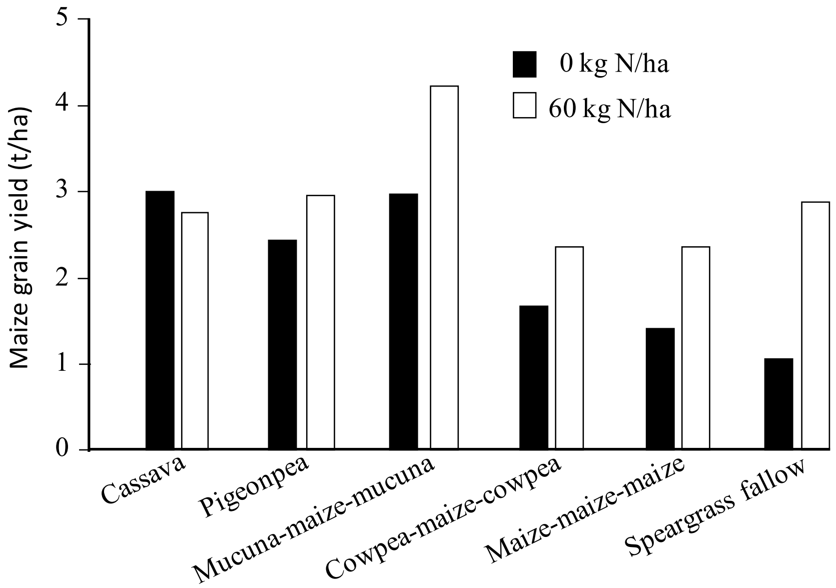

Figure 7. *Effect of crop sequence and N rate on maize grain yield produced on researcher-managed plots in Ghana.*
Source: *Adjei-Nsiah et al., 2007.*

The beneficial effect of cassava was attributed to the relatively high nutrient concentration, especially N, of the fallen leaves and of the crop residues incorporated into the soil after the harvest of the roots (see also **Table 3C**). Since cassava has a relatively deep root system, part of these nutrients may have been taken up from the subsoil and then deposited onto the soil surface, where they are available for rapid uptake by the following maize crop. It is also possible that the growing of cassava has stimulated the reproduction of mycorrhizal fungi in the soil, which may have benefited the following maize crop in the absorption of P from the soil.

Another beneficial effect of cassava preceding the maize crop is that, under the dense canopy of cassava, most weeds had been shaded out. This provided a nearly weed-free seedbed for the following maize crop (**Figure 8**).

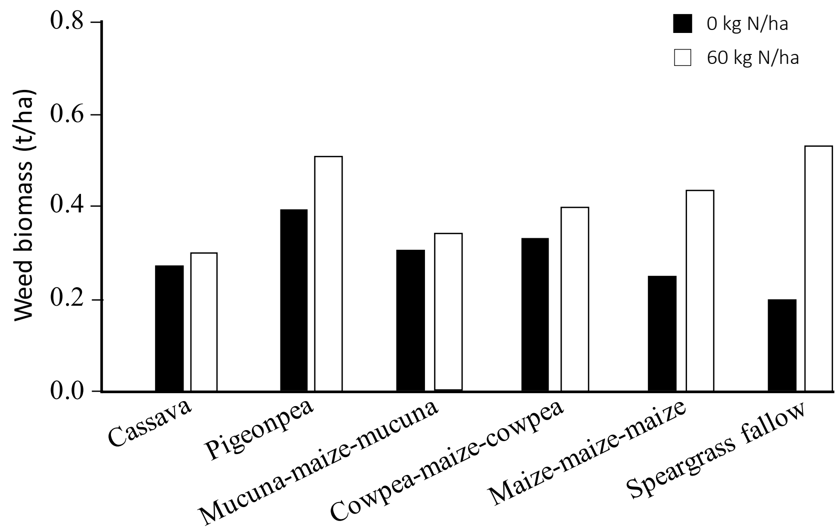

Figure 8. *Effect of crop sequence and N rate on weed mass associated with the maize crop at 8 weeks after planting on researcher-managed plots.*

Source: *Adjei-Nsiah et al., 2007.*

From the numerous experiments conducted on the nutritional requirements of cassava, the amount of nutrients absorbed and removed in different plant parts, as well as on fertilizer and erosion control practices, the following conclusions can be drawn:

a. Cassava grows well on acid and infertile soils because it is more tolerant than most other crops of low pH, high Al, and low P, K, and Ca.

b. The amount of nutrients removed in the harvest of roots is low compared with that in the harvested products of most other crops, with the possible exception of K. However, when leaves and stems are also removed from the field, nutrient removal increases substantially, especially that of N, Ca, and Mg.

c. When cassava is grown for many years in the same fields, it is very likely that the removal of K in the harvested roots will lead to a decrease in exchangeable K in the soil. To prevent this, it is very important to add enough K in the form of fertilizer or manure to prevent K exhaustion and to maintain high yield.

d. Soil and nutrient losses due to erosion may be more severe with cassava cultivation on slopes than with other crops, mainly due to cassava's wide spacing and slow initial growth, leaving much soil exposed to the impact of raindrops, which causes soil aggregate disintegration and soil particle movement down-slope with rainfall runoff.

e. Cassava production may actually improve the soil for the following crop by providing N from the fallen leaves and top growth, by stimulating the population of native mycorrhizal fungi, and by shading out weeds, which reduces early weed competition in the following crop.

Thus, although cassava has certain intrinsic characteristics that make the crop very suitable for growing on poor and degraded soils, it also has characteristics that may result in more serious soil losses by erosion. However, it is mainly the way the crop is managed that determines whether this results in further nutrient depletion, erosion, and soil degradation. Good management will increase yield and farmers' income, while at the same time protecting the soil from degradation. In that case, the continued cultivation of cassava on poor soils is more likely the consequence rather than the cause of soil degradation. In addition, cassava may actually improve the soil for the following crop under certain circumstances.

CHAPTER 6

HOW TO DIAGNOSE NUTRITIONAL PROBLEMS

Cassava is known to grow reasonably well in very acid and low-fertility soils. Still, like other plants, its growth is affected by nutrient supply, and, if some nutrients are not present or are present in inadequate amounts, plant growth and yield will be reduced. In other cases, plant growth decreases because some elements in the soil may be too high, causing either a toxicity or a reduction in the uptake of other essential nutrients. To determine which nutrients are either deficient or too high, we can use several different methods, such as the observation of nutrient deficiency or toxicity symptoms, information from soil or plant tissue analysis, or field or greenhouse experiments. In many cases, it is necessary to use a combination of these methods to determine which nutrients are the most limiting.

1. Observation of deficiency and toxicity symptoms

Cassava has relatively low phloem mobility. Plants do not readily translocate nutrients from the lower to the upper leaves. Instead, when certain nutrients are in deficient supply, plants respond by slowing their growth rate, producing fewer and smaller leaves, and sometimes producing shorter internodes. Leaf life is also reduced. As nutrients are not readily mobilized to the growing point, the symptoms for N, P, or K deficiency, normally found in the lower leaves, tend to be less pronounced in cassava than in other crops. For that reason, farmers may not be aware that plant growth has decreased because of nutritional deficiencies. Oftentimes, the initial diagnosis based on deficiency or toxicity symptoms needs to be confirmed by soil or plant tissue analyses or from experiments. Nevertheless, visual identification is a quick and easy method to diagnose many nutritional problems.

The various nutrients the plant needs also vary in their mobility in the phloem. Thus, N, P, K, Mg, Na, and Cl are considered relatively mobile, so, in case of an insufficient supply of these nutrients, the plant will translocate these nutrients from the lower part of the plant to the growing point, resulting in deficiency symptoms appearing mainly in the lower leaves. In contrast, Ca and B are very immobile and will not readily translocate to the upper part of the plant, resulting in deficiency symptoms of these two nutrients being confined mainly to the growing points of both shoots and roots. Finally, S, Cu, Fe, Mn, and Zn have intermediate mobility, so their deficiency symptoms can appear in various parts of the plant or throughout the plant.

Symptoms have been described and color photos have been included in several publications (Lozano et al., 1981; Asher et al., 1980; Howeler, 1981; 1989; 1996a; 1996b; Howeler and Fernández, 1985). The symptoms of nutrient deficiencies and toxicities are briefly described in **Table 1**, while some symptoms are shown in the photos at the end of the book.

Table 1. Symptoms of nutrient deficiencies and toxicities in cassava.

Deficiency	Symptoms
Nitrogen (N)	▪ Reduced plant growth ▪ In some cultivars, uniform chlorosis of leaves, starting with lower leaves, but soon spreading throughout the plant
Phosphorus (P)	▪ Reduced plant growth, thin stems, short petioles; sometimes pendant leaves ▪ Under severe conditions, 1–2 lower leaves turn yellow to orange, become flaccid and necrotic; leaves may fall off ▪ In some cultivars, lower leaves turn purplish/brown
Potassium (K)	▪ Reduced plant growth with excessive branching, resulting in a prostrate or spreading plant type ▪ Small, sometimes chlorotic upper leaves; thick stems with short internodes ▪ Under severe conditions, premature lignification of upper stems with very short internodes, resulting in zigzag growth of upper stems ▪ In some cultivars, purple spotting, yellowing, and border necrosis of lower leaves ▪ In other cultivars, upward curling of lower leaf borders, similar to drought stress symptoms
Calcium (Ca) (seldom seen in field)	▪ Reduced root and shoot growth ▪ Chlorosis, deformation, and border necrosis of youngest leaves with leaf tips or margins bending downward
Magnesium (Mg) (often seen in field)	▪ Marked interveinal chlorosis or yellowing in lower leaves (fish-bone pattern) ▪ Slight reduction in plant height
Sulfur (S) (similar to N deficiency)	▪ Uniform chlorosis of upper leaves, which soon spreads throughout the plant
Boron (B) (seldom seen in field)	▪ Reduced plant height, short internodes, short petioles, and small deformed upper leaves ▪ Purple-gray spotting of mature leaves in the middle part of the plant ▪ Under severe conditions, gummy exudate on stem or petioles (almost never seen in field) ▪ Suppressed development of fibrous roots
Copper (Cu) (mainly in peat soils)	▪ Deformation and uniform chlorosis of upper leaves, with leaf tips and margins bending upward or downward ▪ Petioles of fully expanded leaves long and bending down ▪ Reduced root growth
Iron (Fe) (mainly in calcareous soils)	▪ Uniform chlorosis of upper leaves and petioles; under severe conditions, leaves turn white with border chlorosis of youngest leaves ▪ Reduced plant growth; young leaves small, but not deformed
Manganese (Mn) (mainly in sandy and high-pH soils)	▪ Interveinal chlorosis or yellowing of upper or middle leaves (fish-bone pattern); uniform chorosis under severe conditions ▪ Reduced plant growth; young leaves small, but not deformed
Zinc (Zn) (often seen in high-pH or calcareous soils; also in acid soils)	▪ Interveinal yellow or white spots on young leaves ▪ Leaves become small, narrow, and chlorotic in growing point; necrotic spotting on lower leaves as well ▪ Leaf lobes turn outward away from stem ▪ Reduced plant growth; under severe conditions, death of young plants
Toxicity	Symptoms
Aluminum (Al) (only in very acid mineral soils)	▪ Reduced root and shoot growth ▪ Under very severe conditions, yellowing of lower leaves
Boron (B) (only observed after excessive B application)	▪ Necrotic spotting of lower leaves, especially along leaf margins
Manganese (Mn) (mainly in acid soils and when plant growth stagnates)	▪ Yellowing or oranging of lower leaves with purple-brown spots along veins ▪ Leaves become flaccid and drop off
Salinity (observed only in saline/alkaline soils)	▪ Uniform yellowing of leaves, starting at bottom of plant but soon spreading throughout ▪ Symptoms similar to Fe deficiency ▪ Under severe conditions, border necrosis of lower leaves, poor plant growth, and death of young plants

2. Soil analysis

This method is advantageous in that problems can be detected before planting and, if necessary, lime and/or nutrients can be applied before plant growth is affected by the problem. Soil analyses are particularly useful for detecting P, K, Ca, Mg, and Zn deficiency, while soil pH will indicate whether Al and/or Mn toxicity or micronutrient deficiency is likely to occur. Analysis for organic matter (OM) content is not very reliable in predicting N responses as high-OM soils may still produce a significant N response if N mineralization is slow, especially in very acid soils.

Representative soil samples should be taken in areas that appear to be uniform in plant growth and previous management. Some 10−20 subsamples are taken in zigzag fashion across the whole area. These subsamples are thoroughly mixed together and then 300−500 g is air-dried, or dried at about 65 °C in a forced-air oven. This compound sample is then finely ground, screened, and sent to the laboratory for analysis.

Soil analyses usually determine the amount of available or exchangeable nutrient as this part of the total soil nutrient is best correlated with plant uptake. These "available" fractions are usually determined by shaking the soil sample with certain extracting solutions and determining the amount of nutrient in the extract. Different laboratories may use different extracting agents as no one method is optimal for all soil types; thus, results from one lab may differ from those of another. In interpreting the results, it is therefore important to consider the methodology used.

Results of the soil analysis can be compared with published data obtained from correlation studies, which indicate either the "critical level" of the nutrient, as determined with a specific extracting agent, or the nutrient ranges according to the particular nutritional conditions of the crop. The ranges are defined according to the various nutritional states of the plant, as shown in **Figure 1. Table 2** shows the ranges for soil nutrients determined for cassava.

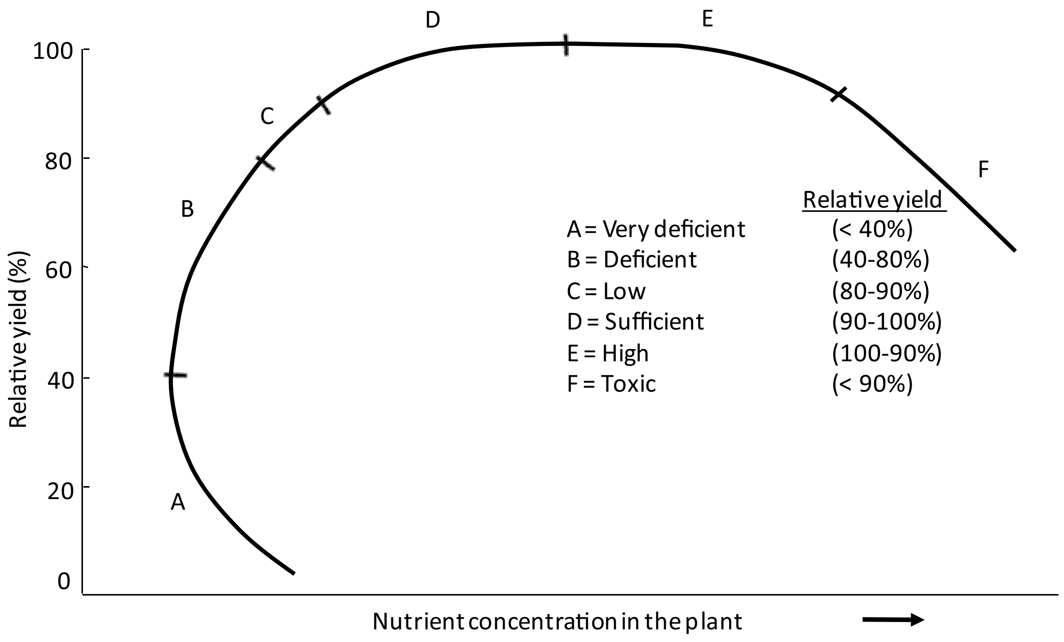

Figure 1. *Relation between the relative yield or dry matter production of the plant and the concentration of the limiting nutrient in the soil or plant tissue. The curve is divided into six defined nutritional states, ranging from very deficient to toxic.*

Table 2. Approximate classification of soil chemical characteristics according to the nutritional requirements of cassava.

Soil parameter	Very low	Low	Medium	High	Very high
pH[1)]	<3.5	3.5–4.5	4.5–7.0	7–8	>8
Organic matter[2)] (%)	<1.0	1.0–2.0	2.0–4.0	>4.0	
Al saturation[3)] (%)			<75	75–85	>85
Salinity (mS/cm)			<0.5	0.5–1.0	>1.0
Na saturation (%)			<2	2–10	>10
P[4)] (ppm)	<2	2–4	4–15	>15	
K[4)] (meq/100 g)	<0.10	0.10–0.15	0.15–0.25	>0.25	
Ca[4)] (meq/100 g)	<0.25	0.25–1.00	1.0–5.0	>5.0	
Mg[4)] (meq/100 g)	<0.2	0.2–0.4	0.4–1.0	>1.0	
S[4)] (ppm)	<20	20–40	40–70	>70	
B[5)] (ppm)	<0.2	0.2–0.5	0.5–1.0	1–2	>2
Cu[5)] (ppm)	<0.1	0.1–0.3	0.3–1.0	1–5	>5
Mn[5)] (ppm)	<5	5–10	10–100	100–250	>250
Fe[5)] (ppm)	<1	1–10	10–100	>100	
Zn[5)] (ppm)	<0.5	0.5–1.0	1.0–5.0	5–50	>50

1) pH in H_2O 1:1.
2) OM by Walkley and Black method.
3) Al saturation = 100 × Al/(Al+Ca+Mg+K) in meq/100 g.
4) P in Bray II; K, Ca, Mg, and Na in 1N NH_4-acetate; S in Ca-phosphate.
5) B in hot water; Cu, Mn, Fe, and Zn in 0.05 N HCl+0.025 N H_2SO_4.

Source: *Howeler, 1996a, b.*

The data in **Tables 2** and **3** were determined from many fertilizer experiments conducted in Colombia and in various Asian countries, as well as from reports in the literature. The data on ranges or critical levels were determined by relating the relative yield in the absence of a particular nutrient (yield without the nutrient over the highest yield obtained with the nutrient) with the corresponding available nutrient content in the soil.

Figure 2 shows an example of the determination of critical levels from NPK experiments conducted in nine locations in four Asian countries. A line was drawn visually through the points to show the relationship and to estimate the "critical level" of the nutrient or soil parameter. This critical level is normally considered as the concentration of the nutrient in the soil or plant tissue above which there is no further significant response to application of the nutrient (usually defined as corresponding to 90% or 95% of maximum yield). Critical levels for cassava were found to be about 3.2% for OM, 7 ppm for P (Bray II), and 0.14 meq/100 g for exchangeable K. The critical levels for P and K are close to those reported earlier in the literature **(Table 3)**. Those for available soil-P reported for cassava (4−10 ppm) are much lower than for most other crops (10−18 ppm), indicating that cassava will grow well in soils that are low in P and where other crops would suffer from P deficiency. This is due to the effective association between cassava roots and vesicular-arbuscular mycorrhizae (VAM) occurring naturally in the soil (Howeler, 1990).

The critical levels for exchangeable K for cassava (0.08−0.18 meq K/100 g) **(Table 3)** are also lower than for most other crops (0.16−0.51 meq K/100 g), indicating that, despite the crop's relatively high K requirement, it will still grow well on soils with only intermediate amounts of K.

Table 3. Critical levels[1] of nutrients for cassava and other crops according to various methods of soil analysis, as reported in the literature.

Soil parameter	Method[3]	Crop	Critical level	Source
Organic matter (%)	Walkley and Black	Cassava	3.1	Howeler, 1998
P (ppm)	Bray-I	Cassava	7	Howeler, 1978
		Cassava	8	Kang et al., 1980
		Cassava	4.2[2]	Cadavid, 1988
		Cassava	7	Howeler, 1989
		Maize	14	Kang et al., 1980
		Soybean	15	Kang et al., 1980
	Bray II	Cassava	8	CIAT, 1982b
		Cassava	4	Howeler, 1985a
		Cassava	6	CIAT, 1985a
		Cassava	5.8[2]	Cadavid, 1988
		Cassava	10	Howeler, 1989
		Cassava	10	Hagens & Sittibusaya, 1990
		Cassava	4	Howeler & Cadavid, 1990
		Cassava	4.5	Howeler, 1995
		Cassava	7	Howeler, 1998
		Common bean[4]	10-15	Howeler & Medina, 1978
	Olsen-EDTA	Cassava	3	Van der Zaag et al., 1979
		Cassava	7.5[2]	Cadavid, 1988
		Cassava	8	Howeler, 1989
	North Carolina	Cassava	5.0[2]	Cadavid, 1988
		Cassava	9	Howeler, 1989
		Common bean	18	Goepfert, 1972
K (meq/100 g)	NH_4-acetate	Cassava	0.09-0.15	Obigbesan, 1977
		Cassava	<0.15	Kang, 1984
		Cassava	<0.15	Kang & Okeke, 1984
		Cassava	0.18	Howeler, 1985b
		Cassava	0.175[2]	Cadavid, 1988
		Cassava	0.15	Howeler, 1989
		Cassava	0.18	Howeler & Cadavid, 1990
		Cassava	0.08-0.10	Hagens & Sittibusaya, 1990
		Rice	0.21	Jones et al., 1982
		Potato	0.20-1.00	Roberts & McDole, 1985
		Sugarcane	0.16-0.51	Orlando Filho, 1985
	Bray II	Cassava	0.15	CIAT, 1985a
		Cassava	0.17	Howeler, 1985b
		Cassava	0.16	CIAT, 1988b
		Cassava	0.175[2]	Cadavid, 1988
	Bray II	Cassava	0.17	Howeler & Cadavid, 1990
		Cassava	0.12	Howeler, 1995
		Cassava	0.14	Howeler, 1998
	North Carolina	Cassava	0.15	Howeler, 1989
Ca (meq/100 g)	NH_4-acetate	Cassava	0.25	CIAT, 1979
		Common bean	4.5	Howeler & Medina, 1978
Mg (meq/100 g)	NH_4-acetate	Cassava	<0.20	Kang, 1984
pH	1:1 in water	Cassava	4.6 and 7.8	CIAT, 1977, 1979
		Common bean	4.9	Abruña et al., 1974
Al-saturation (%)	KCl	Cassava	80	CIAT, 1979
		Common bean	10–20	Abruña et al., 1974

1) Critical level defined as 95% of maximum yield.
2) Critical level defined as 90% of maximum yield.
3) Methods: Bray I = 0.025 N HCl+0.03 N NH4F
Bray II = 0.10 N HCl+0.03 N NH4F
Olsen-EDTA = 0.5 N $NaHCO_3$+0.01N Na-EDTA
North Carolina = 0.05 N HCl+0.025 N H_2SO_4
NH_4-acetate = 1N NH_4-acetate at pH 7

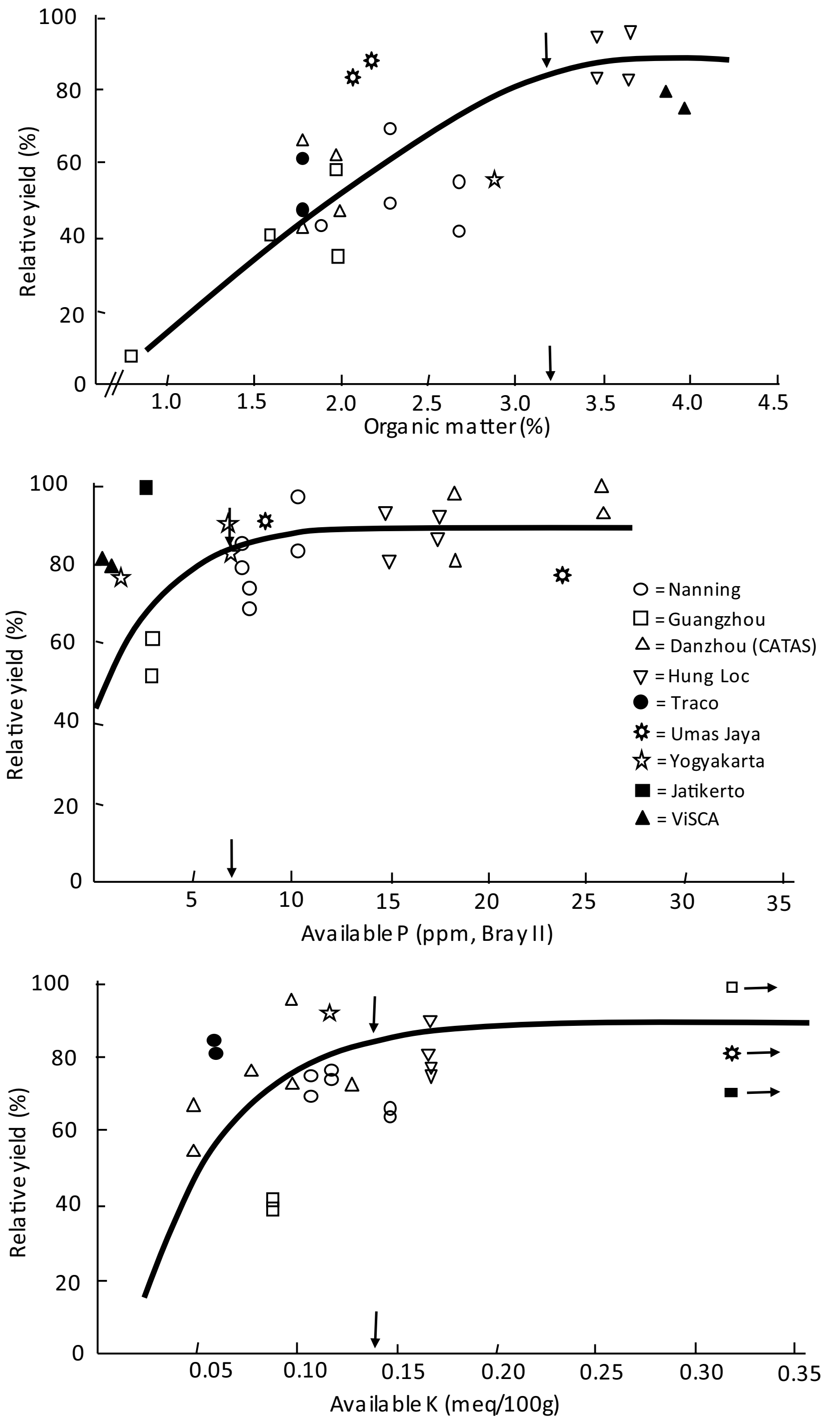

Figure 2. *Relation between the relative yield of cassava (i.e., the yield without the nutrient as a percent of the highest yield with the nutrient) and the OM, available P, and exchangeable K contents of the soil in nine long-term NPK trials conducted in Asia from 1993 to 1996.*

Source: *Howeler, 1998.*

As mentioned above, there is seldom a good relationship between the relative response to N and the soil OM content (Howeler, 1995). Using data from 56 NPK trials conducted in Brazil from 1950 to 1983 (Gomes, 1998), the critical level determined for OM was only 1.3%, considerably lower than the 3.1% determined in Asia (Howeler, 1998).

Using data from 20 NPK cassava trials conducted in Colombia to compare different methods of extracting available P, Cadavid (1988) reported the highest correlation between relative cassava yields and available soil P using Bray I, followed by Bray II, North Carolina, and Olsen-EDTA extracting agents. For determining exchangeable K, Cadavid (1988) found no significant difference between the use of Bray II and NH_4-acetate; both resulted in a critical level of 0.175 meq K/100 g.

Different laboratories may report data in different units. To convert meq K/100 g into ppm, multiply the meq/100 g by 391. Thus, the critical level of K of 0.15 meq/100 g is the same as 0.15 × 391 = 59 ppm. Similarly, for Ca, multiply meq Ca/100 g by 200, and for Mg multiply meq Mg/100 g by 121.5. Also, % OM is often reported as % organic C or total N. In this case, % OM is approximately equal to 1.7 × % org C or 20 × % total N.

3. Plant tissue analysis

Analysis of plant tissue indicates the actual nutritional status of the plants at the time of sampling. The total amount of each nutrient is determined, resulting in data that are fairly similar among different laboratories. These analyses are particularly useful for diagnosing N and secondary or micronutrient deficiencies.

Given that nutrient concentrations vary among different plant tissues as well as in different parts of the plant (**Table 4**), it is very important to use a specific "indicator" tissue, whose nutrient concentration is best related to plant growth or yield. For cassava, the best "indicator" tissue was found to be the blade of the youngest fully expanded leaf (YFEL), that is, normally about the fourth to fifth leaf from the top. Leaf petioles should never be mixed with the leaf blades and analyzed together, as nutrient concentrations are quite different in these two tissues. Nutrient concentrations also change during the growth cycle, depending on the rate of plant growth **(Figure 3)** (Howeler and Cadavid, 1983; CIAT, 1985a,b). Since the concentrations of most nutrients tend to stabilize when cassava plants are 3−4 months old, leaf samples should be taken at 3−4 months after planting (MAP). However, they should not be taken during periods of severe drought or low temperature when plant growth has slowed down. In that case, leaf samples can be taken 2−3 months after normal growth has resumed.

About 20 leaf blades (without petioles) are collected from a plot or uniform area in the field and combined into one sample (Howeler, 1983). If leaves are dusty or have received chemical sprays, they should be washed gently and rinsed in distilled or deionized water. To prevent continued respiration with a consequent loss of dry matter (DM), leaves should be dried as soon as possible at 60−80°C for 24−48 hours. If no oven is available, leaves should be dried as quickly as possible in the sun, preferably in a hot but well-ventilated area, and away from dust. After drying, samples are finely ground in a lab mill. For Cu analysis, samples should be passed through a stainless-steel sieve. For Fe analysis, the dry leaves should be ground with an agate mortar and pestle. Plant tissue samples are normally collected in paper bags to facilitate drying, but, for analysis of B, plastic bags should be used. Once ground and sieved, samples are stored in plastic vials until analysis.

Table 4. Nutrient concentrations in various plant parts of fertilized and unfertilized cassava, cv. MVen 77, at 3–4 MAP in Carimagua, Colombia.

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
	(%)						(ppm)				
Unfertilized											
Leaf blades											
Upper	4.57	0.34	1.29	0.68	0.25	0.29	198	128	49	9.9	26
Middle	3.66	0.25	1.18	1.08	0.27	0.25	267	185	66	8.7	37
Lower	3.31	0.21	1.09	1.48	0.25	0.25	335	191	89	7.6	42
Fallen[1)]	2.31	0.13	0.50	1.69	0.25	0.22	4,850	209	121	9.4	39
Petioles											
Upper	1.50	0.17	1.60	1.32	0.37	0.10	79	172	40	4.4	16
Middle	0.70	0.10	1.32	2.20	0.43	0.10	76	304	72	2.9	15
Lower	0.63	0.09	1.35	2.69	0.45	0.13	92	361	110	2.8	15
Fallen	0.54	0.05	0.54	3.52	0.41	0.13	271	429	94	2.5	18
Stems											
Upper	1.64	0.20	1.22	1.53	0.32	0.19	133	115	36	9.7	14
Middle	1.03	0.18	0.87	1.45	0.30	0.16	74	103	39	8.9	13
Lower	0.78	0.21	0.81	1.19	0.32	0.16	184	95	54	7.9	10
Roots											
Rootlets[1)]	1.52	0.15	1.02	0.77	0.38	0.16	5,985	191	165	-	10
Thick roots	0.42	0.10	0.71	0.13	0.06	0.05	127	10	16	3.0	4
Fertilized											
Leaf blades											
Upper	5.19	0.38	1.61	0.76	0.28	0.30	298	177	47	10.6	26
Middle	4.00	0.28	1.36	1.08	0.27	0.26	430	207	63	9.6	30
Lower	3.55	0.24	1.30	1.40	0.22	0.23	402	220	77	8.5	37
Fallen[1)]	1.11	0.14	0.54	1.88	0.23	0.19	3,333	247	120	8.9	38
Petioles											
Upper	1.49	0.17	2.18	1.58	0.36	0.10	87	238	33	4.9	17
Middle	0.84	0.09	1.84	2.58	0.41	0.07	88	359	49	3.0	14
Lower	0.78	0.09	1.69	3.54	0.42	0.07	95	417	70	3.2	15
Fallen	0.69	0.06	0.82	3.74	0.20	0.08	294	471	155	3.1	17
Stems											
Upper	2.13	0.23	2.09	2.09	0.47	0.14	94	140	37	9.8	14
Middle	1.57	0.21	1.26	1.30	0.26	0.11	110	120	46	10.8	12
Lower	1.37	0.28	1.14	1.31	0.23	0.09	210	99	36	10.0	10
Roots											
Rootlets[1)]	1.71	0.19	1.03	0.71	0.33	0.20	3,780	368	136	-	10
Thick roots	0.88	0.14	1.05	0.16	0.06	0.05	127	15	15	3.9	4

1) Fallen leaves and rootlets were probably contaminated with micronutrients from the soil.
Source: *Howeler, 1985a.*

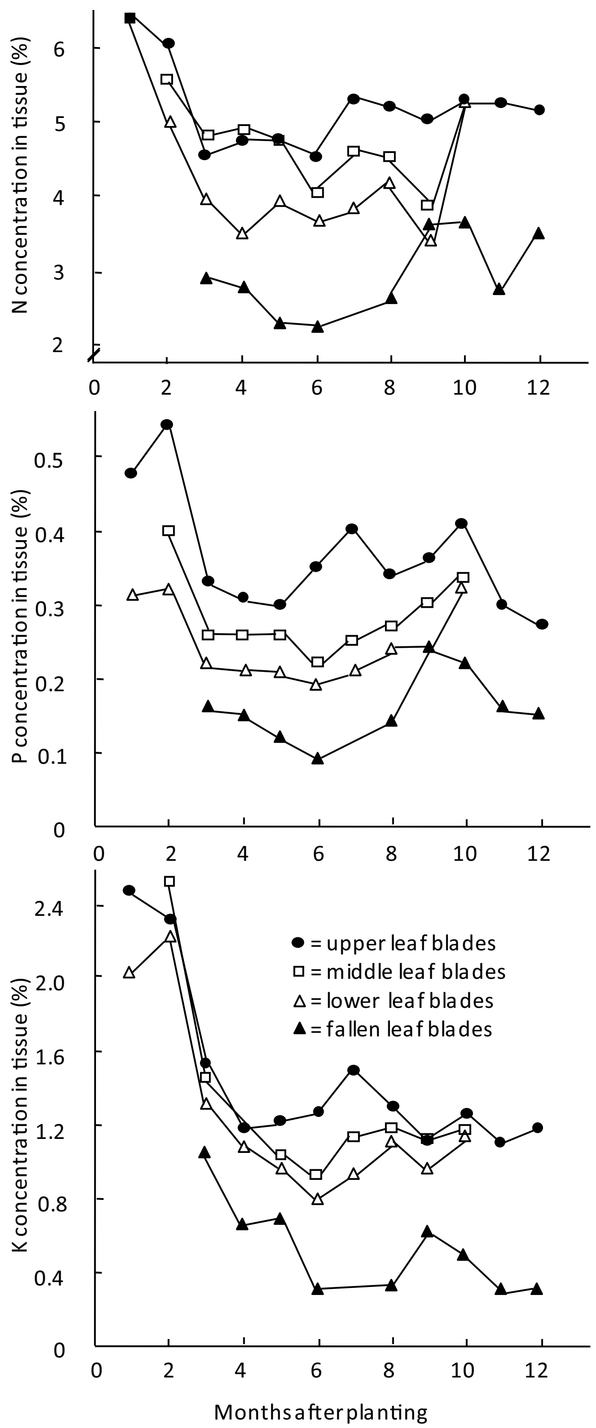

Figure 3. *Concentration of N, P, and K in leaf blades from the upper, middle, and lower part of the plant, as well as from fallen leaves of fertilized cassava, cv. MCol 22, during a 12-month growth cycle in Santander de Quilichao, Colombia.*

Source: *CIAT, 1985a.*

To diagnose nutritional problems, the results are compared with the nutrient ranges corresponding to the various nutritional states of the plant **(Table 5)** or with critical levels reported in the literature (**Table 6**). Although the numbers may vary somewhat, depending on the varieties, soil, and climatic conditions (Howeler, 1983), the data in these tables can be used as a general guide for interpreting plant tissue analyses.

Table 5. Nutrient concentrations in youngest fully-expanded leaf (YFEL) blades of cassava at 3–4 MAP, corresponding to various nutritional states of the plants; data are average values of various greenhouse and field trials.

	Nutritional states[1]					
Nutrient	Very deficient	Deficient	Low	Sufficient	High	Toxic
N (%)	<4.0	4.1–4.8	4.8–5.1	5.1–5.8	>5.8	-[2]
P (%)	<0.25	0.25–0.36	0.36–0.38	0.38–0.50	>0.50	-
K (%)	<0.85	0.85–1.26	1.26–1.42	1.42–1.88	1.88–2.40	>2.40
Ca (%)	<0.25	0.25–0.41	0.41–0.50	0.50–0.72	0.72–0.88	>0.88
Mg (%)	<0.15	0.15–0.22	0.22–0.24	0.24–0.29	>0.29	-
S (%)	<0.20	0.20–0.27	0.27–0.30	0.30–0.36	>0.36	-
B (ppm)	<7	7–15	15–18	18–28	28–64	>64
Cu (ppm)	<1.5	1.5–4.8	4.8–6.0	6–10	10–15	>15
Fe (ppm)	<100	100–110	110–120	120–140	140–200	>200
Mn (ppm)	<30	30–40	40–50	50–150	150–250	>250
Zn (ppm)	<25	25–32	32–35	35–57	57–120	>120

[1] Very deficient = <40% maximum yield
Deficient = 40–80% maximum yield
Low = 80–90% maximum yield
Sufficient = 90–100% maximum yield
High = 100–90% maximum yield
Toxic = <90% maximum yield
[2] - = no data available.
***Source:** Howeler, 1996a, b.*

Table 6. Critical nutrient concentrations for deficiencies and toxicities in cassava plant tissue, as reported in the literature.

Element	Method	Plant tissue	Critical level[1]	Source
N deficiency	Field	YFEL blades[2]	5.1%	Fox et al., 1975
	Field	YFEL blades	5.7%	Howeler, 1978
	Field	YFEL blades	4.6%	Howeler, 1995
	Field	YFEL blades	5.7%	Howeler, 1998
	Nutrient solution	Shoots	4.2%	Forno, 1977
P deficiency	Field	YFEL blades	0.41%	CIAT, 1985a
	Field	YFEL blades	0.33–0.35%	Nair et al., 1988
	Nutrient solution	Shoots	0.47–0.66%	Jintakanon et al., 1982
K deficiency	Nutrient solution	YFEL blades	1.1%	Spear et al., 1978a
	Field	YFEL blades	1.2%	Howeler, 1978
	Field	YFEL blades	1.4%	CIAT, 1982b
	Field	YFEL blades	1.5%	CIAT, 1982b
	Field	YFEL blades	<1.1%	Kang, 1984
	Field	YFEL blades	1.5%	CIAT, 1985a
	Field	YFEL blades	1.7%	Howeler, 1995
	Field	YFEL blades	1.9%	Nayar et al., 1995
	Field	YFEL blades	1.9%	Howeler, 1998
	Nutrient solution	Petioles	0.8%	Spear et al., 1978a
	Field	Petioles	2.5%	Howeler, 1978
	Nutrient solution	Stems	0.6%	Spear et al., 1978a
	Nutrient solution	Shoots and roots	0.8%	Spear et al., 1978a
Ca deficiency	Nutrient solution	YFEL blades	0.46%	CIAT, 1985a
	Field	YFEL blades	0.60–0.64%	CIAT, 1985a
	Nutrient solution	Shoots	0.4%	Forno, 1977
Mg deficiency	Nutrient solution	YFEL blades	0.29%	Edwards and Asher, 1979
	Field	YFEL blades	<0.33%	Kang, 1984
	Field	YFEL blades	0.29%	Howeler, 1985a
	Nutrient solution	YFEL blades	0.24%	CIAT, 1985a
	Nutrient solution	Shoots	0.26%	Edwards and Asher, 1979
S deficiency	Field	YFEL blades	0.32%	Howeler, 1978
	Nutrient solution	YFEL blades	0.27%	CIAT, 1982b
	Field	YFEL blades	0.27–0.33%	Howeler, unpublished
Zn deficiency	Field	YFEL blades	37–51ppm	CIAT, 1978
	Nutrient solution	YFEL blades	43–60 ppm	Edwards and Asher, 1979
	Nutrient solution	YFEL blades	30 ppm	Howeler et al., 1982b
	Field	YFEL blades	33 ppm	CIAT, 1985a
Zn toxicity	Nutrient solution	YFEL blades	120 ppm	Howeler et al., 1982b
B deficiency	Nutrient solution	YFEL blades	35 ppm	Howeler et al., 1982b
	Nutrient solution	Shoots	17 ppm	Forno, 1977

Element	Method	Plant tissue	Critical level [1]	Source
B toxicity	Nutrient solution	YFEL blades	100 ppm	Howeler et al., 1982b
	Nutrient solution	Shoots	140 ppm	Forno, 1977
Cu deficiency	Nutrient solution	YFEL blades	6 ppm	Howeler et al., 1982b
Cu toxicity	Nutrient solution	YFEL blades	15 ppm	Howeler et al., 1982b
Mn deficiency	Nutrient solution	YFEL blades	50 ppm	Howeler et al., 1982b
	Nutrient solution	Shoots	100–120 ppm	Edwards and Asher, 1979
Mn toxicity	Nutrient solution	YFEL blades	250 ppm	Howeler et al., 1982b
	Nutrient solution	Shoots	250–1,450 ppm	Edwards and Asher, 1979
Al toxicity	Nutrient solution	Shoots	70–>97 ppm	Gunatilaka, 1977
	Nutrient solution	Roots	2,000–14,000 ppm	Gunatilaka, 1977

[1] Range corresponds to values obtained in different varieties.
[2] YFEL blades are the leaf blades of youngest fully-expanded leaves.

4. Greenhouse and field experiments

If analysis of soil or plant tissue is not possible, one can also diagnose nutritional problems by planting cassava in pot experiments using the soil in question or directly in the field. To diagnose nutrient deficiencies in a particular soil in either pot or field experiments, it is recommended to use the "missing element" technique, in which all nutrients are applied to all treatments at rates that are expected to be nonlimiting, while one nutrient is missing in each treatment (i.e., −N, −P, −K, etc.). Treatments with the poorest growth or yield indicate the element that is most deficient.

For pot experiments, it is recommended not to sterilize or fumigate the soil, in order not to kill the native mycorrhizae. Rooted plant shoots rather than stakes should be used as the stakes have high nutrient reserves and their use would therefore delay responses to nutrient additions. In pot experiments, cassava plants are generally harvested at 3−4 MAP, and dry weights of top growth are used as indicators of nutrient response.

CHAPTER 7

CAN CHEMICAL FERTILIZER AND MANURE MAINTAIN HIGH YIELD AND LONG-TERM PRODUCTIVITY OF THE SOIL?

In the past, when cassava was mainly a subsistence food crop, farmers tried to maintain their soil's productivity mainly by practicing slash-and-burn or by applying animal manure. Slash-and-burn is still practiced in many parts of Lao PDR and in the border provinces of Cambodia, in the mountainous areas of Vietnam, East Timor and on many of the outer islands of Indonesia. In densely settled areas where slash-and-burn is no longer possible, farmers generally apply between 5 and 10 tons of manure per ha. In India and Indonesia, this is mostly cow manure, while in Vietnam and China it is mostly pig manure, and in some parts of Thailand chicken manure. Municipal compost is also a good source of nutrients and organic matter, but is seldom used on cassava fields.

More recently, cassava in Asia is more and more becoming an industrial crop for the production of dry chips, starch, or ethanol. To benefit from greater demand for cassava roots and higher prices, farmers have been trying to increase their yield mainly by planting the new high-yielding varieties and by applying chemical fertilizer that can be specifically tailored to the nutrient requirements of cassava and according to the native fertility of the soil. As cassava yield goes up, the removal of nutrients in the harvested roots also increases dramatically, leading to the depletion of some nutrients and a marked decline in yield when cassava is grown continuously on the same land. Since cassava is usually grown in areas with infertile light-textured soils and with unpredictable rainfall, not too many other crops can be grown profitably under those unfavorable conditions. This is why many farmers grow cassava in the same fields year after year. With every root harvest, nutrients in the roots are removed from the field, which may lead to depletion of certain nutrients in the soil, leaving a poor soil even poorer. Different crops differ in the types and amounts of nutrients removed with the harvested products. Cassava roots do not necessarily remove more nutrients than other crops, but the roots are relatively high in K, so this is usually the nutrient that is most rapidly depleted if only roots are removed, while relatively large amounts of N and K are removed if the harvested products also include stems and leaves (see **Chapter 5**).

Many experiments have been conducted on different soils to determine which nutrients are most limiting the yield of cassava, and what rates and balance of nutrients are necessary to increase the yield or maintain the same high yield as before. This information will help researchers and extension workers to make the best fertilizer recommendations, which in turn will help farmers to apply those fertilizers that will result in the highest yield at the lowest cost.

When cassava farmers also raise cattle, goats, pigs, or chickens, they may use the manure that these animals produce to apply on their cassava fields. In that case, the manure is cheap, but applying 5–10 tons of manure per ha may be hard work, depending on the distance to the field. Manures are a good source of macro-, secondary-, and micro-nutrients, as well as organic material that will improve the structure and nutrient- and water-holding capacity of the soil. However, manures contain only small amounts of the macronutrients N, P, and K that crops need in greatest quantity. Also, manures tend to be wet, which further reduces their nutrient contents, while the relative amounts of the different nutrients in the manures is fixed and cannot be tailored to the specific requirements of each crop and soil. Moreover, the nutrient content of manure will vary according to the animal producing it, and will also vary with the time and method of storage. In most cases, farmers do not know the nutrient content of the manure they are applying and have no idea what the balance of nutrients is in the manure, and how much they should apply to meet their crop's requirements.

In contrast, each chemical fertilizer has a fixed ratio of nutrients, usually expressed as the percent of N, P_2O_5, and K_2O (in some countries, this is expressed as the percent of each element, N, P, and K). Thus, a fertilizer such as urea will be labeled as fertilizer 46-0-0, because it has 46% N but no P or K, while a fertilizer such as triple superphosphate will be labeled as 0-46-0 because it contains 46% P_2O_5 but no N or K; and potassium chloride will be labeled 0-0-60 because it contains 60% K_2O but no N or P. These are called **single- element** fertilizers, because they contain only one of the three macronutrients. Then, there are **compound fertilizers**, which contain two or all three macronutrients. Thus, a fertilizer labeled 15-15-15 contains 15% N, 15% P_2O_5, and 15% K_2O (this is equivalent to 15% N, 6.5% P, and 12.5% K). When farmers buy single-element fertilizers, they will need to mix two or three of these together to produce a mixture that will supply the nutrients that the crop needs for a particular soil. By mixing single-element fertilizers, one can apply any ratio of N, P, and K desired. However, in countries where many different types of compound fertilizer are available in the store, farmers often prefer to buy these instead of single-element fertilizer so they don't have to mix large amounts of different fertilizers. They can usually buy the type of compound fertilizer that will supply the right balance of N, P_2O_5, and K_2O recommended for their soil and crop. Another advantage of chemical fertilizers is that they are sold in dry form, so they contain a minimum amount of water and a maximum amount of the required nutrients. This will reduce the cost of transportation and the amount of work involved in applying chemical fertilizers compared with animal manures or compost. In very general terms, one 50-kg bag of a compound fertilizer such as 15-15-15 contains about the same amount of N, P, and K as 1,000 kg (1 ton) of animal manure **(Table 1)**.

Table 2 shows the approximate moisture content (on a % wet basis) and the nutrient content (on a % dry basis) of manures and several other chemical fertilizers available on the market.

It is clear that many chemical fertilizers contain 10–20 times more macronutrients (N, P, and K) than most of the organic fertilizers, but the latter also contain small amounts of secondary- and micro-nutrients that are essential for normal plant growth, but in much smaller quantities.

Table 1. Average nutrient content of 1 ton of various types of wet manure and compost compared with 50 kg of 15-15-15 chemical fertilizer.

	DM (%)	N (kg)	P (kg)	K (kg)
1 ton cattle manure	32	5.9	2.6	5.4
1 ton pig manure	40	8.2	5.5	5.5
1 ton chicken manure	57	16.6	7.8	8.8
1 ton sheep manure	35	10.5	2.2	9.4
1 ton city garbage compost	71	6.9	3.3	6.1
50 kg 15-15-15 fertilizer	100	7.5	3.3	6.2

Source: *Howeler, 2001a.*

Table 2. Average nutrient content of various manures, composts, wood ash, and chemical fertilizers.

Source of manure	Moisture (%)	N	P	K	Ca	Mg	S
		(% of dry matter)					
Cattle manure	68.2	1.85	0.81	1.69	1.54	0.62	0.29
Pig manure	60.0	2.04	1.38	1.38	-	-	-
Chicken manure	43.0	2.91	1.37	1.54	4.56	0.83	-
Sheep manure	-	3.00	0.62	2.68	1.72	0.86	0.43
Human manure	-	1.20	0.06	0.21	-	-	-
City/rural compost	-	1.16	0.37	0.90	-	-	-
Rice straw compost	73.7	1.07	0.19	0.69	-	-	-
Peanut stems + leaves (compost)	58.6	0.81	0.10	0.38	-	-	-
Water hyacinth	-	2.00	1.00	2.30	-	-	-
Wood ash	-	-	0.87	4.17	23.2	2.10	0.40
Urea	0	46	0	0	0	0	0
Ammonium sulfate	0	21	0	0	0	0	24
Ammonium nitrate	0	33	0	0	0	0	0
Mono-ammonium phosphate (MAP)	0	11	21	0	0	0	0
Di-ammonium phosphate (DAP)	0	18	20	0	0	0	0
Triple superphosphate (TSP)	0	0	20	0	14	0	0
Single superphosphate	0	0	8	0	19	0	11
Basic slag	0	0	6	0	37	1	0
Potassium chloride	0	0	0	50	0	0	0
Potassium sulfate	0	0	0	42	0	0	18
Calcium sulfate (approx.)	0	0	0	0	12	0	10
Magnesium sulfate	0	0	0	0	0	10	13
Magnesium oxide	0	0	0	0	0	32	0
Calcitic lime (approx.)	0	0	0	0	30	0	0
Dolomitic lime (approx.)	0	0	0	0	24	12	0
Elemental sulfur	0	0	0	0	0	0	100
15-15-15	0	15	6.6	12.5	0	0	0
10-20-20	0	10	8.7	16.7	0	0	0
10-30-10	0	10	13.1	8.3	0	0	0
15-7-18	0	15	3.1	15.0	0	0	0

Source: *Howeler, 2004; 2007.*

1. How do we increase cassava yield without degrading the fertility of the soil?

Chapter 5 already showed that, when cassava is grown continuously on the same land without application of adequate amounts of manure or the right kind and rate of chemical fertilizer, it is likely that yield will decline due to nutrient depletion as a result of nutrient removal in the harvested products. In most soils, the most serious decline is in the amount of the soil's exchangeable K, usually expressed in mg/kg (= µg/g or ppm) or as meq/100 g (= cmol/kg), and over time the greatest response is therefore to the application of K in chemical fertilizer. This is clearly shown in many long-term NPK trials with cassava conducted in Latin America and Asia. **Figures 3** and **4** of **Chapter 5** show that, when cassava was grown without adequate applications of K, the exchangeable K content of the soil decreased. A response to K application is usually expected when the exchangeable K content drops below the critical level of about 0.15 meq/100 g (or 60 ppm). See **Tables 2** and **3** in **Chapter 6** for the critical levels of soil nutrients. Many other long-term NPK trials have been conducted on a wide range of different soils with similar results, as shown below.

a. Long-term NPK experiments conducted in Vietnam

Two long-term NPK experiments were started in Vietnam in 1990, one on a very sandy and infertile Ultisol at Thai Nguyen University (TNU) in Thai Nguyen Province of northern Vietnam, and one on a rather acid but relatively fertile Oxisol at Hung Loc Agricultural Research Center in Dong Nai Province of southern Vietnam.

The long-term NPK trial at Hung Loc Center began in 1990 and has completed its 23rd year of continuous cropping in 2012/13. Like most of the long-term NPK trials described in this book, the experiment had 12 treatments of various combinations of four levels of N, P, and K, applied as urea, single superphosphate, and KCl, respectively, and two varieties in subplots. The medium level of each nutrient was 80 kg N, 40 kg P_2O_5, and 80 kg K_2O/ha, and the low level was half and the high level twice these amounts. After every harvest, the crop residues were removed from the plots, and the next crop was planted in all treatments with the best planting material obtained from the previous crop. The same treatments were applied in the same plots every year.

During the first three years, there were no significant responses to any of the three nutrients. During the fourth year, there was some response to the highest application of NPK and in subsequent years the response became more significant every year, especially to K, followed by N and P.

Figure 1 shows the importance of K in increasing both root yield and root starch content.

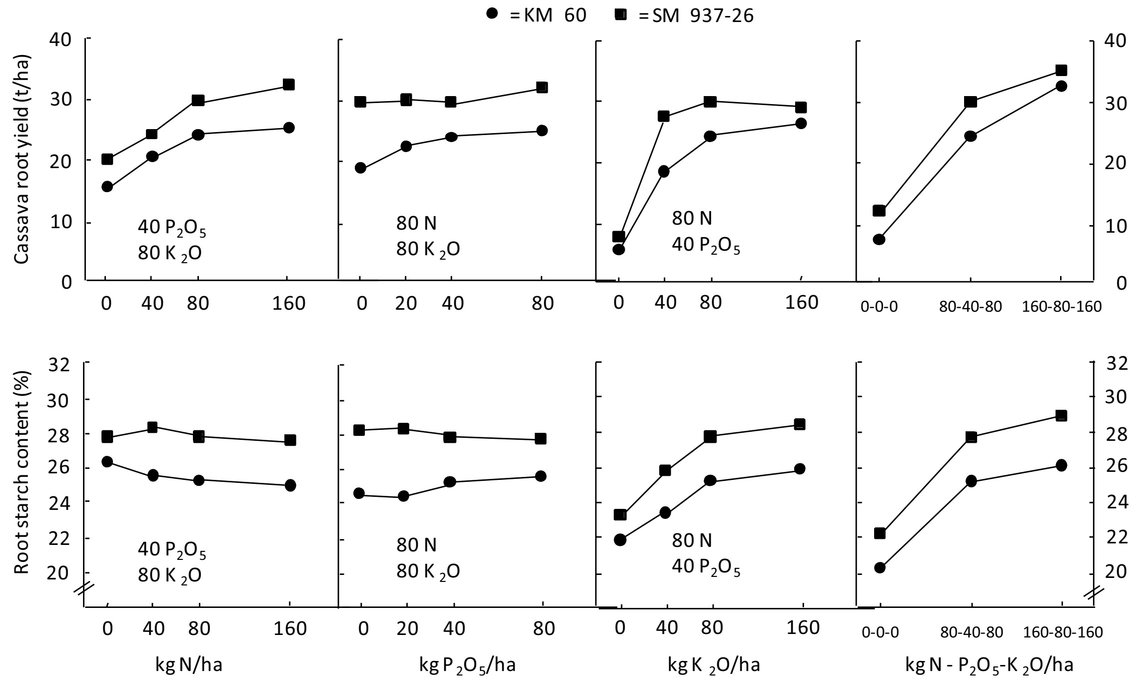

Figure 1. *Effect of annual applications of various amounts of N, P, and K on root yield and starch content of two cassava varieties grown at Hung Loc Agricultural Research Center in Trang Bon District, Dong Nai, Vietnam, during the 19th consecutive cropping cycle in 2008/09.*

Figure 2 shows that, over time, K became the most limiting nutrient when cassava was grown for many years on the same soil. **Figure 2** also shows that high root yield of 20–30 t/ha as well as a reasonable level of soil fertility could be maintained for at least 18 years of continuous cropping when medium amounts of N, P, and K were applied annually.

Table 3 shows that, during the 23rd consecutive year of cropping, there was not only a very significant response to the application of K but also a marked response to that of N and P. The application of medium amounts of N, P, and K (80 kg N, 40 kg P_2O_5, and 80 kg K_2O/ha) increased yield from 7.5 t/ha without fertilizer to 19.6 t/ha. This treatment also produced by far the highest net income, while cropping cassava without fertilizer or without K produced a negative net income during the 23rd year of cropping.

The long-term NPK experiment at Thai Nguyen University also began in 1990 and continued for 17 consecutive cropping cycles until 2006. Already in the first year, there was a highly significant response to all three macronutrients, but especially to K, and this response increased over time (Nguyen Huu Hy et al., 1998; 2001; 2007; 2010). During the last year of the experiment, there was a highly significant response to K—the yield without K was only 3.4 t/ha vs 21.78 t/ha with K—and a significant response to N and P. The highest yield was achieved with the application of 160 kg N, 80 kg P_2O_5, and 160 kg K_2O/ha, but the highest net income was obtained with 80 kg N, 40 kg P_2O_5, and 80 kg K_2O/ha (see **Figures 8** and **9** of **Chapter 8**).

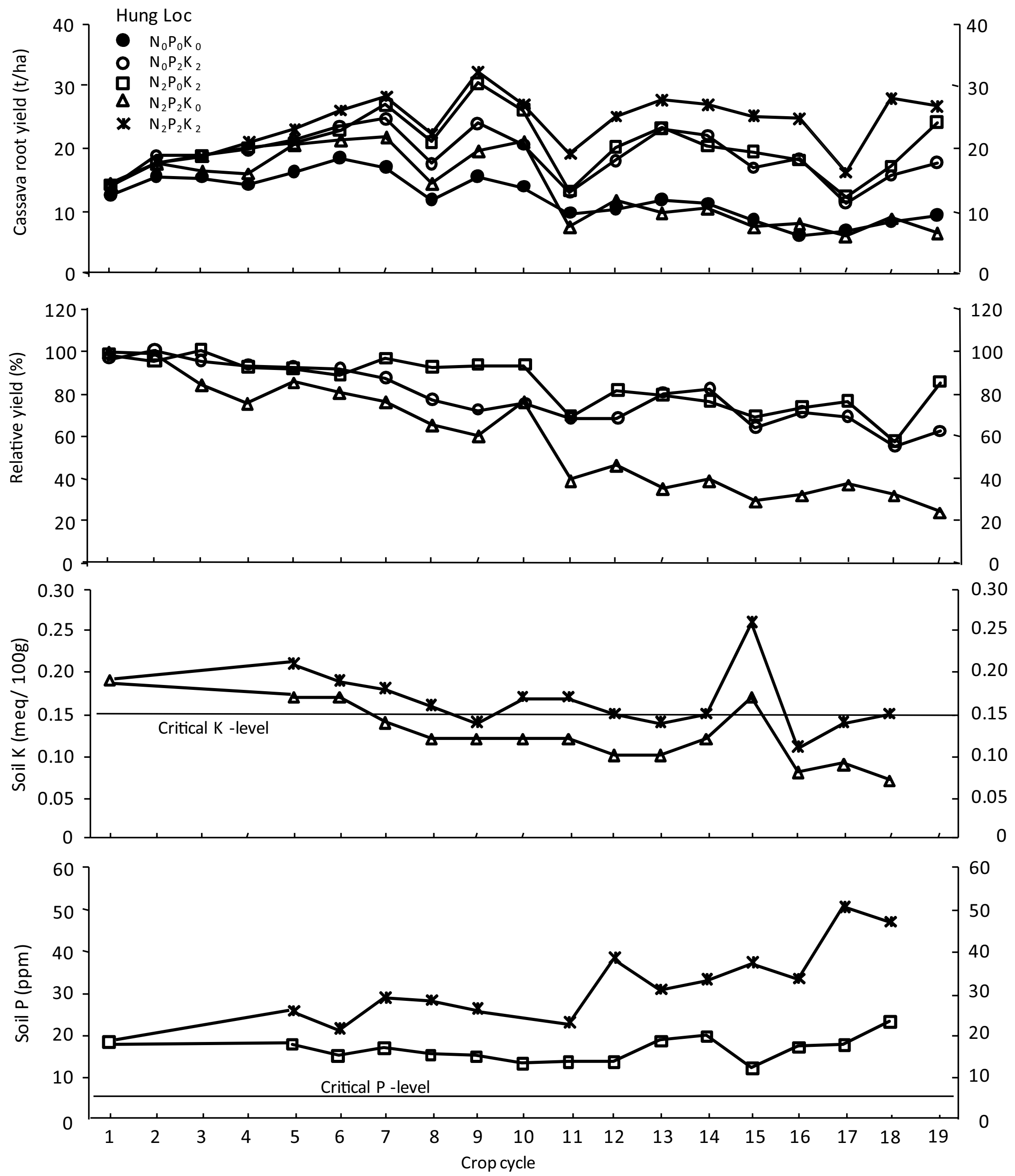

Figure 2. *Effect of annual applications of N, P, and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient), and the exchangeable K and available P (Bray II) content of the soil during 19 years of continuous cropping at Hung Loc Agricultural Research Center in Dong Nai, Vietnam.*

Table 3. Effect of annual application of various amounts of N, P, and K fertilizer on the average root yield and starch content of two varieties as well as the gross and net income obtained during the 23rd consecutive year of cassava cropping at Hung Loc Agricultural Research Center in Dong Nai, southern Vietnam, in 2012/13.

Treatment[1)]	Average root yield (t/ha)	Average starch content (%)	Gross income[2)]	Fertilizer costs[3)]	Total production costs[3)]	Net income
			(000 dong/ha)			
1. $N_0P_0K_0$	7.51	22.45	7,505	0	8,130	–625
2. $N_0P_2K_2$	12.80	23.30	12,792	2,424	10,854	1,938
3. $N_1P_2K_2$	14.99	24.40	14,983	3,293	11,723	3,260
4. $N_2P_2K_2$	19.57	24.95	19,565	4,163	12,593	6,972
5. $N_3P_2K_2$	17.51	25.55	17,500	5,902	14,332	3,168
6. $N_2P_0K_2$	12.50	24.50	12,495	3,339	11,769	726
7. $N_2P_1K_2$	13.65	24.45	13,643	3,751	12,181	1,462
8. $N_2P_3K_2$	18.62	25.35	18,617	4,986	13,416	5,201
9. $N_2P_2K_0$	6.59	22.25	6,588	2,563	10,993	–4,405
10.$N_2P_2K_1$	15.15	24.85	15,147	3,363	11,793	3,354
11.$N_2P_2K_3$	17.76	25.15	17,755	5,763	14,193	3,562
12.$N_3P_3K_3$	19.64	24.84	19,637	8,325	16,755	2,882

1) N_0 = 0 N; P_0 = 0P; K_0 = 0K
N_1 = 40 kg N/ha; P_1 = 20 kg P_2O_5/ha; K_1 = 40 kg K_2O/ha
N_2 = 80 kg N/ha; P_2 = 40 kg P_2O_5/ha; K_2 = 80 kg K_2O/ha
N_3 = 160 kg N/ha; P_3 = 80 kg P_2O_5/ha; K_3 = 160 kg K_2O/ha

2) Prices: cassava dong 1,000/kg fresh roots (includes the harvest of the roots by the buyer)

3) Costs: land preparation dong 2,000,000/ha
planting material 450,000/ha
cassava planting 900,000/ha
weeding 4,500,000/ha
fertilizer application 300,000/ha
Basudin 2H (pesticide) 280,000/ha
Urea (46% N) 10,000/kg
SSP (17% P_2O_5) 3,500/kg
KCl (60% K_2O) 12,000/kg
labor 120,000/person-day
US$1 = 21,000 Vietnamese dong

b. Long-term NPK experiments conducted in Thailand

Three long-term NPK experiments have been conducted in different soil types in Thailand (Nakviroj et al., 2007). Two experiments started in 1975, at the Rayong Field Crops Research Center (RFCRC) in Rayong Province and at Banmai Samrong Experiment Station in Nakorn Ratchasima Province, while another experiment started in 1976 at Khon Kaen Field Crops Research Center (KKFCRC) in Khon Kaen Province. All three experiments had the same eight treatments, including different combinations of N, P, and K fertilizer when all crop residues were removed every year before planting the next crop. N_0, P_0, and K_0 mean that these nutrients were not applied, while N_1, P_1, and K_1 refer to the annual application of 100 kg N, 50 kg P_2O_5, and 100 kg K_2O/ha. In two additional treatments ($N_0P_0K_0$ + CR and $N_1P_1K_1$+ CR), a constant amount (18.75 t/ha) of crop residues was left on the plots and these were incorporated before the next planting, whereas, in another treatment ($N_1P_1K_1$+ MC), the chemical fertilizer was combined with the incorporation of 12.5 t/ha of municipal compost, broadcast and incorporated before each new planting.

Figure 3 shows the root yield obtained in the different treatments during the first 25 years of the experiment conducted at KKFCRC in Khon Kaen.

It is clear that already in the second year of planting the cassava yield was seriously affected when no fertilizer or no K had been applied. In those two treatments, yield declined from about 27 t/ha in the first year to 4 and 8 t/ha, respectively, in the 25th year when all plant tops were removed. However, when plant tops were reincorporated into the soil before every planting, yield also declined over the years, but yield was on average about twice as high as when plant tops were removed. With the annual application of 100 kg N plus 50 kg P_2O_5 and 100 kg K_2O/ha, root yield could be maintained at 20−25 t/ha, but when the chemical fertilizers were combined with the incorporation of either plant tops or municipal compost, high yield of 30−40 t/ha could be maintained. This indicates that the incorporation of organic matter in the form of crop residues or compost can markedly increase cassava yield, in both the presence and absence of chemical fertilizer, but high yield can be maintained only if the organic sources are combined with adequate amounts of well-balanced chemical fertilizers to supply the necessary macronutrients. In 2012/13, the experiment in Khon Kaen was in its 37th year of consecutive cropping, while those in Rayong and Banmai Samrong were in their 38th year.

The experiment in Rayong was also conducted on a rather infertile sandy clay-loam soil at the Rayong FCRC. During the first 15 years, there were only minor responses to the application of N, P, or K, but the treatments without any chemical fertilizer or without K usually had the lowest yield. Yield gradually decreased. During the next 15 years, yield started to increase again, especially in the treatments of NK or NPK. This was even more pronounced when the chemical fertilizer was combined with the incorporation of crop residues or the application of municipal compost. With the application of 100 kg/ha each of N and K, yield of 30-40 t/ha could be obtained, but, when the full NPK fertilizer was combined with residue incorporation or municipal compost, yield of 40−50 t/ha could be obtained (Nakviroj et al., 2007).

The experiment in Banmai Samrong was conducted on a very fertile limestone-derived soil. During 30 years of consecutive cropping, there were only minor responses to the application of any of the macronutrients although the lowest yield was usually obtained when no fertilizer was applied. The highest yield was usually obtained with the combination of chemical fertilizer with the incorporation of crop residues or the application of compost. In this high-pH soil, cassava yield may have been limited by deficiencies of micronutrients, especially Fe and Zn (Nakviroj et al., 2007).

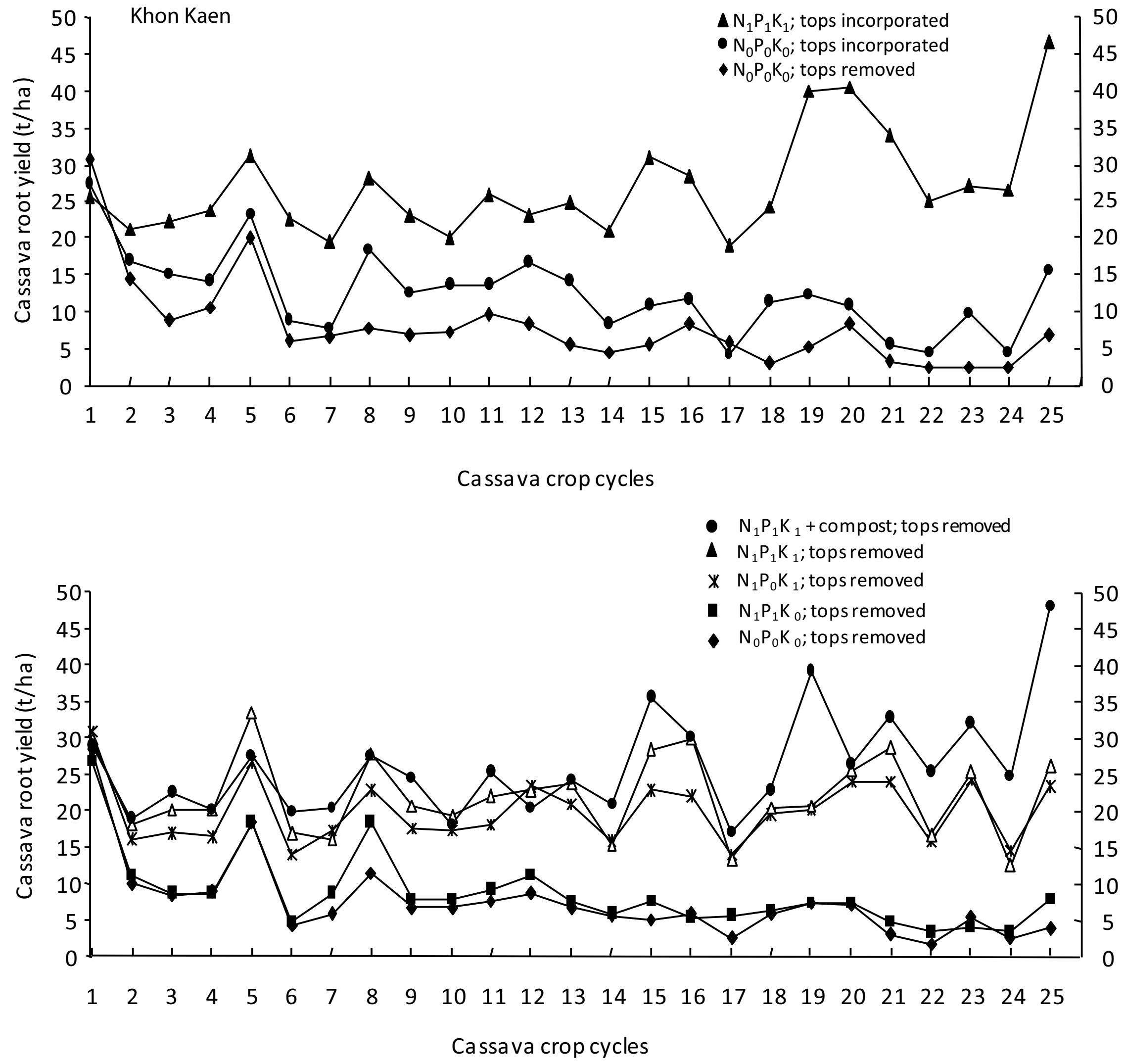

Figure 3. *Effect of annual fertilizer application and crop residue management on cassava yield during 25 consecutive cropping cycles in Khon Kaen, Thailand.*

***Source:** Chumpol Nakviroj and Kobkiet Paisancharoen, personal communication.*

c. Long-term NPK experiments conducted in Indonesia

Four long-term NPK experiments have been conducted in different parts of Indonesia, one on Umas Jaya farm in Lampung from 1987 to 1997 (10 years), one at Jatikerto station near Malang, East Java, from 1988 to 1995 (8 years), one in Yogyakarta from 1991 to 1994 (4 years), and one in Tamanbogo in Lampung from 1991 to 2006 (16 years).

The long-term NPK trial in Tamanbogo was conducted on an infertile Ultisol. Cassava was initially intercropped with maize and upland rice, followed by peanut after the harvest of the first intercrops. Two-thirds of each fertilizer treatment was applied to cassava and one-third to the upland rice. Residues of all crops were removed from the plots before the next planting.

Already in the first year, there was a significant response of cassava to the application of K and that response was highly significant in the second and following years. Maize and peanut yields were very low. Peanut showed a negative response to the application of fertilizer due to the increased competition for light when cassava was fertilized. In the second and subsequent years, cassava was intercropped only with rice and maize. However, intercropped maize yield declined over time and was near zero in the sixth and eighth crop, after which cassava was intercropped only with upland rice (see **Figure 8** in **Chapter 9**). Starting with the ninth crop, all plots were divided into subplots of cassava monoculture and cassava intercropped with rice. In the monoculture plots, all fertilizer was applied to cassava.

Table 4 shows the effect of the various fertilizer treatments on the average cassava yield during the first, second, third, and fourth 4-year cropping cycles for intercropped cassava, and the last two 4-year cycles for monoculture cassava. The data clearly show that initially there was some response to K, and that this response increased over time until yield without K was only about 25% of that with high amounts of applied K. The response to N became significant in the sixth year and to P in the seventh year. The yield of all treatments decreased over time, but yield in those with the high rates of applied K decreased less than in other treatments. Cassava grown in monoculture had higher yield than intercropped cassava grown during the same years. There was again a very significant response to K and N, but only a slight response to P.

Table 4. Effect of the application of various combinations of N, P, and K on the average root yield of cassava during four 4-year cropping cycles for cassava intercropped with maize and upland rice, as well as two 4-year cycles for monoculture cassava grown in Tamanbogo in Lampung Province of Indonesia from 1991 to 2006.

	Cassava fresh root yield (t/ha)					
	Cassava intercropped with maize and rice				Cassava monoculture	
Treatment[1)]	Average 1^{st}-4^{th} year	Average 5^{th}-8^{th} year	Average 9^{th}-12^{th} year	Average 13^{th}-16^{th} year	Average 9^{th}-12^{th} year	Average 13^{th}-16^{th} year
1. $N_0P_0K_0$	12.06	8.32	7.15	4.44	7.03	4.76
2. $N_0P_2K_2$	14.55	10.98	9.70	10.25	12.84	10.71
3. $N_1P_2K_2$	15.47	13.35	12.18	13.54	16.84	14.84
4. $N_2P_2K_2$	18.69	14.87	14.37	13.91	18.87	16.39
5. $N_3P_2K_2$	18.13	18.18	14.54	13.15	17.75	18.25
6. $N_2P_0K_2$	18.60	15.50	10.82	9.63	16.04	14.04
7. $N_2P_1K_2$	17.80	17.10	14.27	13.80	19.42	16.53
8. $N_2P_3K_2$	19.81	16.60	14.19	11.96	18.73	14.83
9. $N_2P_2K_0$	11.75	5.86	4.61	4.18	6.92	6.55
10. $N_2P_2K_1$	17.48	14.90	12.15	12.98	19.74	15.82
11. $N_2P_2K_3$	18.79	16.41	14.14	13.99	20.96	18.56
12. $N_3P_3K_3$	19.87	18.08	15.04	15.09	19.87	20.02
Average	**16.92**	**14.18**	**11.93**	**11.41**	**16.25**	**14.27**

[1)] N_0 = 0 N; P_0 = 0 P; K_0 = 0 K
N_1 = 45 kg N/ha; P_1 = 25 kg P_2O_5/ha; K_1 = 45 kg K_2O/ha
N_2 = 90 kg N/ha; P_2 = 50 kg P_2O_5/ha; K_2 = 90 kg K_2O/ha
N_3 = 180 kg N/ha; P_3 = 100 kg P_2O_5/ha; K_3 = 180 kg K_2O/ha
For cassava monoculture, all fertilizer was applied to cassava; for cassava intercropped with maize and rice, two-thirds of the fertilizer was applied to cassava and one-third to upland rice.

Figure 4 shows the response of cassava grown in monoculture, and that of cassava and rice grown in an intercropping system, to the annual application of various rates of N, P, and K as well as the combined application of all three nutrients during the 15th cropping cycle in Tamanbogo in 2005/06. It is clear that cassava responded mainly to the application of K, but also to that of N to the amount of 90 kg N/ha, and to P to the amount of 25 kg P_2O_5/ha. Rice showed a negative response to N (mainly due to increasing cassava competition) and a very strong response to P and K, as well as to the combined application of NPK. Without fertilizer, the intercropped rice yield was 0 t/ha, while with the application of 90-50-180 kg N-P_2O_5-K_2O/ha, yield increased to 1.17 t/ha.

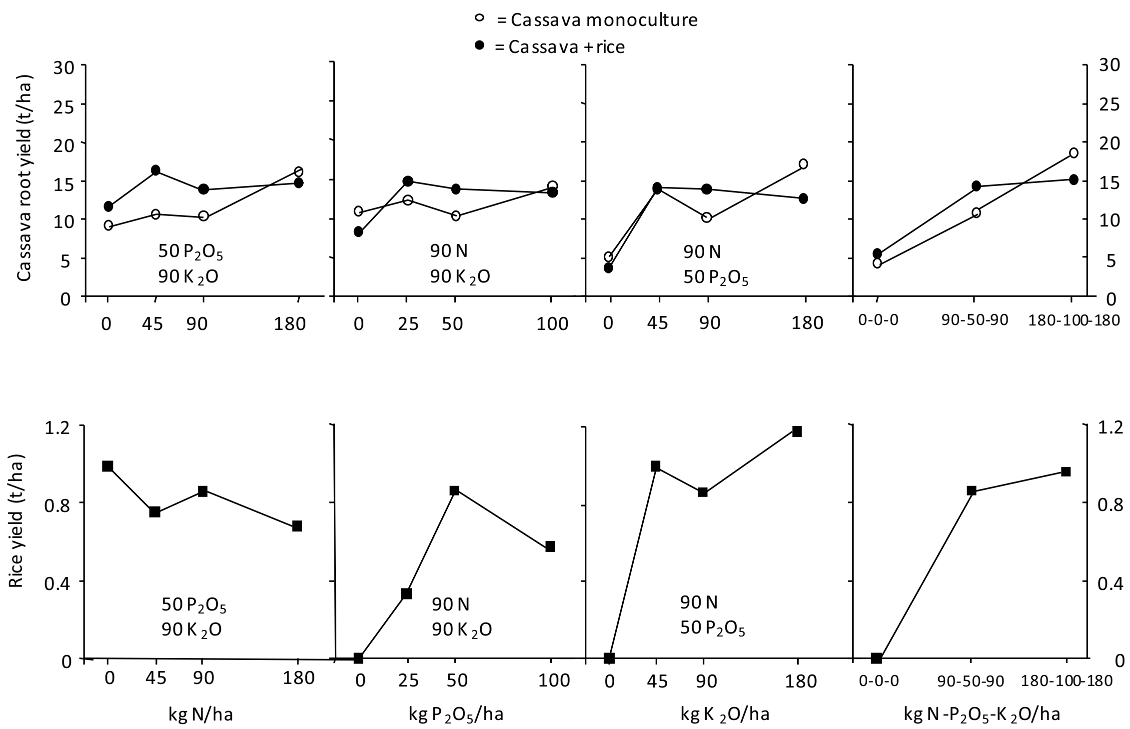

Figure 4. *Effect of annual applications of various amounts of N, P, and K on the yield of cassava and intercropped rice during the 15^{th} consecutive cropping cycle in Tamanbogo, Lampung, Indonesia, in 2005/06.*

An economic analysis of the results of the last three years indicates that, for cassava monoculture, the highest net income was obtained with the highest rate of NPK, while for intercropped cassava the highest net income was obtained with treatment $N_1P_2K_2$ or 45 kg N, 50 kg P_2O_5, and 90 kg K_2O/ha **(Table 5)**.

After 10 years of consecutive cropping in Umas Jaya, there were still no significant responses to any of the three macronutrients, but there was a significant response to the combined application of NPK up to the highest rate of 100 kg N, 50 kg P_2O_5, and 200 kg K_2O/ha.

In contrast, in Jatikerto on a volcanic ash-derived soil, there was already a significant response to N in the second year, which increased dramatically in the following years; at the end of the eighth year, there was a very significant response to N, a significant response to K and a non-significant response to P (see also **Figure 3** of **Chapter 8**). In Jatikerto, cassava was intercropped with maize.

Table 5. Effect of annual applications of various combinations of N, P, and K on the average root yield of monocropped and intercropped cassava, and the yield of intercropped rice, as well as the gross and net income obtained during the last three years (2004–2006) of a long-term NPK experiment conducted for 16 consecutive years in Tamanbogo, Lampung, Indonesia.

	C[1)]	C + R							
	Cassava yield (t/ha)	Cassava yield (t/ha)	Rice yield (t/ha)	Gross income		Production costs (000 Rp/ha)		Net income	
Treatment				C	C + R	C	C + R	C	C + R
1. $N_0P_0K_0$	4.46	4.63	0.11	1,561	1,840	1,675	2,370	-114	-530
2. $N_0P_2K_2$	11.20	10.99	1.25	3,920	6,346	2,580	3,275	1,340	3,071
3. $N_1P_2K_2$	15.88	14.75	1.11	5.558	7,382	2,678	3,373	2,880	4,009
4. $N_2P_2K_2$	14.70	13.91	1.05	5,145	6,968	2,827	3,522	2,318	3,446
5. $N_3P_2K_2$	17.35	13.66	0.98	6,072	6,741	3,073	3,768	2,999	2,973
6. $N_2P_0K_2$	13.96	8.55	0.06	4,886	3,112	2,627	3,322	2,259	-210
7. $N_2P_1K_2$	15.85	14.67	0.62	5,548	6,374	2,727	3,422	2,821	2,952
8. $N_2P_3K_2$	15.97	13.47	0.97	5,590	6,654	3,027	3,722	2,563	2,932
9. $N_2P_2K_0$	6.63	4.22	0.40	2,320	2,277	2,257	2,952	63	-675
10. $N_2P_2K_1$	15.72	13.37	1.13	5,502	6,940	2,542	3,237	2,960	3,703
11. $N_2P_2K_3$	19.33	14.03	1.22	6,766	7,350	3,397	4,092	3,369	3,258
12. $N_3P_3K_3$	20.83	15.39	1.11	7,290	7,606	3,843	4,538	3,447	3,068

1) C = cassava monoculture; C +R = cassava intercropped with upland rice.

2) Prices: cassava Rp 350/kg fresh roots.
rice 2,000/kg dry grain

3) Cost:

urea (46% N)	Rp	1,260/kg	planting rice	Rp	200,000/ha
SP36 (36% P_2O_5)		1,800/kg	applying fertilizer		135,000/ha
KCl (60% K_2O)		3,800/kg	weeding (2x)		500,000/ha
land preparation		450,000/ha	applying insecticides		45,000/ha
cassava planting material		220,000/ha	harvesting cassava		280,000/ha
rice seed		200,000/ha	harvesting rice		250,000/ha
planting material preparation		75,000/ha	C mono without fert.		1,810,000/ha
planting cassava		150,000/ha	C + R without fert.		2,505,000/ha

US$1 = about Rp 9,000

On calcareous soils near Yogyakarta, cassava was intercropped with maize and rice followed by mungbean. Under those conditions, cassava yield was very low and there was no significant response to any of the macronutrients even after 4 years of cropping, but there was a significant response to the combined application of NPK up to the highest rate of 180 kg N, 90 kg P_2O_5, and 180 kg K_2O/ha.

d. Long-term NPK experiments conducted in China

Long-term NPK experiments were conducted in the three most important cassava-producing provinces: at the Guangxi Subtropical Crops Research Institute (GSCRI) in Nanning, Guangxi; at the Upland Crops Research Institute (UCRI) in Guangzhou, Guangdong; and at the Chinese Academy of Agricultural Sciences (CATAS) in Danzhou, Hainan Province. The two experiments in Nanning and Guangzhou started in 1989 and the one at CATAS in 1992. The experiment in Guangzhou continued for 4 years until 1992, the one in Nanning for 8 years until 1996, and the one at CATAS is still continuing in 2012/13 (20 years), *albeit* with only two replications since 2006.

The experiment at CATAS is being conducted on a sandy clay-loam soil with an intermediate amount of organic matter, high in available P and low-medium in exchangeable K. The experiment had 16 treatments, the first 12 similar to other long-term NPK trials described above, but with four additional treatments of a low amount of NPK (50 kg N, 25 P_2O_5, and 50 K_2O/ha), combined with 15, 30, or 60 t/ha of "burned soil", that is, soil that was mixed with plant residues and slowly burned, a common "fertilizer" used in China. Each main plot had two subplots with two varieties, SC205 and SC124.

In spite of an intermediate level of soil OM, there was a significant response only to N during the first year, and this response increased in subsequent years of continuous cropping, especially in SC205. This variety also showed a highly significant response to both N and K in the third year, while SC124 showed only a significant response to N and no significant response to K. The results of the eighth consecutive cycle (**Figure 5**) indicate that at that time there was a very strong response of both varieties to N and K, but only a response to P by SC205. Both varieties responded very strongly to the combined application of NPK, up to the highest level of 200 kg N, 100 kg P_2O_5, and 200 kg K_2O/ha. Neither variety showed a significant response to the application of even 60 t/ha of burned soil in the presence of a low amount of chemical fertilizer. Root starch content was not significantly affected by the application of N or P, but increased significantly with the first increment of 50 kg K_2O/ha, especially in SC205. It is clear that SC205 is quite responsive to fertilizer application, or poorly adapted to infertile soils, compared with SC124.

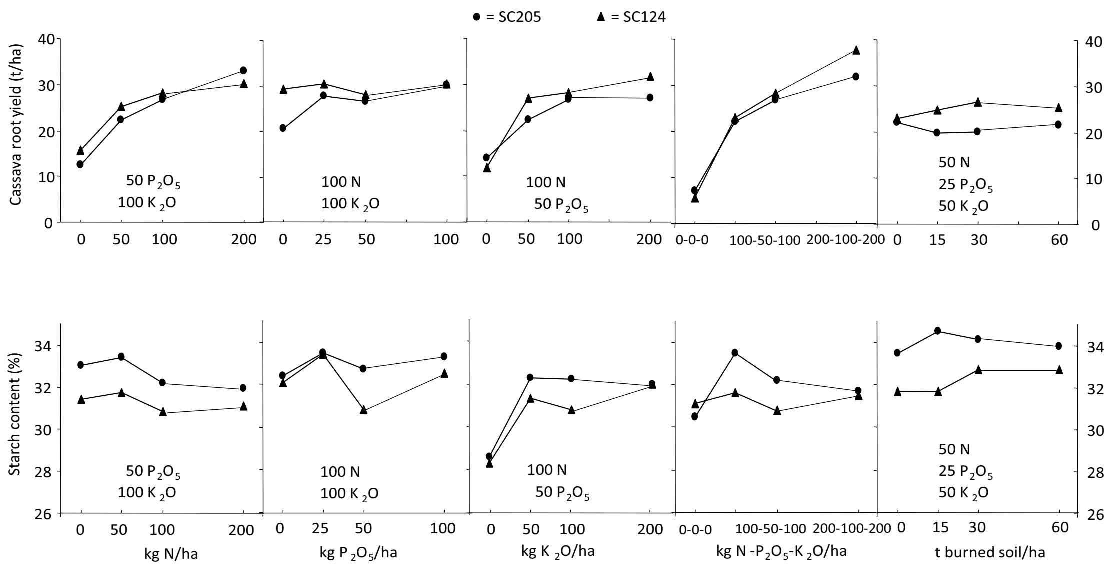

Figure 5. *Effect of annual applications of various amounts of N, P, and K, as well as that of "burned soil," on cassava fresh root yield and starch content during the eighth consecutive cropping cycle at CATAS in Danzhou, Hainan, China, in 1999/2000.*

Figure 6 shows that yield of about 20 t/ha could be maintained with the application of intermediate rates of NPK of 100 kg N, 50 kg P_2O_5, and 100 kg K_2O/ha, but that yield declined rapidly if no N or K was applied, while the application of P was not necessary during 8 years of cropping, except for SC205 during the seventh and eighth crop cycle. **Figure 6** also shows that the exchangeable K content of the soil declined gradually during the first 4 years of cropping and remained far below the critical level, even with the annual application of 100 kg K_2O/ha. Available P also declined and was close to the critical level of 5 ppm during the last years of cropping when no P had been applied. With the annual application of 50 kg P_2O_5/ha, the soil P increased over time and remained far above the critical level (Li Jun et al., 2001)

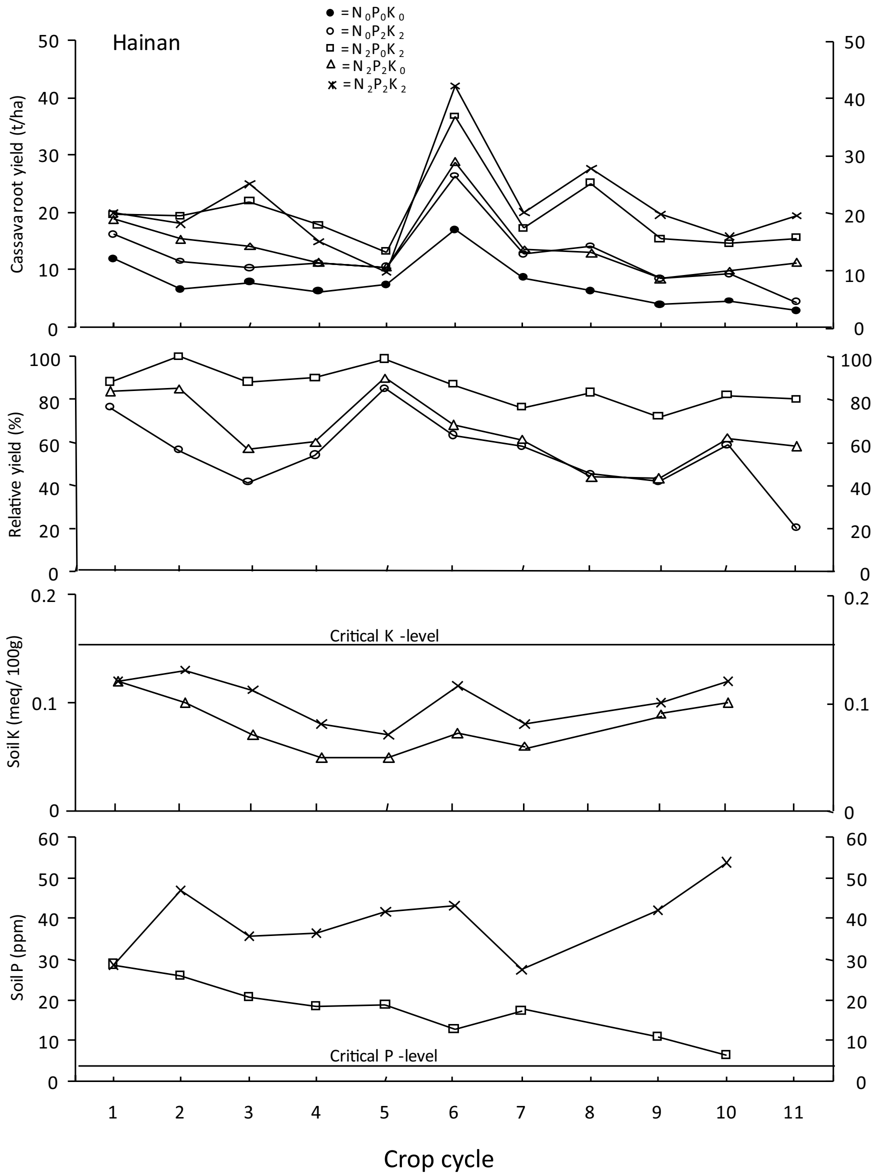

Figure 6. *Effect of annual applications of N, P, and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient), and the exchangeable K and available P (Bray 2) content of the soil during 11 years of consecutive cropping at CATAS in Danzhou, Hainan, China. Data are averages for two varieties.*

The long-term NPK experiment in Guangzhou was conducted for 4 years on a sandy clay-loam soil with relatively low OM, available P, and exchangeable K. There was a significant response to the application of N already in the first year, and to N and P in the second year. During the fourth year, there was a highly significant response to all three macronutrients. The highest yield was obtained with the combined application of NPK, which increased yield from 3.3 t/ha without fertilizer to 25.9 t/ha with the annual application of 200 kg N, 100 kg P_2O_5, and 200 kg K_2O/ha (Zhang Weite et al., 1998).

The long-term NPK trial in Nanning was conducted for 8 consecutive years on a clay-loam soil with low-medium OM, high available P, and medium K. During the first year, there was a significant response only to N and only in SC205, while during the second year there was already a very significant response to both N and K in SC205, but a significant response only to N in SC201. During the eighth year, both varieties showed a highly significant response to N, a significant response to P by SC205, and no response to K in either variety. During the 8 years of cropping, the amount of soil OM and available P had declined markedly while the amount of soil K had remained slightly below the critical level. This experiment also had three additional treatments of a low amount of NPK in chemical fertilizer (50 kg N, 25 kg P_2O_5, and 50 kg K_2O/ha) combined with either 5 or 10 t/ha of pig manure. **Table 6** shows the average cassava yield over the 8 years of cropping for the four rates of combined NPK application plus the additional treatments of a low rate of NPK together with the two rates of pig manure. It is clear that the combination of low rates of NPK in chemical fertilizer combined with 5 t/ha of pig manure produced about the same, or even higher, cassava yield as the application of higher rates of chemical fertilizer, depending on the variety used (Li Jun et al., 2001).

Table 6. Effect of four rates of NPK chemical fertilizer as well as that of two rates of pig manure on the average fresh root yield of two cassava varieties planted for 8 consecutive years at the Guangxi Subtropical Crops Research Institute in Nanning, Guangxi, China, from 1989 to 1996.

Chemical fertilizer	Pig manure	Average cassava root yield (t/ha) during 8 cropping cycles	
(N-P_2O_5-K_2O in kg/ha)	(t/ha)	Variety SC205	Variety SC201
0-0-0	-	14.94	16.89
50-25-50	-	17.79	21.41
50-25-50	5	20.78	23.71
50-25-50	10	20.87	21.77
100-50-100	-	20.25	22.78
200-100-200	-	21.61	20.13

In all three long-term NPK experiments conducted in China, variety SC205 was much more responsive to the application of high rates of NPK than either SC124 in Hainan or SC201 in Guangzhou and Nanning.

e. Long-term NPK experiments conducted in the Philippines

Long-term NPK experiments were conducted on three different islands of the Philippines: at the UPLB La Granja Experiment Station on Negros Occidental Island from 1989 to 1992; at the Bohol Experiment Station on Bohol Island from 1989 to 1992; and at the ViSCA Experiment Station in Baybay, Leyte Island, from 1989 to 1994.

The NPK experiment in Bohol was conducted on a very light-textured soil with low OM, intermediate P, and medium-high K. **Table 7** shows that the average yield of the two varieties, Golden Yellow and VC-1, was very good during the first year, but decreased markedly during the following 3 years, especially in those plots that did not receive N or K. During the first year, there were no significant responses to any of the three macronutrients nor to their combined application, but, in the following years, there was a significant or highly significant response to N, and in the third and fourth year a highly significant response to K. The fifth-year trial was not harvested due to severe root rots as a result of typhoon damage.

Table 7. Effect of annual applications of different combinations of N, P, and K on the average fresh root yield of two cassava varieties, Golden Yellow and VC-1, planted for 4 consecutive years at Bohol Experiment Station on Bohol Island of the Philippines from 1989 to 1992.

Treatment	Cassava root yield (t/ha)				
N-P_2O_5-K_2O (kg/ha)	Year 1 1989/90	Year 2 1990/91	Year 3 1991/92	Year 4 1992/93	Average 4 years
1. 0-0-0	25.4	11.8	10.1	7.5	**13.7**
2. 0-60-60	29.6	10.8	8.2	11.9	**15.1**
3. 30-60-60	31.0	10.2	18.1	17.3	**19.2**
4. 60-60-60	30.3	13.4	15.6	20.4	**19.9**
5. 90-60-60	29.8	17.9	17.6	22.4	**21.9**
6. 60-0-60	31.1	13.2	16.2	17.1	**19.4**
7. 60-30-60	33.0	11.5	18.0	20.2	**20.7**
8. 60-90-60	31.5	13.5	17.4	20.2	**20.7**
9. 60-60-0	32.6	12.3	8.2	6.8	**15.0**
10. 60-60-30	28.1	15.1	14.9	15.2	**18.3**
11. 60-60-90	33.0	14.2	19.6	22.2	**22.3**
12. 90-90-90	29.4	18.1	20.1	23.5	**22.8**
Average	**30.4**	**13.5**	**15.3**	**17.1**	**19.1**

The experiment in Leyte was conducted under mature coconut trees spaced at 8×8 m. Cassava yield was generally low and quite variable due to the heavy shade of the coconut trees and occasional severe damage by typhoons. The soil had rather high OM, but very low P and intermediate K. During the 6 years of consecutive cropping, there was a significant response to N in only 2 years, a significant or highly significant response to P also in 2 years, and no response to K application. However, there was a highly significant response to the combined application of NPK in 4 years. The highest yield was generally obtained with the application of 60 kg N, 90 kg P_2O_5, and 60 kg K_2O/ha.

The NPK experiment in Negros Occidental was conducted on a rather heavy clay soil with low-medium OM, low P, and medium K. The main treatments were nine combinations of three rates of N, P, and K (0, 50, and 100 kg/ha), while in subplots crop residues were either removed or incorporated into the soil. The two varieties were Golden Yellow and Lakan. The first-year yield was very high, but declined markedly in the second year because of typhoon damage. There were highly significant responses to N and the combined application of NPK, but no significant response to P or K nor to the two different methods of crop residue management.

Several other long-term fertility trials have been conducted to determine the optimum amount and

balance of N, P, and K to maintain soil fertility and obtain high cassava yield (or total income when intercropped) for different types of soil. **Table 8** summarizes the results of 20 long-term fertility trials

Table 8. Cassava root yield response to annual applications of various rates of NPK and the relative response[1)] to each nutrient during the last year of cropping in 20 long-term fertility trials conducted in Asia and Latin America.

Location	Varieties	# of years	Yield (t/ha) $N_0P_0K_0$	Yield (t/ha) $N_2P_2K_2$	Relative yield (%) $N_0P_2K_2$	Relative yield (%) $N_2P_0K_2$	Relative yield (%) $N_2P_2K_0$
Bohol, Philippines	VC-1+Golden Yellow	4	7.5	20.4	58	84	**33**
Negros Occidental, Philippines	Lakan	4	7.1	13.9	**71**	129	76
Yogyakarta, Indonesia	Adira-1	4	6.2	10.9	**60**	87	81
Leyte, Philippines	Golden Yellow	6	17.1	17.3	**88**	110	98
Jatikerto, Java, Indonesia	Faroka	8	3.1	11.3	**31**	72	81
GSCRI, Nanning, China	SC201+SC205	8	12.9	18.6	**70**	82	85
Umas Jaya, Lampung, Indonesia	Adira-4	10	11.1	15.0	111	92	**84**
Serdang, Malaysia	Black Twig	10	20.7	51.0	69	72	**57**
Santander de Quilichao, Colombia	MCol 1684	11	12.2	30.7	64	92	**42**
	MCol 1684	13	12.9	30.0	94	96	**71**
Trivandrum, Kerala, India	H 1687	13	1.0	22.3	24	42	**7**
CATAS, Hainan, China	SC205+SC124	16	7.2	15.1	**41**	77	63
Tamanbogo, Lampung, Indonesia	Adira 4 [2)]	16	2.9	12.2	58	80	**26**
	Adira 4 [3)]	16	3.6	13.2	64	57	**26**
TNUAF, Thai Nguyen, Vietnam	KM60+Vinh Phu	17	4.4	21.8	67	71	**16**
Hung Loc ARC, Dong Nai, Vietnam	KM60 + SM937-26	20	6.8	20.1	70	81	**24**
Rayong FCRC, Thailand	Rayong 1	10	8.7	18.3	-	96	**51**
	R 1 + R 5	21	20.7	41.1	-	**55**	65
Khon Kaen FCRC, Thailand	Rayong 1 + R5	30	2.5	31.9	-	77	**9**
B. Samrong FCRC, Thailand	Rayong 1 + R5	31	21.7	26.9	-	**66**	99

1) Yield in the treatment without the nutrient over the yield with the nutrient ($N_2P_2K_2$).
2) Monoculture.
3) Intercropped with rice and maize.

conducted for 4 to 31 years of continuous cropping. The table shows that, during the last year, K had become the most limiting nutrient in 12 trials, N in six trials, and P in only two, as indicated by the low relative yield in plots where these nutrients had not been applied. In general, the longer the experiments were continued, the greater the response to the application of K.

In many cases, there was not a response to fertilizer application in the first or first few years, but over time the responses to all macronutrients tended to increase, especially the response to K, indicating that over time K became the nutrient most limiting yield, due to the relatively high removal of K in each root harvest. In general, the highest yield was achieved with the highest level of the combined application of N, P, and K, such as 180−200 kg N plus 90−100 kg P_2O_5, and 180−200 kg K_2O/ha, but the highest net income was obtained with intermediate rates of fertilization, such as 80 kg N, 40 kg P_2O_5, and 80 kg K_2O/ha, or even lower if the chemical fertilizer was combined with at least 5 t/ha of manure.

Other experiments were specifically designed to compare the use of chemical fertilizer with that of different manures, or the combination of the two sources.

2. The use of pig manure and chemical fertilizer in Vietnam

An experiment was conducted at Thai Nguyen University in Thai Nguyen, northern Vietnam, to compare the effectiveness of various rates of pig manure with chemical fertilizer, or a combination of manure and fertilizer, in increasing cassava yield and net income. **Table 9** shows that cassava yield increased from 3.25 to 13.11 t/ha with the application of 15 t/ha of wet pig manure. However, yield of 15.47 t/ha was obtained with the application of 80 kg N and 80 kg K_2O/ha, while yield of 18.70 t/ha was obtained with

Table 9. Effect of the application of FYM[1] and chemical fertilizer on cassava yield and economic benefit at Thai Nguyen University of Agriculture and Forestry in Thai Nguyen Province of Vietnam, in 2001 (second year).

Treatment[1]	Cassava root yield (t/ha)	Leaf life at 3 months (days)	HI	Gross income[2]	Fert. costs[2]	Product. costs[3]	Net income
				(000 dong/ha)			
No fertilizer, no FYM	3.25	46.5	0.39	1,625	0	2,800	−1.175
5 t FYM/ha	7.79	55.2	0.49	3,895	500	3,300	0.595
10 t FYM/ha	10.02	65.0	0.52	5,010	1,000	3,800	1.210
15 t FYM/ha	13.11	66.1	0.52	6,555	1,500	4,300	2.255
80 N+80 K_2O/ha, no FYM	15.47	66.8	0.50	7,735	680	3,580	4.155
80 N+80 K_2O/ha + 5 t FYM/ha	17.98	68.5	0.48	8,990	1,180	4,080	4.910
80 N+80 K_2O/ha + 10 t FYM/ha	18.70	70.8	0.49	9,350	1,680	4,580	4.770
80 N+80 K_2O/ha + 15 t FYM/ha	18.50	73.1	0.48	9,250	2,180	5,080	4.170

1) FYM = farmyard manure (pig manure), HI = harvest index.
2) Prices: cassava dong 500/kg fresh roots
urea (45% N) 2,100/kg
KCl (60% K_2O) 2,300/kg
manure+application 100/kg
3) Cost of cassava cultivation: 2.8 mil. dong/ha
Cost of chemical fertilizer application: 0.10 mil. dong/ha
Source: *Nguyen The Dang, personal communication, 2002.*

the combination of 80 kg N, 80 kg K_2O, and 10 tons of pig manure/ha. Considering the cost of fertilizer and the cost of manure application, the highest net income was obtained with the combined application of chemical fertilizer with 5 t/ha of pig manure.

3. The use of cattle manure, compost, and chemical fertilizer in Indonesia

A similar experiment was conducted at the Jatikerto Experiment Station near Malang, Indonesia, to compare the effectiveness of cattle manure or compost with various combinations of N, P, and K fertilizer, applied either alone or in combination with manure or compost, in increasing the yield of cassava and intercropped maize as well as net income. **Table 10** shows that cassava yield increased from 10.96 to 37.47 t/ha, while intercropped maize yield increased from 1.10 to 2.10 t/ha with the application of 135 kg N, 50 kg P_2O_5, and 100 kg K_2O/ha, while cassava yield was only 26.53 and 22.67 t/ha with the application of 10 t/ha of cattle manure and compost, respectively. The highest cassava yield and net income were obtained with the combination of 135 kg N/ha and 5 t/ha of compost.

Table 10. Effect of various fertilization alternatives on the yield of cassava cv. Faroka, and intercropped maize, as well as gross and net income when grown at the Jatikerto Station in Malang, East Java, Indonesia, in 2005/06 (second year).

Treatment N-P_2O-K_2O (kg/ha)	Organic matter (t/ha)	Maize yield[2] (t/ha)	Cassava yield (t/ha)	Gross income[3]	Fertil. costs[3]	Prod. costs[4]	Net income	Farmers' preference ranking
				(mil. Rp/ha)				
0-0-0	0	1.10	10.96	4.72	0	4.10	0.62	
135-0-0	0	1.93	35.60	13.52	0.45	7.01	6.51	2
135-50-0	0	2.07	36.80	14.05	0.69	7.37	6.68	3
135-50-100	0	2.10	37.47	14.30	1.27	8.02	6.28	4
0-0-0	10 cattle manure	1.66	26.53	10.32	2.00	7.65	2.67	
0-0-0	10 compost	1.63	22.67	9.05	1.00	6.27	2.78	
135-0-0	5 cattle manure	2.26	35.63	13.89	1.45	8.01	5.88	1
135-0-0	5 compost	1.97	39.33	14.75	0.95	7.88	6.87	5
135-50-0	5 compost	1.87	39.07	14.56	1.19	8.10	6.46	
135-0-0	5 sugar mud[1]	1.67	33.73	12.63	0.95	7.32	5.31	

1) Sugar mud = blotong = by-product of sugar mill.
2) Maize grain yield.
3) Prices: cassava: Rp 320/kg fresh roots KCl (60% K_2O) Rp 3,500/kg
maize 1,100/kg dry grain cow manure 200/kg
urea (45% N) 1,500/kg compost 100/kg
SP-36 (36% P_2O_5) 1,700/kg sugar mud 100/kg
4) Costs: cassava harvest+transport 100/kg
production costs, without fertilizer or cassava harvest, estimated at Rp 3 mil./ha
US$1 is about 9,000 rupiahs.
Source: *Utomo et al., 2010.*

From these experiments, we can conclude that the application of the right amount and balance of N, P, and K in chemical fertilizer tends to be more effective in increasing cassava (and intercrop) yield than the application of animal manure or compost, even at fairly high rates of application of the latter. But, these and other experiments have also shown that the combination of medium amounts of manure or compost with the right balance of N, P, and K in chemical fertilizer will produce the highest yield and net income. In this case, the chemical fertilizer will supply most of the macronutrients that are needed for a particular soil and crop, while the manure supplies some additional nutrients as well as organic matter to improve the physical conditions of the soil. Similarly, the combination of chemical fertilizer with alley cropping, intercropping, green manuring, the application of mulch, or the incorporation of crop residues will generally give the highest yield and income (see **Chapter 10)**.

CHAPTER 8

HOW TO APPLY NPK FERTILIZERS: WHAT KIND, HOW MUCH, WHEN, AND WHERE?

Throughout the tropics and subtropics, cassava is grown on a wide range of soils, the main requirement being that the soils have to be reasonably well drained. **Table 1** shows that, in Latin America, most cassava is grown on Ultisols, Alfisols, and Oxisols, while in Asia by far most cassava is grown on Ultisols, followed by Inceptisols, Alfisols, and Entisols. In contrast to Latin America, in Asia very little cassava is grown on Oxisols and at elevations above 1,000 m. Except for the Alfisols, most cassava soils are characterized by a low pH and low contents of N, P, and K. Cassava can grow well on Mollisols and the better-drained Vertisols, but these highly fertile soils are generally used for higher-value crops such as sugarcane, maize, sorghum, soybeans, and cotton. Even though cassava performs better than most crops on acid and infertile soils, the crop is highly responsive to fertilizer applications. Still, fertilizer or lime is seldom applied to the crop since farmers generally believe that the crop does not need good fertility and does not respond to fertilizer. However, thousands of fertilizer experiments conducted by

Table 1. Soils on which cassava is produced in Latin America and Asia, and their principal nutritional constraints for the crop.

	Cassava production (%)		Constraints [1]			
Soil order	Latin America [2]	Asia [3]	Acidity	N	P	K
Ultisols	27	55	+	+	+	++
Alfisols	23	11	-	-	-	-
Oxisols	19	<1	++	+	++	++
Entisols	13	9	-	++	+	++
Inceptisols	7	18	++	+	++	+
Mollisols	6	2	-	-	-	-
Vertisols	4	3	-	-	-	-
Aridisols	<1	<1	-	-	-	-
Histosols	<1	<1	++	-	-	+

[1] + means constraint; ++ means serious constraint
[2] ***Source:*** *Agro-ecological Studies Unit, CIAT, 1985a; Howeler et al., 2001a.*
[3] ***Source:*** *Howeler, 1992.*

FAO throughout the world between 1961 and 1977 (FAO, 1980) indicate that cassava is as responsive to fertilizer applications as other crops that traditionally are fertilized, and that fertilizer application to cassava can be highly economical.

However, cassava is quite sensitive to over-fertilization, especially with N, which will result in excessive leaf formation at the expense of root growth. Cock (1975) reported that cassava has an optimal leaf area index of 2.5−3.5 and that high rates of fertilization may lead to excessive leaf growth and a leaf area index of >4. High N applications not only reduce the harvest index (HI) and root yield, but can also reduce the starch and increase the HCN content of the roots. Moreover, nutrients generally interact with each other, and the excessive application of one nutrient may induce a deficiency of another. Howeler et al. (1977) and Edwards and Kang (1978) have shown that high rates of lime application may actually reduce yield by inducing Zn deficiency. Spear et al. (1978b) showed that increasing the K concentration in nutrient solution decreased the absorption of Ca and especially Mg, leading to Mg deficiency. However, in both nutrient solution and field experiments with varying rates of application of K, Ca, and Mg, Howeler (1985b) did not find a significant effect of increasing K on the Ca concentration in the leaves. The Mg concentration decreased slightly in the field, but increased in the nutrient solution experiment. However, increasing the Mg supply markedly decreased the concentrations of K and Ca. Similarly, Ngongi et al. (1977) reported that high applications of KCl induced S deficiency in a low-S soil in Colombia, while Nair et al. (1988) found that high rates of P application induced Zn deficiency. Hence, it is important to apply not only the right amount of each nutrient but also the right balance among the various nutrients.

1. Short- vs Long-term Responses to Fertilization

Short-term fertilizer experiments are usually conducted for 1−2 years at any particular site, while long-term experiments may be conducted for many years at the same site, applying the same fertilizer treatments to the same plots in every successive crop cycle. The short-term responses to the various applied nutrients depend largely on the original fertility characteristics of the soil as well as on the nutrient requirements of the test crop. In long-term experiments, the response to particular nutrients may change over time, depending initially on the original fertility of the soil, but subsequently this will depend more and more on which nutrients are being depleted most by the removal of the harvested products.

The fertilizer experiments conducted by FAO are mostly short-term trials. These indicate that in West Africa (Ghana) cassava responded mainly to K, in Latin America (Brazil) to P, and in Asia (Indonesia) to N, followed by K and P (Richards, 1979). In nearly 100 NPK cassava trials conducted in Thailand in the early 1980s, the crop also responded mainly to N, followed by K and P (Hagens and Sittibusaya, 1990). Similarly, many short-term NPK trials conducted in India indicate mainly a response to N, with an occasional response to K and P (CTCRI, 1971−1976). However, long-term trials, in which cassava was grown continuously for 8 up to 37 years, invariably showed that K became the most limiting nutrient in India (Kabeerathumma et al., 1990); Thailand (Nakviroj et al., 2007); Malaysia (Chan, 1980), and Vietnam (Nguyen Huu Hy et al., 2007).

Unlike in Latin America, where cassava is generally grown on highly P-deficient Oxisols, Ultisols, and Inceptisols, and thus responds principally to the application of P, in Asia cassava is generally grown on low-OM Ultisols and Entisols and the main initial response is therefore to the application of N. Significant initial responses to P have been reported only in East Java, southern Sumatra, northern Vietnam, and Hainan Island of China. A very marked initial K response has been obtained only in Thai Nguyen Province of Vietnam, where cassava is grown on very poor eroded slopes. However, it was found that, after several years of continuous cassava production in the same fields, the main response in nearly all locations was to K (see **Chapter 7**). How long it takes to get a significant K response depends on the native fertility and mineralogy of the soil.

Chapter 6 already discussed various ways to diagnose nutritional problems in cassava, either from observation of plant growth and deficiency/toxicity symptoms or by soil or plant tissue analyses. Results of soil analyses are most useful to determine the short-term fertilizer recommendation for a specific site. The nutritional status of a soil, according to the nutritional requirements of cassava or the critical level of the nutrient, as shown in **Tables 2** and **3** of **Chapter 6**, gives a good idea about which nutrient(s) should be applied to obtain high cassava yield.

If the result of the soil analysis indicates that the amount of a particular nutrient is within the "medium" range shown in **Table 2**, or is above the critical level shown in **Table 3** of **Chapter 6**, cassava will probably not respond to the application of that nutrient. But if the amount is in the "low" or "very low" range, or is below the critical level, the application of that nutrient will probably increase yield. If the amount is in the "very low" range, or is far below the critical level, there will more likely be a very significant response to the application of that nutrient, and there may be a response to a fairly high rate of application.

How much of the nutrient will need to be applied to reach maximum yield, or to obtain the highest net income, can best be determined by conducting simple NPK trials at the site. In the absence of that, it was found that in most soils the application of 80-160 kg N/ha will increase yield when the OM of the soil is below 3%; similarly, 25−50 kg P_2O_5/ha will increase yield when the available P content is less than 4−7 ppm, while 80−160 kg of K_2O/ha will do the same if the exchangeable K content is below 0.15 meq/100 g (60 ppm).

Based on the results of a large number of FAO-sponsored on-farm fertilizer trials, the Department of Agriculture of Thailand issued the following fertilizer recommendations for cassava growing in infertile light-textured Ultisols (Sittibusaya, 1996):

Organic matter (%)	**Recommended N rate (kg/ha)**
<0.65 (low OM)	100
>0.65 (high OM)	50
Available P (ppm)	**Recommended P_2O_5 rate (kg/ha)**
<5 (low P)	50
>5 (high P)	25
Exchangeable K (ppm)	**Recommended K_2O rate (kg/ha)**
<30 (low K)	100
>30 (high K)	50

To make a more precise recommendation, some people calculate the fertilizer requirement based on the availability of the nutrient in the soil (from soil analyses), the nutrient requirement of the crop (based on the nutrients removed in the harvested product(s) at expected yield amounts), the type and efficiency of the fertilizer to be applied, and the time and method of application (Cadavid, 2011). These calculations are quite complicated and also depend on many estimates and assumptions.

If no soil analysis results are available and little is known about the characteristics of the soil, it is recommended to apply initially about equal amounts of N, P_2O_5, and K_2O, such as 500−600 kg/ha of a fertilizer such as 15-15-15 or 16-16-16. Depending on the growth of the plants, the yield obtained, and whether or not crop residues are incorporated or removed, the amount of application of N and K should increase over time, while the amount of P application can probably be reduced. Huang Jie et al. (2010), based on results of a long-term NPK trial conducted at CATAS in Hainan, China, recommended an N:P_2O_5:K_2O ratio of 1−2:1:1−2 during the first 4 years of cropping, 2−3:1:2−3 during the fifth to eighth year, and 3−4:1:3−4 after the ninth year. Averaged over 10 years of cropping, they obtained the highest net income from the annual application of 100 kg N, 50 kg P_2O_5, and 100 kg K_2O/ha. When soils are particularly low in available P or are known to be highly P-fixing, it may be necessary to apply initially as much as 100−200 kg P_2O_5/ha, but these amounts should be drastically reduced in later years as the applied P tends to build up in the soil and this will reduce the soil's mycorrhizal population as well as the uptake of Fe and Zn.

Thus, although in short-term fertilizer experiments there are often no significant responses to the application of chemical fertilizer or the response is mainly to N and P, when these trials are continued in the same plots for many years, the response to fertilizer tends to increase over time due to the depletion of soil nutrients by the removal of the harvested roots. This is particularly the case for K, which is removed in large quantities in the roots; and for N, which may be removed in large quantities if leaves and stems are also taken from the field. Thus, in most cases, K becomes the most limiting nutrient after several years of continuous cassava production in the same fields.

a. Nitrogen

Nitrogen is a basic component of protein, chlorophyll, enzymes, hormones, and vitamins. It is also a constituent of the cyanogenic glycosides linamarin and lotaustralin, which produce hydrocyanic acid (HCN) when cells are damaged. HCN is the bitter, highly toxic component of cassava leaves, stems, and roots, which must be eliminated by drying or cooking the roots before consumption.

Cassava plants suffering from N deficiency may not show any visible deficiency symptoms, but they are shorter and grow less vigorously than normal. In some varieties and under severe N deficiency, leaves are slightly lighter green in color, the chlorosis being rather uniform throughout the plant. In nutrient solution trials, Forno (1977) observed only slight N-deficiency symptoms in cassava, while sorghum, maize, and cotton showed severe symptoms. However, the growth of cassava declined markedly. This corresponds with observations at CIAT (Lozano et al., 1981) in which N deficiency in cassava resulted mainly in reduced growth rather than deficiency symptoms. However, this may vary with the variety being used; some varieties show a clear and rather uniform chlorosis of all leaves, while in other varieties the leaves remain dark green but plant growth decreases.

Severe N deficiency is usually observed in very sandy soils low in OM, but may also be found in high-OM but acid soils, mainly due to a low rate of N mineralization. For instance, in Santander de Quilichao, Colombia, there was a highly significant response to the application of N in a volcanic ash soil with 7.1% OM but having a pH of 4.3 (Howeler and Cadavid, 1990). Some of the most dramatic responses to N have been obtained on the sandy soils of Jaguaruna in Santa Catarina State of southern Brazil. **Figure 1** shows a nearly linear response of two varieties up to 150 kg N/ha. In this location, yield increased from 10 t/ha to 35 t/ha by N application in a soil with 89% sand and 0.7% organic matter (Moraes et al., 1981). For both varieties, the highest yield was obtained with a fractionated application with one-third applied at 30, 60, and 90 days after planting.

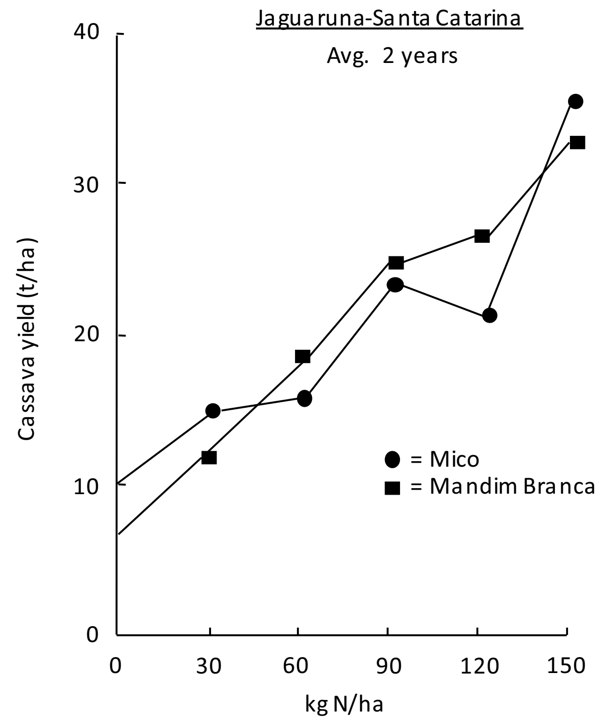

Figure 1. *Response of two cassava varieties to different amounts of application of N in a sandy soil of Jaguaruna, Santa Catarina, Brazil.*
Source: *Moraes et al., 1981.*

Similar results were obtained in Carimagua, Colombia, where cassava responded to the application of 100 kg N/ha, with the highest yield obtained with a fractionated application of one-third at 30, 120, and 150 days. However, the yield differences due to time of application were not statistically significant **(Figure 2)**. Trials on optimum time and fractionation of N applications have generally shown nonsignificant differences between single applications at planting, at 1 month after planting (MAP), or various fractionations (0−3 MAP) using N rates up to 100 kg N/ha (Howeler, 1985a). At higher rates, fractionation was found to be better than a single application.

A similar spectacular response to N was also observed in a clay soil with 1.2% OM in Jatikerto, East Java, Indonesia **(Figure 3)**. In this case, cassava was intercropped with maize, which competed strongly for the limited supply of N in the soil (Wargiono et al., 1998). In Kerala State of southern India, cassava responds principally to the application of N, with 100 kg N/ha being the recommended rate, half applied at planting and half at 2 months (Mandal et al., 1971). Similarly, in Thailand, where cassava is generally grown on moderately acid and low-OM soils, the crop responds mainly to the application of 50−100 kg N/ha (Sittibusaya et al., 1974).

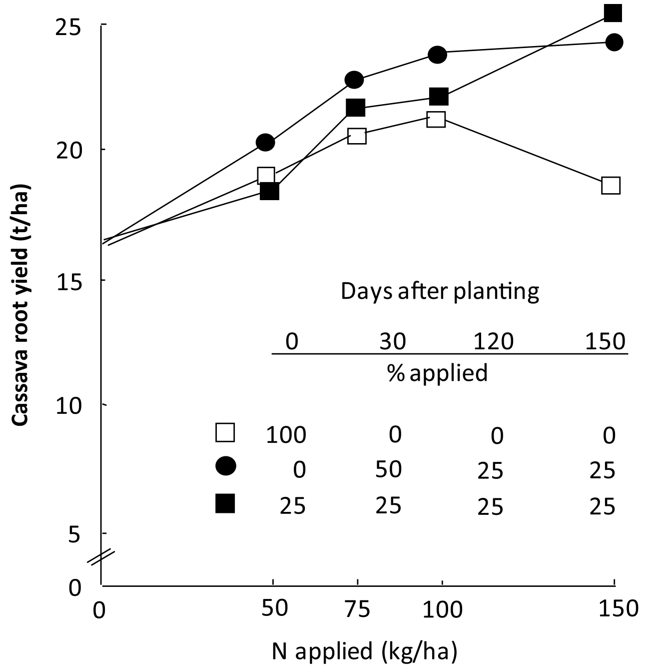

Figure 2. *Response of cassava, cv. Llanera, to different rates and times of application of N in Carimagua, Colombia.*

Source: *Howeler, 1985a.*

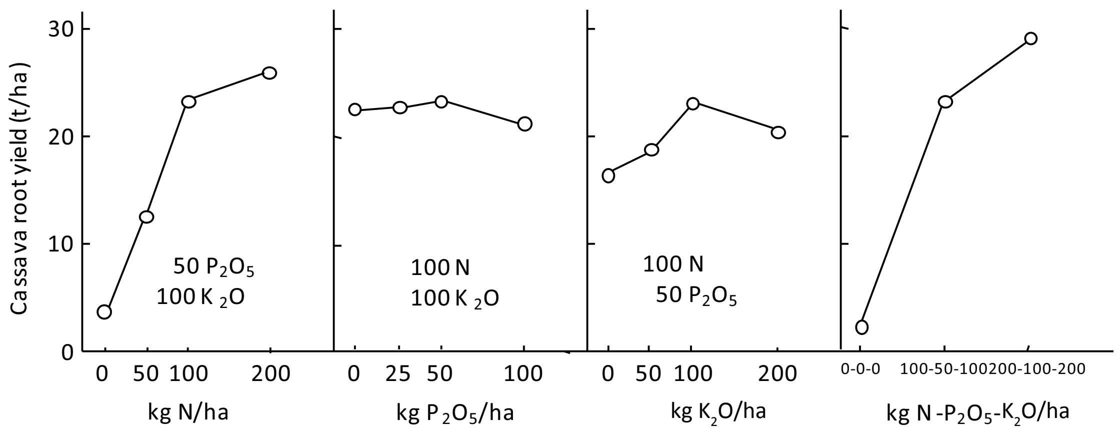

Figure 3. *Response of cassava, cv. Faroka, to the annual application of various rates of N, P, and K during the seventh crop cycle in Jatikerto, East Java, Indonesia, in 1994/95.*

Source: *Wargiono et al., 1998.*

In Nanning, Guangxi, China, there was also a highly significant response to N, up to 200 kg N/ha in one cultivar (SC205), but only up to 50 kg N/ha in the other (SC201) (Zhang Weite et al., 1998). As the latter cultivar is extremely vigorous, high N produced too much top growth at the expense of root production. High N application may also stimulate the production of N-containing compounds such as protein and HCN, and may result in a decrease in starch content **(Figure 4)**.

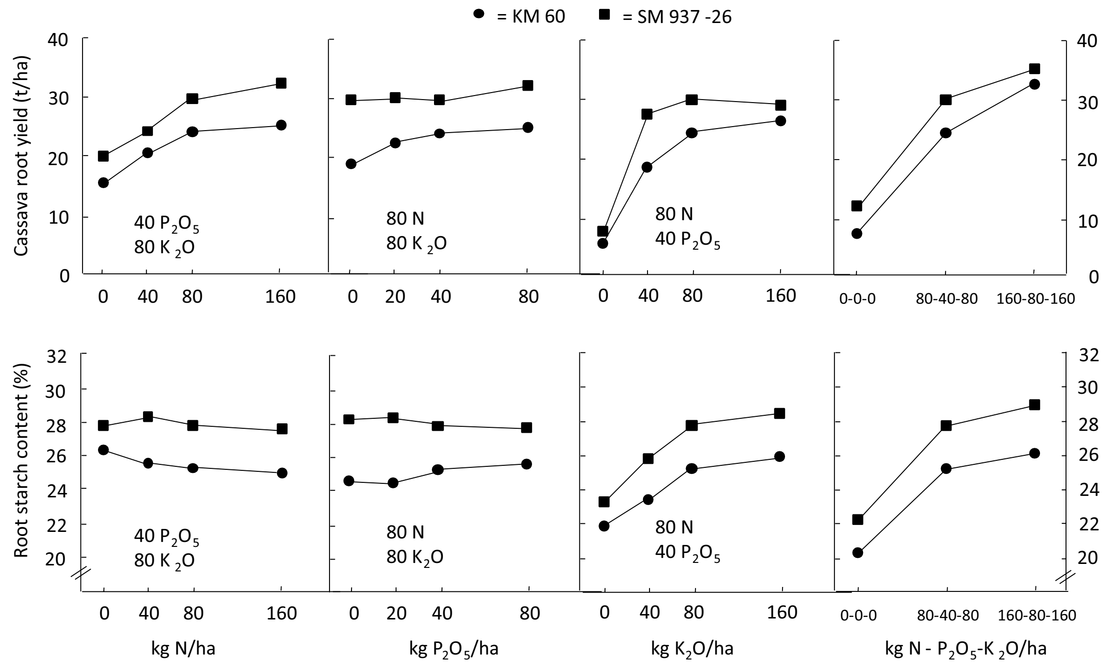

Figure 4. *Effect of annual applications of various amounts of N, P, and K on the root yield and starch content of two cassava varieties grown at Hung Loc Agricultural Research Center in Trang Bon District, Dong Nai Province, Vietnam, in 2008/09 (19th year).*

High rates of N application may also increase the intensity of diseases such as cassava bacterial blight (Kang and Okeke, 1984). Thus, N rates must not only be adjusted to a particular soil but also tailored to the needs of a particular cultivar.

There are usually no significant differences among N sources such as urea, ammonium nitrate, and mono- or di-ammonium phosphate. Vinod and Nair (1992) reported significantly higher yield with slow-release N sources such as neem cake-coated urea or supergranules of urea.

High N applications may be necessary for cassava foliage production since the frequent cutting of tops will remove large amounts of N. **Figure 5** shows the response to N, P, and K application in Carimagua, Colombia, in terms of total dry forage and protein production as well as root yield. There was a highly significant response to the application of all three nutrients up to the highest amount of 200 kg/ha of N, P, and K. The application of 200 kg N/ha (plus 100 kg/ha of P and K) increased total dry forage production from 3.3 to 6.3 t/ha and protein yield from 0.7 to 1.4 t/ha. The latter corresponds to an N extraction of 224 kg/ha in the tops. The periodic cutting of tops affected cassava root yield and the response to fertilizer.

Without N application, forage harvesting decreased root yield about 50%, whereas, with 200 kg N/ha applied, root yield decreased from 25 to 16 t/ha, corresponding to a 35% yield reduction. Application of the highest fertilizer amount of 200 kg/ha of N, P, and K resulted in the highest dry forage production of over 8 t/ha, equivalent to 2 t/ha of protein, while still producing 20 t/ha of fresh roots (CIAT, 1988a).

Similar results were obtained in Thailand by Putthacharoen et al. (1998), who reported a total N removal in roots and forage of 330 kg/ha during a 22-month crop cycle when green tops were cut at 3−4-month intervals. Thus, when cassava tops are cut off regularly for forage production, high rates of N (>200 kg/ha) need to be applied to sustain high amounts of both shoot and root production.

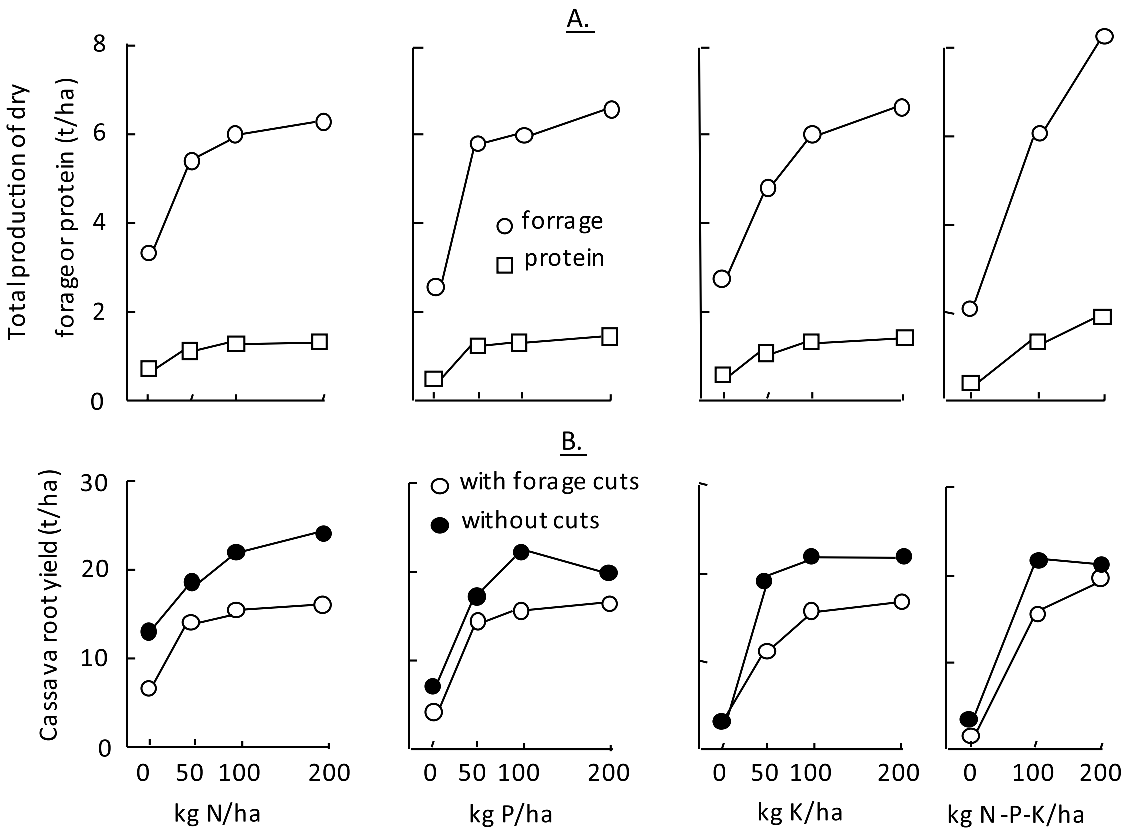

Figure 5. *Effect of N, P, and K application on total production of cassava dry forage and protein (A), as well as its effect on root production with or without forage cuts (B) of variety CM 523-7 during a 14-month crop cycle in Carimagua, Colombia.*

Source: *Howeler, 1985a.*

b. Phosphorus

Phosphorus is a basic component of nucleoproteins, nucleic acids, and phospholipids as well as all enzymes that play a role in energy transfer. Phosphorus is an important element for the processes of phosphorilization, photosynthesis, respiration, and the synthesis of carbohydrates, proteins, and fats.

Through these processes, an adequate P supply is essential for the synthesis of starch and thus for normal root production. Malavolta et al. (1952) reported a reduction from 32% to 25% of starch in cassava roots when P was not supplied in a nutrient solution experiment, while Muthuswamy et al. (1974) reported no effect of P on the HCN content of roots.

The storage roots of cassava contain relatively small amounts of P, and P removal from the soil in the root harvest is therefore much lower than that of N or K. However, in Latin America, where the majority of the cassava-growing areas are characterized by extremely P-deficient soils, this element most limits cassava yield, at least in those fields where P fertilizer has not been applied before.

P-deficient plants seldom show clear deficiency symptoms; instead, they are shorter and less vigorous, and have thinner stems and smaller and narrower leaves than normal plants. Root yield can be seriously depressed by P deficiency. Only with extreme deficiency do plants have a few dark yellow or orange lower leaves, which later become necrotic and flaccid and fall off. In the absence of clear deficiency symptoms, P deficiency is generally diagnosed from knowledge about the soil or from soil or plant tissue analyses. When the soil contains less than 4−5 ppm Bray II-extractable P, or YFEL blades have less than 0.4% P at 3−4 months of age of the plant, the crop will very likely respond to P application.

Cassava's tolerance of low P concentrations in soil solution is not due to the efficient uptake of P by the root system. In fact, cassava grown in flowing nutrient solution required a much higher P concentration for maximum growth than rice, maize, cowpeas, or common beans (Jintakanon et al., 1982; Howeler et al., 1981; Howeler, 1990). When inoculated with endotrophic vesicular arbuscular mycorrhizae (VAM), the growth of cassava in nutrient solution improved significantly (Howeler et al., 1982a). Masses of mycorrhizal hyphae growing in and around the fibrous roots of cassava markedly increased the plant's ability to absorb P from the surrounding medium (**Photo 1**). When planted in natural soil, the crop's fibrous roots soon become infected with native soil mycorrhizae. The resulting hyphae grow into the surrounding soil and help in the uptake and transport of P to the cassava roots. Through this highly effective symbiosis, cassava is able to absorb P from soils with low available P, mainly by extending the soil volume from which P can be absorbed through the associated mycorrhizal hyphae (Howeler, 2012c).

It has been clearly shown (Yost and Fox, 1979; Van der Zaag et al., 1979; Howeler et al., 1982a; 1982b) that cassava is extremely dependent on an effective VAM association for absorption of P from the soil. In soils with a low or ineffective native mycorrhizal population, cassava growth and production can be greatly increased by soil inoculation with a highly effective strain of mycorrhizae. In the presence of an effective mycorrhizal population, cassava is extremely tolerant of low available P. Maize and soybean have a critical soil P level of 14−15 ppm, whereas cassava requires only 8 ppm Bray I-extractable P (Kang et al., 1980). **Table 2** shows that, in nutrient solutions in the absence of a mycorrhizal association, cassava has a very high P requirement due to a coarse and inefficient root system. However, in natural soils in the presence of an effective VAM population, cassava is extremely efficient in P uptake and has a low external P requirement.

Severe P deficiency has been reported mainly in Latin America, particularly on Oxisols, Ultisols, and Inceptisols in Brazil and Colombia. These soils are highly P-fixing and have available (Bray II or Mehlich I) P of only 1−2 ppm. During the first year(s) of cropping, cassava responds markedly to P application; but, with continuous cropping on the same land, responses to P become less significant as soil P builds up from previous applications (Nair et al., 1988; Howeler and Cadavid, 1990; Kabeerathumma et al., 1990).

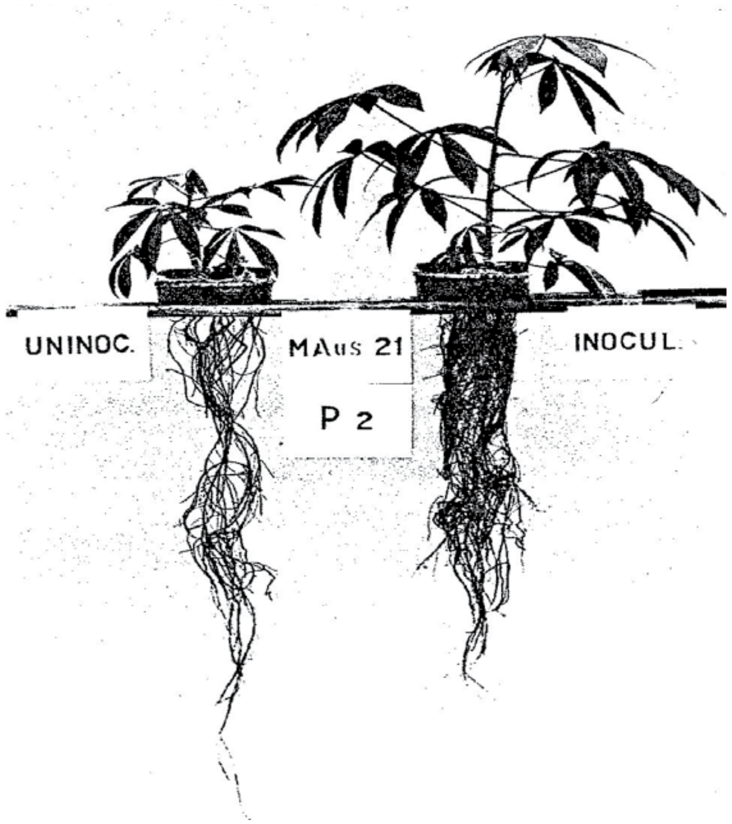

Photo 1. *Cassava cv. MAus 21 grown in flowing solution culture with 1 µM phosphate; with (right) and without (left) mycorrhizal inoculation.*

Table 2. External P requirement of various crops in terms of "available" soil P concentration in soil or nutrient solution (data are in ppm).

Crop	Soil extract	Soil solution	Nutrient solution
Cassava	8 (Bray I) [1] 6 (Bray II) [2]	0.01–0.04 [3]	0.9–2.4 [4)5)6]
Maize	14 (Bray I) [1]	0.06 [7]	0.03 [5]
Phaseolus beans	18 (North Carolina) [8] 10–15 (Bray II) [10]	0.06 [9]	0.03 [6]
Cowpea		0.016–0.1 [11]	0.03 [6]
Soybean	15 (Bray I) [1]	0.018–0.2 [11]	0.02 [5]
Rice		0.03–0.12 [12]	
Sorghum		0.05 [7]	
Sweet potato		0.10 [3)7]	
Irish potato		0.20 [3)7]	
Chinese cabbage		0.20 [7]	
Lettuce		0.40 [7]	
Cotton			0.02 [5]

References: 1) Kang et al., 1980.
2) CIAT, 1985b.
3) Van der Zaag et al., 1979.
4) Asher and Edwards, 1978.
5) Jintakanon et al., 1982.
6) Howeler et al., 1982a.
7) Fox et al., 1974.
8) Goepfert, 1972.
9) CIAT, 1978.
10) Howeler and Medina, 1978.
11) IITA, 1981
12) IITA, 1982

In Asia, P deficiency is seldom the principal factor limiting cassava production because most cassava is grown on soils with more than 4 ppm of available P or on soils that had previously been fertilized with P. Nevertheless, significant responses to P application have been observed in Guangzhou (Guangdong), in Nanning (Guangxi), and on Hainan Island of China; in northern and southern Vietnam; and on Leyte Island of the Philippines. In low-P soils in Kerala, India, significant initial responses to 100 kg P_2O_5/ha were reported, but these declined over time. Nair et al. (1988) determined an optimum economic rate of 45 kg P_2O_5/ha. The most marked responses to P application in Asia were observed in the Plain of Jars in Xieng Khouang Province of northeast Laos in soils with only 0.9 ppm Bray II-extractable P **(Figure 6)** (CIAT, 2007).

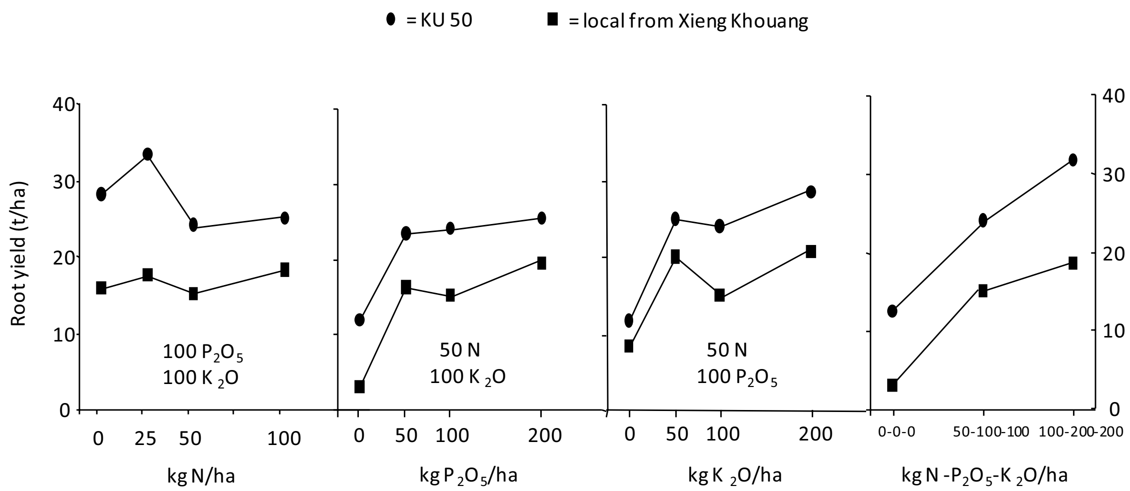

Figure 6. *Effect of the application of various amounts of N, P, and K on the root yield of two cassava varieties grown at the Cattle Bank in Paek District, Xieng Khouang Province of Lao PDR in 2005/07 (2-year crop).*

Source: *CIAT, 2007.*

Responses to P application depend on the available-P content of the soil, the mycorrhizal population, and the variety used. Van der Zaag et al. (1979) reported high yield of 42 t/ha in an Oxisol in Hawaii with only 3 ppm P ($NaHCO_3$-extractant) using cultivar Ceiba. CIAT (1988a) similarly reported that some varieties produced yield of 40–50 t/ha without P application in a soil with only 4.6 ppm P (Bray II). In other soils with equally low available P but with a less efficient mycorrhizal population, cassava responded very markedly to P applications. Thus, in the Oxisols of the Eastern Plains of Colombia, with only 1.0 ppm P (Bray II), cassava responded markedly to applications of 200–400 kg P_2O_5/ha **(Figure 7).** Of the seven P sources tested, banding of triple superphosphate (TSP) or broadcast applications of basic slag were the most effective. Partially acidulated rock phosphate or rock phosphate mixed with elemental sulfur (S) was also quite effective in these acid soils (CIAT, 1978). Locally produced simple superphosphate (SSP) was less effective, except at high rates of application. Similarly, Santos and Tupinamba (1981) reported significant responses to 60 or 120 kg P_2O_5 /ha in three soils of Sergipe, Brazil, with TSP and hyperphosphate being more effective than two local sources of rock phosphate.

Soluble-P sources such as TSP, SSP, and mono- or di-ammonium phosphate should be band applied near the stakes, while less soluble sources such as basic slag and rock phosphates should be broadcast and incorporated. All P should be applied at or shortly after planting as fractionation of P had no significant effect on yield. Alternative methods of P application, such as stake treatments or foliar sprays, are not as effective as soil application in increasing yield (Howeler, 1985a).

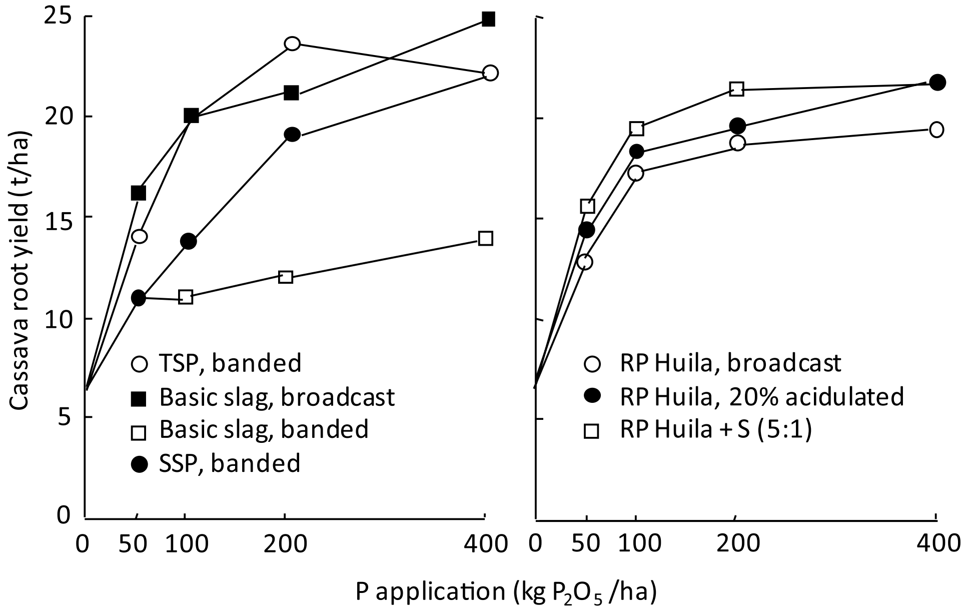

Figure 7. *Effect of different amounts, sources, and methods of application of P on the root yield of cassava cv. Llanera grown in Carimagua, Meta, Colombia.*

Source: *Howeler, 1985a.*

c. Potassium

Potassium is not a basic component of proteins, carbohydrates, or fats, but it plays an important role in their metabolism. Potassium stimulates net photosynthetic activity of a given leaf area and increases the translocation of photosynthates to the tuberous roots. This results in low carbohydrate in the leaves, thus further increasing photosynthetic activity (Kasele, 1980).

Blin (1905), Obigbesan (1973), and Howeler (1998) reported that K application not only increased cassava root yield but also starch content. Similar increases in starch content with increasing applications of K have been observed in Carimagua (CIAT, 1982a) and Pescador, Colombia (Howeler, 1985a), as well as in southern Vietnam (Nguyen Huu Hy et al., 1998) and China (Howeler, 1998). In general, root starch content increases up to 80−100 kg K_2O/ha and then levels off or decreases at higher rates of K application (see **Figure 4**). Obigbesan (1973) and Kabeerathumma et al. (1990) reported that K application also decreased the HCN content of roots, and Payne and Webster (1956) found the highest HCN in roots produced in low-K soils.

Like that of N and P, deficiency of K results mainly in reduced plant height and vigor. Stem internodes are shorter than normal and the upper stem tends to lignify prematurely, resulting in a zigzag growth. In general, stems are thick and highly branched, producing a prostrate growth habit. Clear deficiency symptoms in leaves are seldom observed. In pot and nutrient solution experiments, K-deficient plants often have small and light green leaves at the top of the plant. In the field, K-deficient plants are seldom chlorotic, but upper leaves are small and have fewer lobes, and lower leaves may be yellow and necrotic along the borders. Some of this necrosis seems to be due to K-deficiency-induced diseases, mainly anthracnose. The edges of lower leaves may also curl up, similar to drought symptoms.

Potassium deficiency in cassava is generally found in tropical soils with low-activity clay such as in Oxisols, Ultisols, and Inceptisols, as well as in Alfisols derived from sandstone. After land clearing, the Alfisols have a reasonable content of exchangeable K, but often show a significant K response in the second year of planting because of low K reserves in the parent material (Kang and Okeke, 1984). Most light-textured soils have low K reserves, which are rapidly depleted after one or more cassava harvests.

Long-term experiments in Asia and Colombia have shown that K almost invariably becomes the main limiting nutrient when cassava is grown continuously on the same soil without adequate K fertilization. **Figures 8** and **9** show the results of a long-term NPK trial conducted on a light-textured soil at Thai Nguyen University in Thai Nguyen, northern Vietnam. Two cassava varieties were grown in the same plots with

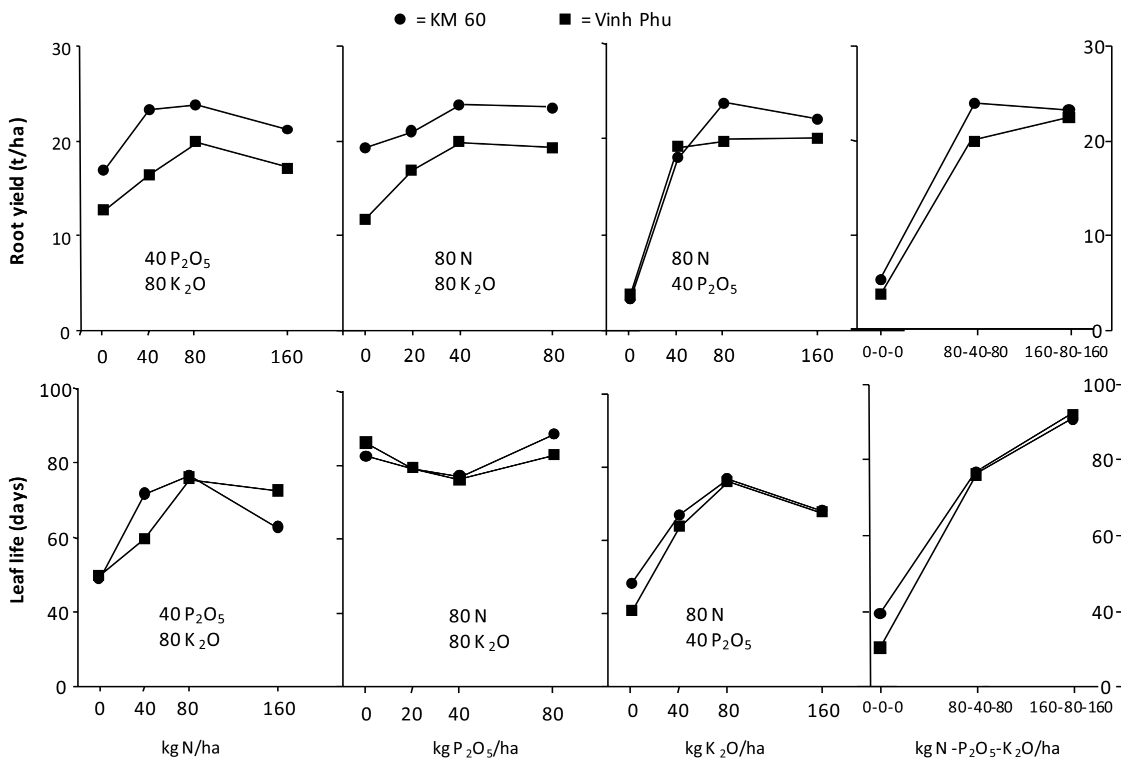

Figure 8. *Effect of annual applications of various amounts of N, P, and K on root yield at 10 MAP and leaf life at 3 MAP of two cassava varieties during the 17th consecutive crop cycle at Thai Nguyen University in Thai Nguyen, northern Vietnam, in 2006.*

Source: *Howeler, 1985a.*

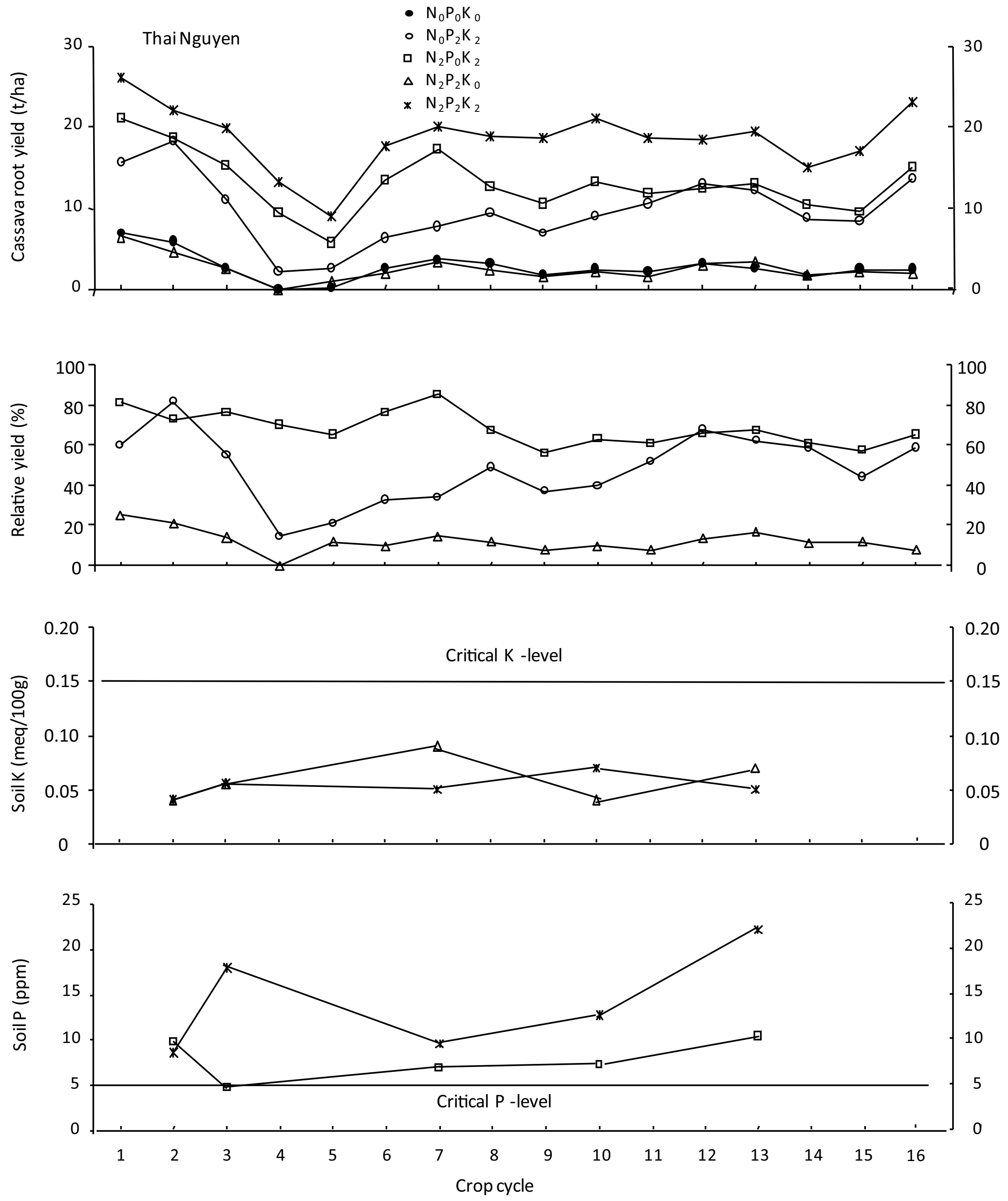

Figure 9. *Effect of annual application of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during 16 years of continuous cropping in Thai Nguyen University of Agriculture and Forestry, Thai Nguyen, Vietnam.*

the same annual applications of N, P, and K for 17 years. During the last year, the average yield increased from 3.40 to 21.78 t/ha with the application of 80 kg K_2O/ha, but did not increase further with the higher rate of application of 160 kg K_2O/ha. **Figure 8** also shows that a lack of adequate N and K drastically reduced leaf life, that is, the average number of days between leaf formation and leaf fall, while a lack of P did not have a similar effect. Thus, relatively high yield of 20–25 t/ha could be maintained during 17 years of continuous cropping with the annual application of 80 kg N, 40 kg P_2O_5, and 80 kg K_2O/ha. However, the exchangeable K content of the soil did not increase with these rates of K application and remained far below the critical level at around 0.06 meq/100 g **(Figure 9)**.

In a very poor sandy soil near the Atlantic Coast of Colombia, Cadavid et al. (1998) also found that annual applications of 50 kg N, 50 kg P_2O_5, and 50 kg K_2O/ha increased yield during 8 years of continuous cropping, but had no effect on soil K, which remained low (0.06 meq/100 g).

Figure 10 shows the response to K application during 4 years of consecutive cropping in Carimagua, Colombia, in a soil with only 0.08 meq exchangeable K/100 g. In the first year, there was no response to K application, but in subsequent crops the response became more marked. In the fourth year, the yield of the K check plot was only 7.8 t/ha compared with 20 t/ha at the highest rate of 200 kg K_2O/ha.

Many experiments on time of K application have given somewhat contradictory results. In India, Kumar et al. (1971) recommended the application of K half at planting and half side-dressed at 1 month, whereas Ashokan and Sreedharan (1977) recommended a split application only when small amounts of K are applied. In the same country, the Central Tuber Crops Research Institute (CTCRI, 1972) reported no significant differences between a full basal application and half basal application and half application at 2 months.

Similar results have been reported by CIAT (1977; 1978; 1982a; 1982b). A basal application at 30 days after planting produced the highest overall yield **(Figure 11)**. Thus, it appears that split applications of K are generally not necessary but may have some advantages on well-drained soils and with low rates of K application.

Among different K sources, KCl is the cheapest and most commonly used source. Ngongi et al. (1977) showed that KCl and K_2SO_4 were equally effective K sources, except in soils with low S content. In those, it is recommended to use K_2SO_4 or to mix elemental S with KCl to prevent the induction of S deficiency by high applications of chlorides.

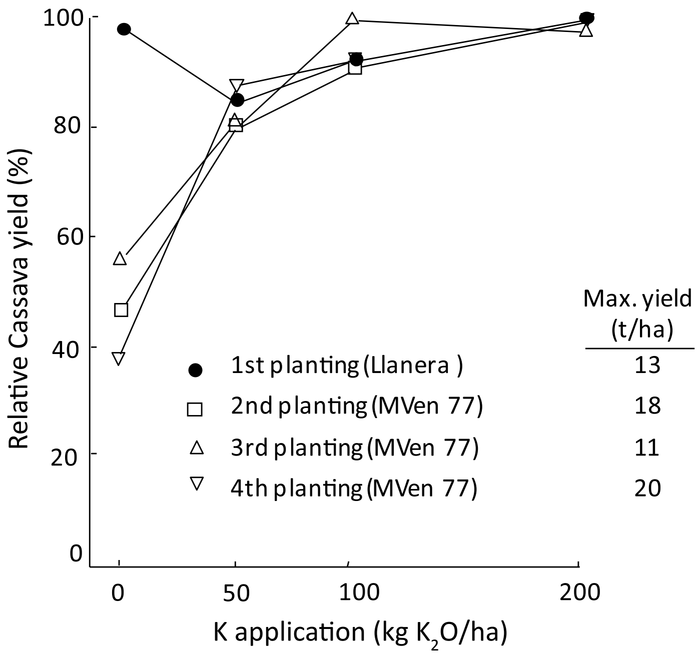

Figure 10. *The effect of annual application of four amounts of applied K on the relative yield of cassava cv. MVen 77 during 4 consecutive cropping cycles in Carimagua, Colombia.*

Source: *Howeler, 1985a.*

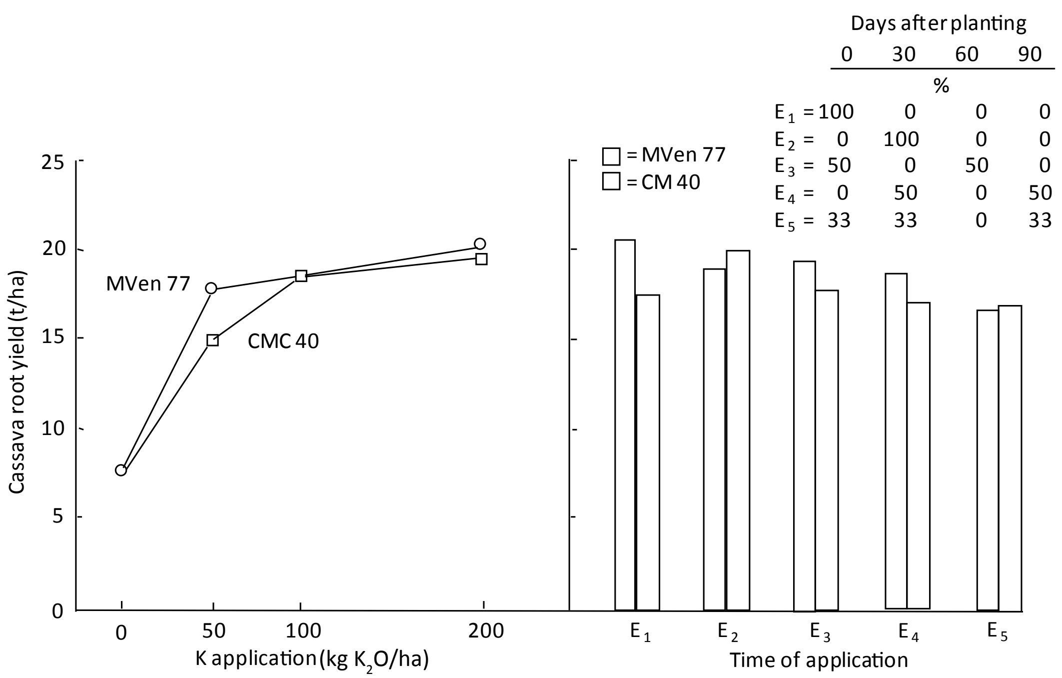

Figure 11. *Effect of amounts and times of application of K on the root yield of two cassava varieties grown in Carimagua, Meta, Colombia.*

2. Time and Method of Application of Chemical Fertilizers

Most chemical fertilizers dissolve rather rapidly in soil solution. These fertilizers should be applied in short (20–30 cm) bands made with a hoe at 5–10 cm from the cassava stake or plant. After application, the fertilizers should be covered with soil to prevent volatilization of N and losses of nutrients by runoff and erosion. The roots of cassava will grow toward the fertilizer band to take up the nutrients dissolved in the soil solution. This localized application will prevent fertilization of the weeds growing nearby. These rather soluble fertilizers, such as urea, single (SSP) and triple superphosphate (TSP), di-ammonium phosphate (DAP), potassium chloride (KCl), or sulfate (K_2SO_4), as well as most compound fertilizers, should be applied at the time of planting the stakes or, preferably, about 1 month after planting when the roots have emerged to take up the nutrients. Phosphorus fertilizers should all be applied at or shortly after planting, while N and K can best be applied in split doses, about one-half at or shortly after planting, and the rest at 2–3 months after planting when cassava reaches its maximum growth rate.

Less soluble fertilizers, such as basic slag, rock phosphates, lime, gypsum, sulfur, compost, and manures, should be broadcast over the entire field and incorporated before planting in order to achieve good contact with the soil and enhance their dissolution or decomposition.

3. Effect of Fertilizers on Root Quality

Fertilizer applications affect not only cassava yield but also the quality of the harvested roots, primarily the dry matter and starch content of the roots as well as the HCN content, and thus the bitterness of the roots. Chan and Lee (1982) reported that root starch content increased with K application, reaching a maximum of 36.8% with the application of 180 kg K_2O/ha. Higher K rates decreased the starch content. Obigbesan (1973) also found a marked effect of K application on starch content, being maximum with 67 and 100 kg K_2O/ha applied, whereas HCN content decreased from 270 to 160 ppm of fresh roots with the application of 134 kg K_2O/ha.

The Central Tuber Crops Research Institute (CTCRI, 1975) reported a slight increase in starch content due to K application, but a marked decrease in HCN content of the roots. CIAT (1980) also reported an increase in starch content from 26.7% to 34.2% with the application of 50 kg K_2O/ha, above which there was no significant effect. In NPK trials in Colombia, it was found that, in most cases, K application had no significant effect on starch content. Only in two out of 19 trials was there a significant positive effect, whereas in one trial the effect was negative. Thus, it appears that the effect of K on starch content is rather variable; in low K soils (<0.15 meq K/100g), there is generally a positive effect with low amounts of application, above which there is not a significant effect.

High rates of N application, on the other hand, will generally decrease root starch content (see **Figure 4** above), while they will increase the production of N-containing compounds such as proteins and HCN. P application tends to increase root starch content, but not to the same extent as the application of K. **Figure 12** shows that, at a high-elevation site in Cauca, Colombia, the application of 100 kg K/ha (120 kg K_2O) increased root starch content from 32% to 35%. Higher applications of K had no more beneficial effect. P application up to 100 kg P/ha (229 kg P_2O_5/ha) also increased starch content, while N application had no effect at low amounts of application and decreased starch content at rates of 200 kg N/ha.

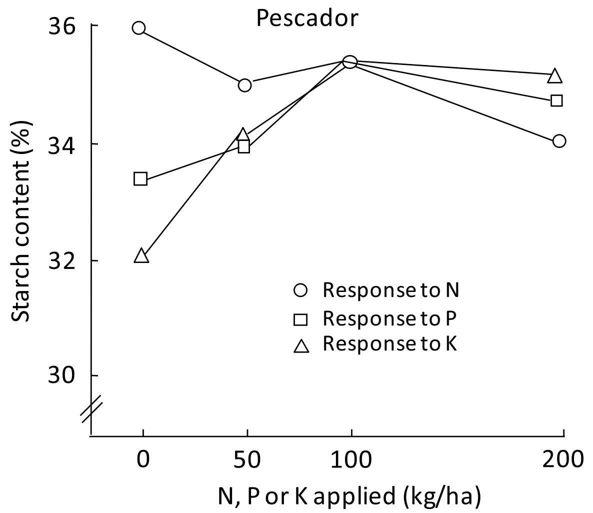

Figure 12. *Effect of different amounts of applied N, P, and K on the starch content of cassava roots in Pescador, Cauca, Colombia.*

Note: N, P, and K are in kg/ha of N, P, and K, not N, P_2O_5, and K_2O.
Source: *Howeler, 1985a.*

4. Effect of Fertilizers on Stake Quality

Fertilizer application affects not only root yield and the quality of the roots but also top growth, the thickness of stems, and ultimately the quality of stakes produced from those stems, which in turn affects the yield of the following crop. **Table 3** shows that, when stakes were cut from plants that had been fertilized with different combinations of N, P, and K during the previous 8 years in Santander de Quilichao, Colombia, these stakes had markedly different nutrient contents, depending on the previous fertilization of the mother plants. This was partially due to the well-fertilized plants producing thicker stakes (dry weight per stake increased from 11.0 to 16.0 g/stake) and partially due to an increase in the concentration of each nutrient in the stake; this was especially true for K. Moreover, the previous fertilizer treatments increased the starch and sugar contents of the stakes, which are important for improving sprouting and the early vigor of the new plants. This was clearly evident in the significant improvement in sprouting, and ultimately resulted in marked improvements in top growth and root production of the following cassava crop. Fertilizer application of that crop did increase yield, but the previous fertilization of the mother plants had an even more marked effect on yield, almost doubling yield under both fertilized and unfertilized conditions of the crop (**Table 3**) (López and El-Sharkawy, 1995). Similar results were obtained by Keating et al. (1982).

Table 3. Effect of N, P, and K fertilization of mother plants on the quality of stakes cut from the stems, and on the sprouting and yield of the subsequent cassava crop in Santander de Quilichao, Colombia, in 1991/92.

Treatments [1]			Nutrient content of stakes			Starch content of stakes	Sprouting of stakes	Root yield (t/ha)	
N	P	K	N	P	K				
(kg/ha)			(mg/stake)			(g/stake)	(%)	Unfertilized	Fertilized [2]
0	0	0	70	10	19	2.62	85b	13.5	19.1
0	100	100	76	21	54	3.38	97a	17.5	24.7
100	0	100	146	14	87	4.68	98a	14.9	23.5
100	100	0	117	21	28	3.17	77b	15.8	24.7
100	100	100	139	25	72	4.29	97a	24.2	30.2

[1] Fertilization of mother plants from which stakes were cut.
[2] Fertilization of subsequent crop with 50 kg N, 43 P and 83 K/ha;
Note: Data within a column followed by the same letter are not significantly different
Source: *Adapted from Lopez and El-Sharkawy, 1995.*

CHAPTER 9

SECONDARY AND MICRONUTRIENT REQUIREMENTS AND THE USE OF SOIL AMENDMENTS

1. Calcium and Magnesium

Calcium (Ca) plays an important role in the supply and regulation of water in the plant, while Mg is a basic component of chlorophyll and as such is essential for photosynthesis.

Symptoms of Ca deficiency are seldom observed on cassava in the field; but, in very acid soils with low exchangeable Ca (<0.25 meq/100 g), the crop may respond to Ca applications. Plants suffering from Ca deficiency are slightly smaller and the fibrous root system is less developed. In nutrient solutions, severe Ca deficiency results in short plants, yellowing of the margins of older leaves, and curling and puckering of leaf tips and margins of young leaves. Since Ca is a phloem-immobile element, its deficiency affects principally the growing points of both tops and roots. Thus, Ca deficiency reduces root growth and results in a coarse and stubby root system.

In flowing solution culture, cassava was found to be more tolerant of extremely low Ca concentrations than maize, sorghum, sunflower, and soybean (Edwards et al., 1977). Also, in very Ca-deficient soils in Nigeria, Edwards and Kang (1978) did not observe Ca-deficiency symptoms in cassava, while maize, soybean, and lima beans were severely affected.

In Carimagua-Alegría, Colombia, highly significant responses to the application of Ca were obtained in a sandy loam soil with a pH of 5.1 and only 0.18 meq Ca/100 g and 0.05 meq Mg/100 g (**Figure 1**). The highest yield was obtained with the application of 200−400 kg Ca/ha as broadcast gypsum. Broadcast calcitic or dolomitic limes were less effective, while band-applied gypsum was ineffective in increasing cassava yield (CIAT, 1985a). As these Ca sources are relatively insoluble, they should all be broadcast and incorporated before planting. The good response to gypsum was not a response to S because either $MgSO_4$ or elemental S had been applied uniformly to all plots. Because of its low Ca content (8−11%) and high cost, gypsum is an expensive source of Ca compared with lime. However, **Figure 1** shows that 100 kg Ca/ha as gypsum was more effective than 400 kg Ca/ha as calcitic lime, both being equivalent to about 1 t/ha of product to be applied.

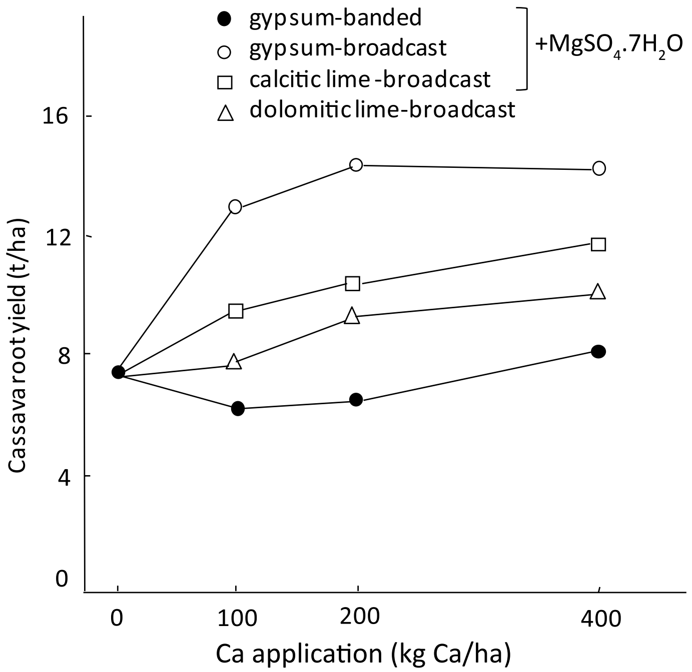

Figure 1. *Effect of different amounts, sources, and methods of application of Ca on the fresh root yield of cassava cv. CM 523-7 in Carimagua, Colombia.*

Source: *CIAT, 1985a.*

Symptoms of magnesium (Mg) deficiency are frequently observed in cassava grown on acid Oxisols, Ultisols, Inceptisols, and Entisols. These plants are characterized by interveinal chlorosis and a distinct yellowing of the margins of lower leaves. Under very severe Mg deficiency, plants are smaller in size and the lower leaves may be completely yellow with necrosis along the leaf borders. Cassava was found to be quite susceptible to Mg deficiency, requiring for maximum growth higher Mg concentrations in nutrient solution than cowpea or cotton (Whitehead, 1979). Also, Mg-deficiency symptoms were easily induced by high concentrations of K in nutrient solution (Spear et al., 1978b).

In the same soil in Carimagua, two Mg experiments were conducted to determine the optimum rates and best sources of Mg (CIAT, 1985a). There was a significant response up to the highest amount of 60 kg Mg/ha, but there were no overall significant differences among sources. The more soluble Sulphomag was more effective at intermediate rates, while banded $MgSO_4$ or broadcast MgO was better at higher rates of application (**Figures 2** and **3**).

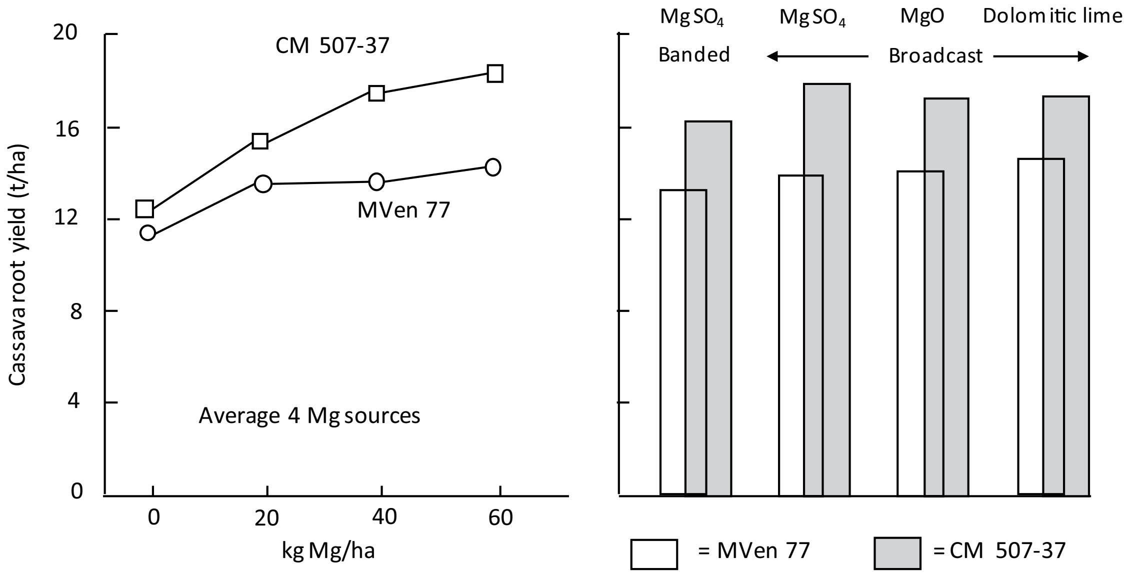

Figure 2. *Response of two cassava varieties to different amounts (left) and sources (right) of applied Mg in Carimagua, Colombia.*

Source: *CIAT, 1985a.*

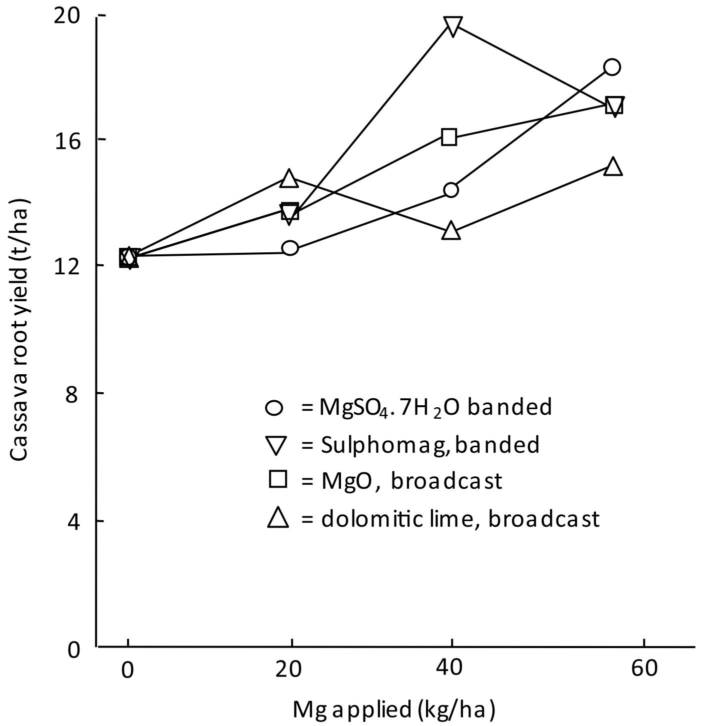

Figure 3. *Response of cassava cv. CM 430-37 to various amounts of Mg applied as four different sources in Carimagua-Alegría, Colombia.*

Source: *CIAT, 1985a.*

2. Interactions between Potassium, Calcium, and Magnesium

There are numerous reports in the literature on the interaction between K, Ca, and Mg in a range of crops, including such tropical crops as bananas (Lahav, 1974) and peanuts (Fageria, 1973). In general, it was found that increasing the application of K resulted in a decrease in the absorption of other cations, such as Ca and Mg. In the case of cassava, Spear et al. (1978b) reported that, in flowing solution culture in which the concentrations of K, Ca, and Mg were closely controlled, increasing the concentration of K in solution from 0.5 to 8,024 µM resulted in an increase in K and a decrease in Ca and Mg absorption as well as the concentrations in plant tissue. In some cultivars, the rate of Ca absorption increased with increasing K concentration between 0.5 and 6 µM, but decreased at higher concentrations. The rate of Mg absorption was strongly depressed by increasing concentrations of K, and this resulted in the induction of Mg-deficiency symptoms at high concentrations of K in solution. Cassava had a lower rate of Mg absorption and a greater retention of Mg in the roots than maize and sunflower, making it inherently more susceptible to K-induced Mg deficiency. Conversely, cassava had a higher rate of Ca absorption than maize, and this rate was less affected by increasing the K concentration, making it less susceptible to K-induced Ca deficiency.

However, in nutrient solution studies in which K, Ca, and Mg concentrations increased according to the rate of plant growth [programmed nutrient solution techniques, as described by Asher and Cowie (1970)], there was no consistent effect of increasing solution K concentrations on the Ca concentration of youngest fully expanded leaf (YFEL) blades, whereas that of Mg increased slightly (**Table 1**). Thus, when the Ca and Mg supply was high enough to maintain an optimum rate of absorption throughout the 2-month growth period, there was no effect of K on Ca and Mg uptake. Conversely, when the solution Mg concentration increased, the K concentration of YFEL blades decreased markedly from 2.74% to 1.59%, while the Ca concentration decreased from 0.75% to 0.32%. With increasing Ca concentration in solution, there was a marked decrease in the Mg concentration of YFEL blades but no consistent effect on the K concentration (**Table 1**). Thus, under these experimental conditions, increasing the K supply had no effect on Ca and Mg concentrations, but increasing the Mg supply had a marked depressing effect on the K and Ca concentration in YFEL blades.

Field experiments with the same cultivar in Carimagua, Colombia (**Table 2**), showed that increasing applications of K slightly decreased the Mg concentration and had no effect on the Ca concentration in YFEL blades. Increasing applications of Ca had no significant effect on K but slightly depressed the Mg concentration, whereas increasing applications of Mg slightly decreased the concentrations of both K and Ca in YFEL blades.

The discrepancy in results between these three sets of trials is due mainly to the greater range of K, Ca, and Mg concentrations used in the nutrient solution studies than in the field trials. If only the intermediate concentrations 3, 4, 5, and 6 in **Table 1** are compared with those of **Table 2**, one would find more correspondence of results. One could conclude that, under normal field conditions, the application of K is not likely to have a significant effect on Ca, but may depress the Mg concentration in YFEL blades, whereas the application of increasing amounts of Ca or Mg does not affect the concentration of K, but may depress the concentration of Mg and Ca, respectively, in the YFEL blades.

Table 1. Concentration of K, Ca, and Mg in youngest fully expanded leaf blades of 2-month-old cassava cv. MVen 77 grown with increasing concentrations of each element in nutrient solution experiments at CIAT, Colombia.

K experiment				Ca experiment				Mg experiment			
K level applied	K (%)	Ca (%)	Mg (%)	Ca level applied	Ca (%)	K (%)	Mg (%)	Mg level applied	Mg (%)	K (%)	Ca (%)
K-1	0.85	0.37	0.25	Ca-1	0.05	1.95	0.31	Mg-1	0.05	2.74	0.75
K-2	1.43	0.40	0.24	Ca-2	0.11	1.70	0.27	Mg-2	0.07	2.27	0.67
K-3	1.16	0.35	0.28	Ca-3	0.33	1.81	0.26	Mg-3	0.15	1.68	0.43
K-4	1.35	0.42	0.27	Ca-4	0.47	1.65	0.22	Mg-4	0.20	1.67	0.41
K-5	1.68	0.51	0.29	Ca-5	0.52	1.73	0.21	Mg-5	0.22	1.69	0.37
K-6	1.90	0.39	0.28	Ca-6	0.57	1.87	0.18	Mg-6	0.24	1.54	0.35
K-7	2.36	0.32	0.29	Ca-7	0.72	1.76	0.16	Mg-7	0.30	1.59	0.32

Source: *Howeler, 1985b.*

Table 2. Effect of application of various amounts of K, Ca, and Mg on the concentration of these nutrients in youngest fully expanded leaf blades of 2–4-month old cassava cv. MVen 77 grown in field experiments in Carimagua-Alegría, Colombia.

K experiment				Ca experiment				Mg experiment			
K applied (kg/ha)	K (%)	Ca (%)	Mg (%)	Ca applied (kg/ha)	Ca (%)	K (%)	Mg (%)	Mg applied (kg/ha)	Mg (%)	K (%)	Ca (%)
K-0	1.25	0.67	0.26	Ca-0	0.32	1.82	0.28	Mg-0	0.20	1.99	0.70
K-50	1.82	0.68	0.24	Ca-100	0.51	2.00	0.27	Mg-20	0.23	1.91	0.69
K-100	1.87	0.66	0.23	Ca-200	0.48	1.87	0.25	Mg-40	0.25	1.93	0.69
K-200	2.07	0.66	0.23	Ca-400	0.51	1.90	0.24	Mg-60	0.25	1.94	0.60

Source: *Howeler, 1985b.*

3. Sulfur

Sulfur is a basic component of several amino acids and therefore it plays an important role in protein synthesis. When the S supply is deficient, the plant accumulates in its leaves excessive amounts of inorganic N, amino acids, and amids, without sufficient protein production (Stewart and Porter, 1969).

Sulfur deficiency in cassava is characterized by a uniform yellowing of upper leaves similar to that caused by N deficiency. Usually, the whole plant becomes uniformly chlorotic and the leaves remain small. This deficiency can be induced by high applications of KCl and eliminated by applications of K_2SO_4 or other sulfate sources, as well as by the incorporation of elemental S (Ngongi et al., 1977).

In industrial areas, much of the plant's S requirements are met from S emissions into the atmosphere, but, in isolated areas, far from any industrial activity, cassava may suffer from S deficiency. This has been reported only for Carimagua in the Eastern Plains of Colombia, which are far removed from any industrial center. Soils there contained only 23 ppm of Ca phosphate-extractable S; with the application of 40 kg S/ha as elemental S, this increased to 36 ppm. **Figure 4** shows a clear response to the application of S up to 20−40 kg S/ha. There were no significant differences among S sources although yield was slightly higher with banded K- and Mg-sulfate than with broadcast elemental S. Clear S-deficiency symptoms were observed in the check plots. These plants had 0.20–0.25% S in YFEL blades compared with 0.30–0.32% in plants that had received S applications. Critical levels of 0.27% and 0.33% S were estimated in two field experiments (Howeler, 2002).

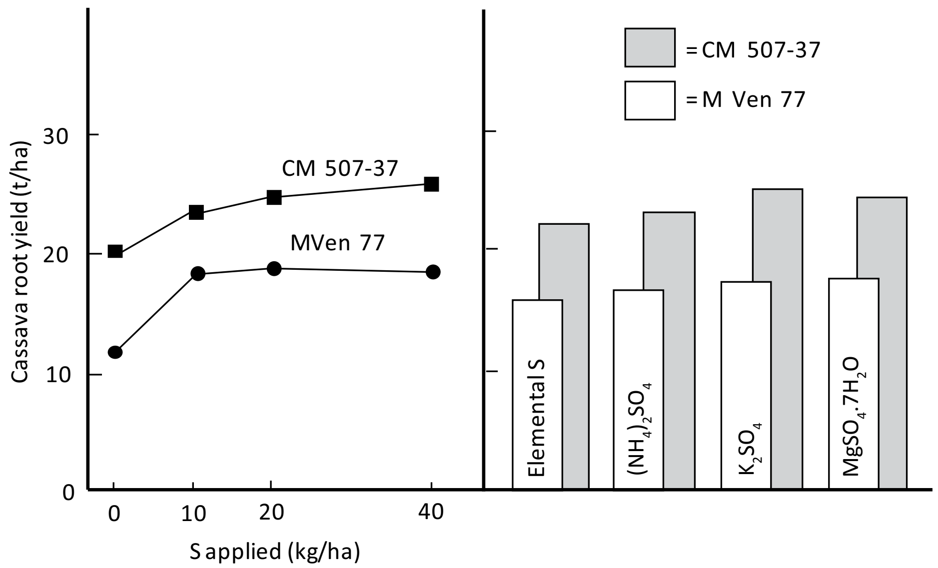

Figure 4. *Effect of sources and amounts of applied S on the fresh root yield of two cassava varieties grown in Carimagua-Yopare, Colombia, in 1986/87.*

Source: *Howeler, 2002.*

4. Micronutrients

Micronutrients are absorbed by the plant in very small quantities, but they are a basic component of many enzymes and thus play an essential role in most metabolic processes. There are few reports on micronutrient deficiencies in cassava, but these deficiencies may be more common than is generally recognized. Deficiencies of micronutrients B, Cu, Fe, Mn, and Zn are most often observed in high-pH or calcareous soils, but deficiencies of Zn have been observed in both acid and alkaline soils. Lime application to acid soils with low available Zn may induce Zn deficiency, resulting in low yield and even death of young plants.

Cassava grown on high-pH Vertisols in Tamil Nadu, India, often show symptoms of Fe, Zn, and B deficiencies, while deficiencies of Zn and B are often seen on cassava grown on Alfisols. Zn deficiency is also common on acid Ultisols, especially after many years of cropping and the use of only chemical NPK fertilizers (Pillai et al., 1991; Sheeja et al., 1993).

a. Zinc

Cassava is susceptible to Zn deficiency, especially at the early stages of growth. Symptoms of Zn deficiency appear as interveinal chlorotic spots or lines on younger leaves. When the deficiency is very severe, the whole leaf becomes pale green to white, and leaf lobes become smaller and tend to point outward away from the stem. Oftentimes, lower leaves show necrotic white or brown spotting and the plant remains small and weak. Plants showing early symptoms of Zn deficiency may later recuperate once the fibrous root system is well established and roots become infected with mycorrhizae. If the deficiency is severe, however, plants may either die or produce very low yield.

Symptoms of severe Zn deficiency have been observed in acid soils in Colombia, Brazil, Malaysia, Thailand, Nigeria, Tanzania, and Mexico, as well as in alkaline and/or calcareous soils in Colombia, Cuba, Mexico, and Indonesia.

On acid soils, Zn deficiency can be controlled by the incorporation of ZnO or band placement of $ZnSO_4.7H_2O$ at the rate of 10–20 kg Zn/ha. Also effective are foliar applications of 1–2% $ZnSO_4.7H_2O$, or stake treatments in 2–4% $ZnSO_4.7H_2O$ solution during 15 minutes before planting.

Figure 5A shows the response of two varieties to soil application of different amounts of Zn as $ZnSO_4.7H_2O$ in a very acid soil in Carimagua-Alegría, Colombia, after applying 2 t/ha of lime (CIAT, 1985a). Both varieties were seriously affected by Zn deficiency in the check plots, but reached maximum yield with the application of 10 kg Zn/ha, band-applied together with NPK fertilizer at planting. **Figure 5B** shows the relation between the root yield of MVen 77 and the Zn concentration in YFEL blades at 4 MAP. A critical level of 33 ppm Zn was estimated. Broadcast application of 10–20 kg/ha of Zn as ZnO was also effective in increasing yield in acid soils (CIAT, 1978).

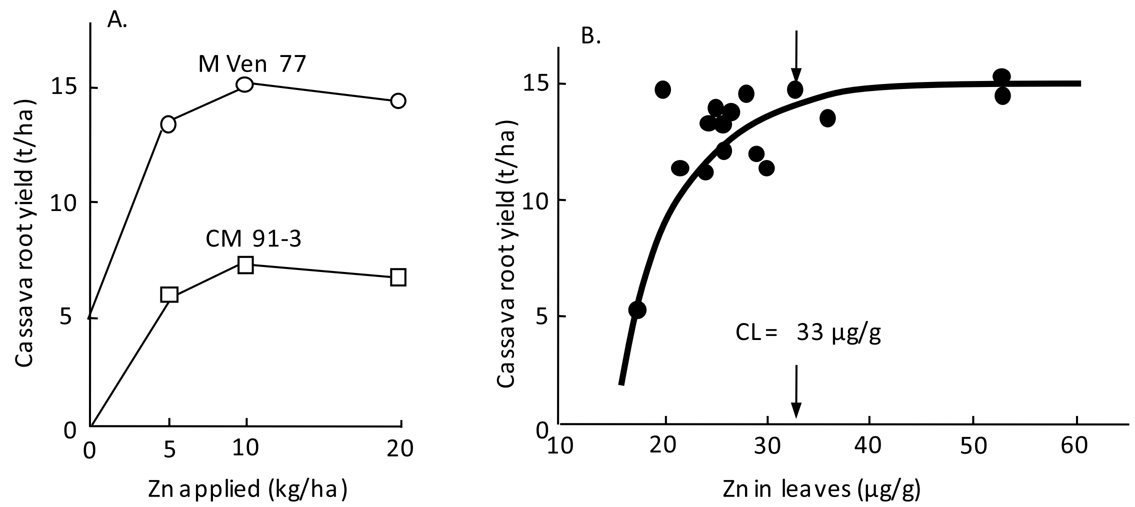

Figure 5. *Root yield response of two cassava varieties to various amounts of applied Zn (A), and the relation between the root yield of cv. MVen 77 and Zn concentration in YFEL blades at 4 months after planting in Carimagua-Alegría, Colombia (B). Arrows indicate the critical level for Zn deficiency.*

Source: *CIAT, 1985a.*

In high-pH soils, application of $ZnSO_4.7H_2O$ to the soil is not as effective because the applied Zn will be precipitated rather rapidly (CIAT, 1978). Foliar application or stake treatments may be more effective. When 20 cassava cultivars were planted in a high-pH (7.9), low-Zn (1.0 ppm) soil, with or without treating stakes for 15 minutes in a solution of 4% $ZnSO_4.7H_2O$ before planting, yield increased from an average of 11.5 t/ha to 25.0 t/ha due to the Zn treatment (CIAT, 1985a). Large varietal differences in low-Zn tolerance were observed, with some cultivars dying off completely without the Zn treatment and others producing high yield with or without Zn (**Table 3**).

Table 3. Zinc concentration of YFEL blades at 4½ months after planting and root yield of 20 cassava varieties planted with and without a stake treatment with 4% $ZnSO_4$. $7H_2O$ in an alkaline soil at CIAT, Palmira, Colombia.

Variety	Zn concentration in leaves with Zn treatment (ppm)	Fresh root yield (t/ha)	
		With Zn	Without Zn
MPer 176	22	3.9	0
MPer 193	19	24.9	10.7
MPer 196	17	30.5	13.8
MPer 200	22	35.4	15.0
MPer 206	20	31.1	9.0
MPer 211	20	21.9	9.2
MPer 239	20	25.9	13.0
MPer 243	24	7.6	6.5
MPer 244	25	18.0	14.1
MPer 245	23	1.0	0.6
MPer 247	22	48.7	31.3
MPer 252	26	22.8	17.2
MPer 253	20	44.9	10.7
MPer 266	20	20.4	8.1
MCol 22	21	23.3	11.2
MCol 113	25	35.3	9.4
MCol 438	22	3.7	2.3
MVen 290	20	8.8	3.4
CM 231-188	21	47.6	23.5
CM 498-1	18	44.8	21.2
Average		**25.0**	**11.5**

Source: *CIAT 1985a.*

b. Copper

Copper deficiency in cassava results in reduced plant height, chlorosis and curling of upper leaves, and necrosis of leaf tips. Lower petioles tend to be long and droopy.

Severe Cu deficiency has been reported only in peat soils of Malaysia. A basal application of 2.5 kg Cu/ha as $CuSO_4.5H_2O$ increased yield from 4 to 12 t/ha (Chew, 1971; Chew et al., 1978).

c. Iron

Iron-deficient plants have smaller but normal-shaped upper leaves that are light-green, yellow, or white in color. When the deficiency is severe, even the upper petioles are white.

Iron deficiency has been observed in calcareous soils of the Yucatan peninsula of Mexico, in northern Colombia, in Tamil Nadu State of India, in western Nakorn Ratchasima Province of Thailand, and along the southern coast of Java island in Indonesia. It is also commonly seen when cassava is grown on what used to be termite hills, which tend to have a soil pH considerably higher than the surrounding area.

A practical solution is probably a stake treatment with 2−4% $FeSO_4.7H_2O$ or foliar applications of Fe-sulfate or chelates

d. Manganese

Manganese deficiency is characterized by interveinal chlorosis (fish-bone pattern) of middle leaves, similar to Mg deficiency but generally not present in lower leaves. When the deficiency is severe, the whole leaf turns uniformly yellow, similar to Fe deficiency or salinity.

Manganese deficiency has been observed in alkaline soils in the Cauca valley of Colombia, along the coast in northeast Brazil, and in northern Vietnam, near houses where lime had been used for their construction. Stake treatments before planting with $MnSO_4.4H_2O$ or foliar sprays with sulfates or chelates are probably the most practical solutions.

e. Boron

Being a phloem-immobile nutrient, B is not readily translocated to the growing points. Thus, in case of B deficiency, both the young shoots and the root system are affected. In nutrient solution, cassava plants suffering from severe B deficiency have a deformed growing point with very short internodes and small dark green leaves. Sometimes the petioles or stem exude a brown gummy substance, which later produces brown lesions. The root system is short and stubby. In the field, however, these severe symptoms are seldom observed; instead, B-deficient plants have chlorotic small spots on the middle or lower leaves. Similar symptoms were also observed in northern Vietnam and southern China, although the exact nature of those problems was never identified.

Some symptoms of B deficiency have been observed both in acid soils of Carimagua and Santander de Quilichao, and in alkaline soils at CIAT-Palmira. Applications of 1−2 kg B/ha, band-applied as Borax at the time of planting, eliminated these symptoms, increased plant height, and increased the B concentration in the leaves from 3 to 40 ppm, but had no significant effect on yield. Cassava seems to be much more tolerant of a low B concentration in the soil than maize or *Phaseolus vulgaris* beans (Howeler et al., 1978).

Boron toxicity has not been observed under natural conditions, but is easily induced by excessive applications of B to the soil or in stake treatments. B toxicity causes necrosis of lower leaves. Since the element is not readily translocated to the growing points, plants generally recuperate.

5. Aluminum and Manganese Toxicity and Low pH

Large parts of the tropics are unproductive because the soils are too acid for most cultivated crops, and the lack of adequate roads makes the transport of lime prohibitively expensive. In these areas, cassava is often the staple food because this crop is highly tolerant of low pH and the associated high Al and Mn, low Ca, Mg, and K, and sometimes low P and N. Cassava as a species is particularly tolerant of soil acidity and high Al (Gunatilaka, 1977; CIAT, 1979; Islam et al., 1980), but some varietal differences in acid soil tolerance have also been observed (CIAT, 1982a; 1985a; Howeler, 1991a).

Clear symptoms of Al toxicity in the field are seldom observed, except that plants are small and lack sufficient vigor. Under severe Al toxicity conditions in nutrient solutions, the lower leaves may have interveinal chlorosis and necrotic spots. A high concentration of Al has an especially detrimental effect on root growth, which in turn affects nutrient and water absorption.

Plants suffering from Mn toxicity have droopy yellow bottom leaves with brown or black spots along the veins. These leaves may later fall off, leaving the plant without recognizable symptoms. Mn toxicity occurs only in very acid soils high in Mn and mainly in areas of compacted soils, leading to poor drainage. This enhances the solubility of Mn due to reduction processes. Mn toxicity not only reduces the vigor of the plant tops but also seriously affects the root system. Compared with other crops, cassava is relatively tolerant of high Mn. Among 13 plant species studied, only three species were more tolerant (Edwards and Asher, unpublished). Among cassava cultivars, considerable differences in tolerance were also observed. Mn toxicity in cassava has been reported only in acid Ultisols and Inceptisols in Santander de Quilichao, Colombia, and in a compacted sandy clay-loam soil in Thailand (Silpamaneephan, 1994). The application of lime in acid soils decreases the concentration of both Al and Mn, thus reducing their toxic effects.

Unlike in Latin America, cassava production on very acid soils in Asia is rare. Although cassava is mostly grown on acid soils, the pH is seldom low enough or the Al saturation high enough to warrant lime applications. However, a significant response to lime application has been reported when cassava was grown on acid peat soils in Malaysia. When peat is drained, the soil may become extremely acid, the pH may drop to as low as 3.2, but the Al saturation is usually not as high as in mineral soils. A long-term fertilizer and lime trial on a peat soil at Pontian Station in the south of Peninsular Malaysia indicated a highly significant response to the application of 3 t/ha of lime, but no consistent response to the application of N, P, or K fertilizer (Tan and Chan, 1989; Tan 1992).

Another long-term fertilizer experiment conducted for 12 years on an acid Ultisol at CTCRI in Kerala, India, indicated that the annual application of 2.65 t/ha of wood ash increased soil pH from 4.7 to 6.1 and markedly increased exchangeable K, Ca, and Mg, but had no effect on the OM or available P, Cu, and Zn content. In contrast, with the annual application of only chemical fertilizer, at 100 kg/ha each of N, P_2O_5, and K_2O, there was a marked build-up of P, some increase in K, and a marked decline in Ca, Mg, Cu, and Zn (Nayar et al., 1995).

Another experiment conducted at CTCRI over 4 years using five rates of application of lime, ranging from zero to 3.5 t/ha of $CaCO_3$, resulted in a 39% increase in root yield—from 18.7 to 26.0 t/ha—with the highest rate of lime application. In addition to increasing root yield, lime application also improved the quality of roots by increasing the starch content and decreasing the concentration of HCN (Mohan Kumar and Nair, 1985).

In mineral soils, a low pH is usually associated with high Al and/or Mn, which can both be toxic at high concentrations, although Al toxicity is much more common than Mn toxicity. Lime application to a mineral soil will simultaneously increase pH, reduce the exchangeable Al, and increase the exchangeable Ca, as well as Mg if a dolomitic lime is used. This will reduce the Al saturation of the soil. Usually, at pH>5.5, Al saturation is zero and Al toxicity is not a problem. But, at pH<5.5, Al saturation increases with decreasing pH. Crops differ in their tolerance of high Al, with cotton and some grain legumes being seriously affected by even low Al saturation of 10–20%, while coffee and cassava will tolerate up to 60% and 80% Al saturation, respectively (**Table 4**). Within each species, there are also varietal differences in tolerance of high Al, and, through greenhouse or field screening, varieties can be identified with particularly good tolerance of high Al (Howeler, 1991a; Howeler and Cadavid, 1976).

Table 4. Critical levels of nutrients in soil for cassava and some other crops as reported in the literature.

Soil parameter	Crop	Critical level[1]	Source
pH (1:1 in water)	Cassava	4.6 and 7.8	CIAT, 1977, 1979
	Common bean[2]	4.9	Abruña et al., 1974
Al (% saturation)[3]	Cassava	80	CIAT, 1979; Howeler, 1980
	Coffee	60	Abruña et al., 1964,1965,1975
	Rice	40	Salinas and Sanchez, 1977
	Maize	30–45	Salinas and Sanchez, 1977
	Sorghum	20	Abruña et al., 1964,1965,1975
	Soybean	20	Abruña et al., 1964,1965,1975
	Common bean	10–23	Abruña et al., 1975; Howeler, 1991a
	Cotton	10	Abruña et al., 1964,1965,1975
P (µg/g in Bray I)	Cassava	3–8	Howeler, 1978, 1989
	Maize	14	Kang et al., 1980
	Soybean	15	Kang et al., 1980
P (µg/g in Bray II)	Cassava	4–6	Howeler, 1985a
	Common bean	10–15	Howeler and Medina, 1978
K (meq/100 g in NH_4-acetate)	Cassava	0.10–0.18	Howeler, 1985b, 1989
	Rice	0.21	Jones et al., 1982
	Potato	0.20–1.0	Roberts and McDole, 1985
	Sugarcane	0.16–0.51	Orlando Filho, 1985
Ca (meq/100 g in NH_4-acetate)	Cassava	0.25	CIAT, 1979
	Common bean	4.5	Howeler and Medina, 1978
Mg (meq/100 g in NH_4-acetate)	Cassava	<0.20	Kang, 1984

[1] The critical level is usually defined as the level corresponding to 95% of maximum yield.
[2] Phaseolus vulgaris.
[3] $\text{Al saturation} = 100\% \times \frac{\text{Exchangeable Al}}{\text{Exch. Al + Ca + Mg + K}}$

where Al, Ca, Mg, and K are all expressed in meq/100 g of soil.
Source: *Howeler, 1991a, 2002.*

Figure 6 shows that, in a field screening of a large number of varieties of five food crops in very acid soils with four rates of lime application, cassava and cowpea were the most Al-tolerant, followed by rice, black beans, maize, and nonblack beans. Without lime, this soil had a pH of 4.3 and 85% Al saturation. The exchangeable Al content decreased from 3.5 to 0.9 meq/100 g with the application of 6 t/ha of lime, resulting in an Al saturation of only 20% (**Figure 7**).

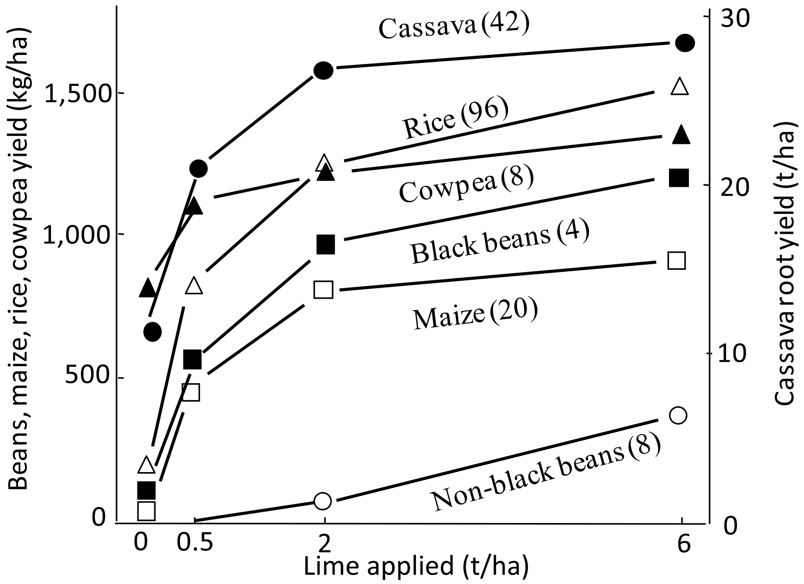

Figure 6. *The response of cassava, upland rice, cowpea, beans, and maize to the application of various rates of lime in Carimagua, Colombia. The number of cultivars or lines screened is shown in parentheses.*

Source: *Howeler, 1991a.*

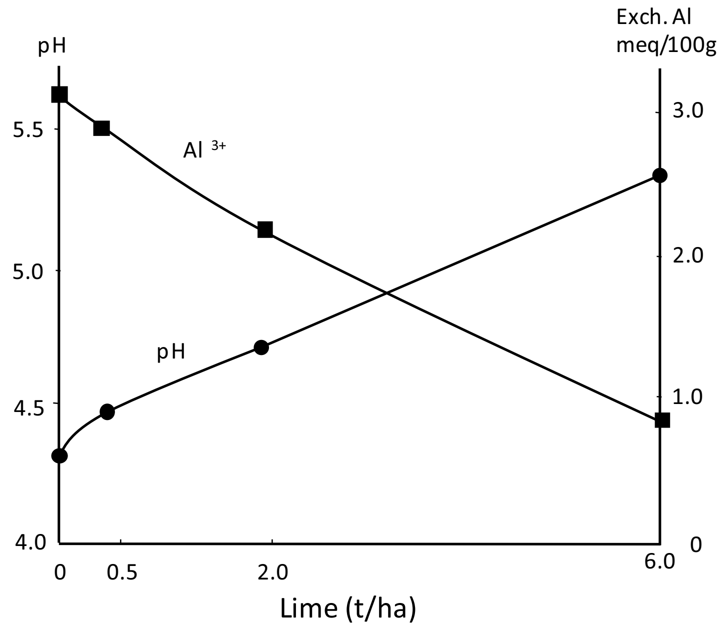

Figure 7. *Effect of different rates of lime application on the pH and exchangeable Al in an acid Oxisol in Carimagua, Colombia.*

Source: *Spain et al., 1975.*

Another illustration of these differences is shown in **Figure 8**. In a long-term NPK trial conducted for 16 years in Tamanbogo, Lampung, Indonesia, cassava was intercropped with maize and rice in 12 treatments of different rates of N, P, and K applied annually in the same plots. Over the course of the years, the annual application of fertilizer, especially with high rates of N, resulted in a gradual acidification of the soil with a simultaneous increase in Al saturation, from 51% in 1992 to 82% in 2004. Intercropped maize yield was low from the start, but decreased to zero as the Al saturation reached about 65% in the sixth year; intercropped rice yield started to decline drastically when the Al saturation reached 78% in the 10th year, while cassava yield remained relatively high (in the well-fertilized plots) even though Al saturation surpassed 80% in the 12th year. Rice yield increased again when lime was applied to all plots in the 15th and 16th year of continuous cropping.

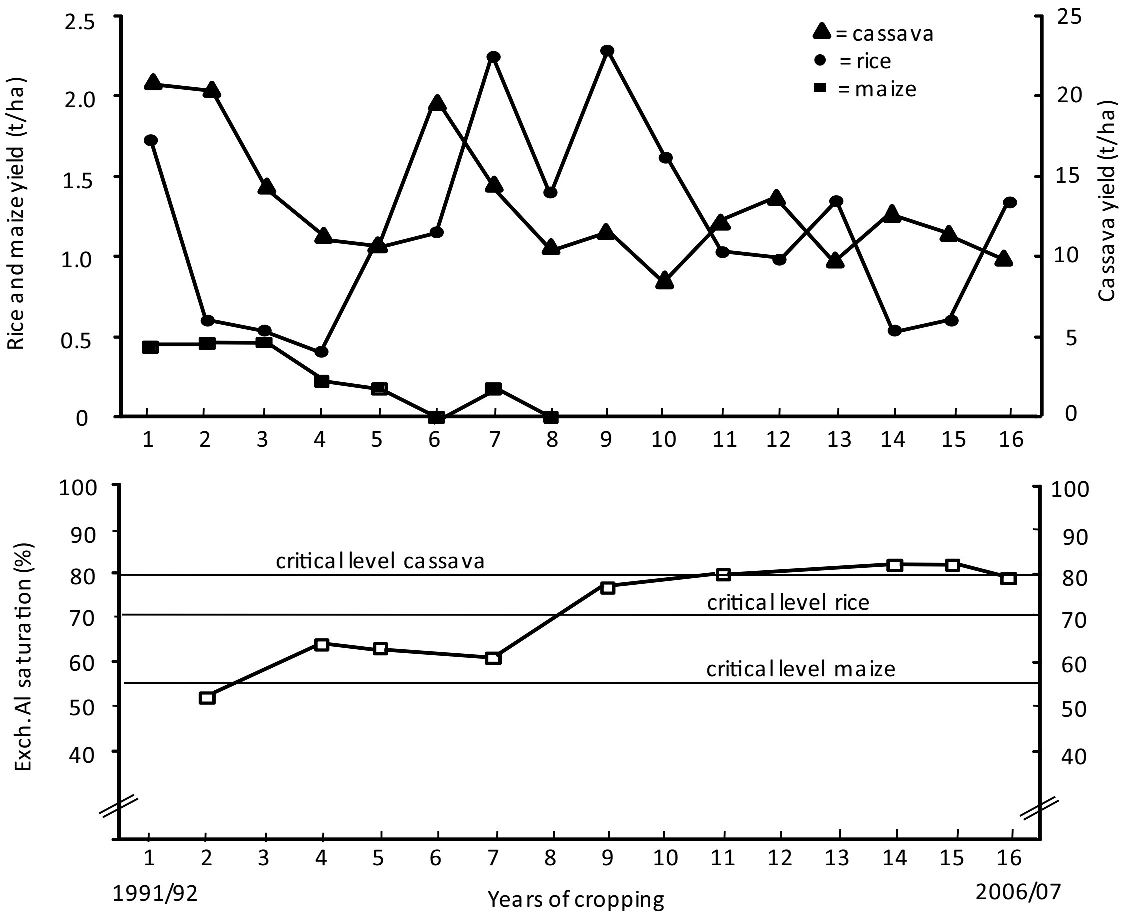

Figure 8. *Change in the yields of cassava and intercropped maize and rice during 16 consecutive years of growing cassava, cv. Adira 4, with intercropped rice and maize. Data are average values of 12 NPK treatments in a long-term NPK trial conducted in Tamanbogo, East Lampung, Lampung, Indonesia from 1991 to 2007. Below: The change in the average percent Al-saturation of the soil and the estimated critical levels for Al-toxiciy of the three crops.*

Note: 2 t/ha of lime were applied in Rep III before the 15th crop cycle and another 2 t/ha in Reps I and III before the 16th crop cycle.

Source: *Howeler, 2007.*

In very acid (pH<4.5) and high-Al (>80% Al saturation) soils, lime application may increase cassava yield, mainly by supplying Ca and Mg as nutrients. High rates of lime, however, may induce micronutrient deficiencies, particularly Zn, resulting in decreased yield (Spain et al., 1975; Edwards and Kang, 1978).

Figure 9A shows that, without applied Zn, cassava responded to lime applications only up to 2 t/ha, but, with applied Zn, there was a positive response up to 6 t/ha of lime. Analysis of cassava leaves (**Figure 9B**) confirmed that liming reduced Zn uptake and that, with 6 t/ha of lime without Zn, the Zn concentration in YFEL blades dropped below the critical level of 40−50 ppm. Large varietal differences have been observed for both high-Al and low-Zn tolerance (Spain et al., 1975; CIAT, 1985a).

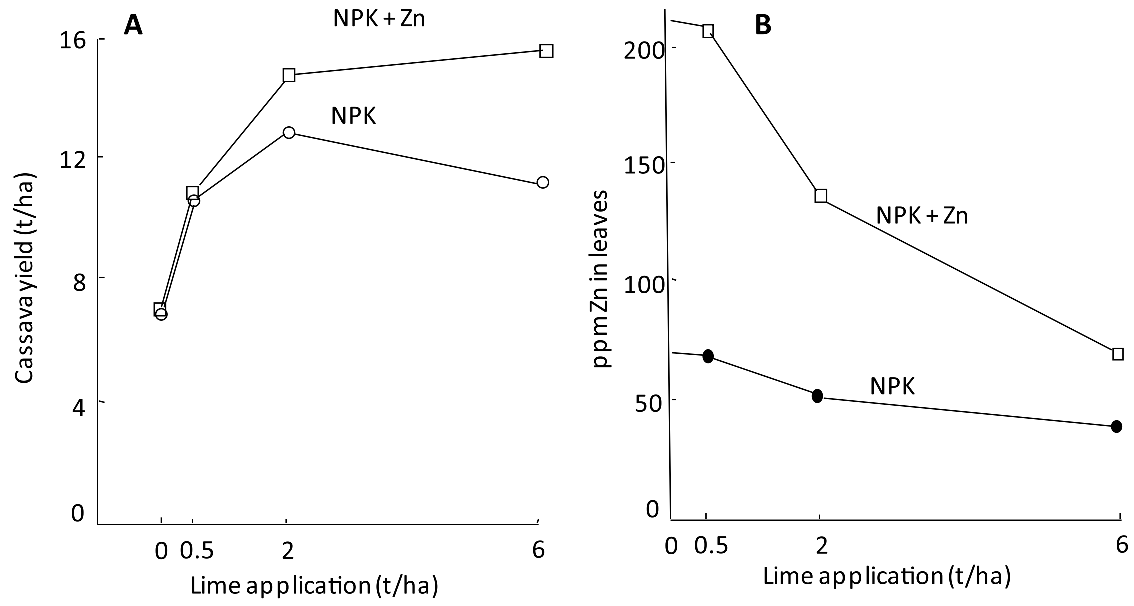

Figure 9. *Effect of lime application on root yield (A) and Zn concentration in YFEL blades at 2 MAP of cassava cv. Chirosa de Acacias grown with and without the application of 20 kg/ha of Zn in Carimagua, Colombia.*

Source: *CIAT, 1976.*

6. Soil Salinity, Alkalinity, and High pH

Although cassava is very tolerant of soil acidity, it is quite susceptible to salinity, alkalinity, and high pH. Islam (1980) showed that, in nutrient solution, cassava had optimum growth at pH 5.5 to 7.0 but top growth declined markedly above pH 7.5−8.0. The species was among the most tolerant of low pH and most susceptible to high pH **(Figure 10)**. In natural soils, high pH is generally associated with high concentration of salts (salinity) and Na (alkalinity), poor drainage, and micronutrient deficiencies. The crop usually suffers from a combination of these factors, which are difficult to study individually under field conditions. Also, salinity-alkalinity problems occur in spots in the field, giving rise to extremely heterogeneous soils and highly variable plant growth.

In **Figure 11**, cassava root yield was related to soil pH, percent Na saturation, and soil solution conductivity. Although there were significant differences among the three cultivars, root yield declined markedly above pH 8.0, above 2.5% Na saturation, and above 0.5−0.7 mmhos/cm of electrical conductivity (CIAT, 1977). Yield reductions are probably due to the combined effect of all three factors. In comparison, many other crops tolerate up to 15% Na saturation or 4 mmhos/cm conductivity.

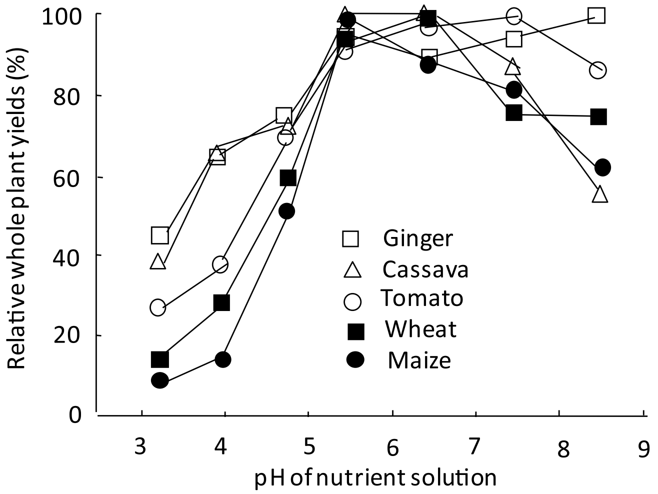

Figure 10. *Relative growth response of various plant species to a series of constant pH values maintained in flowing nutrient solution.*

Source: *Islam et al., 1980.*

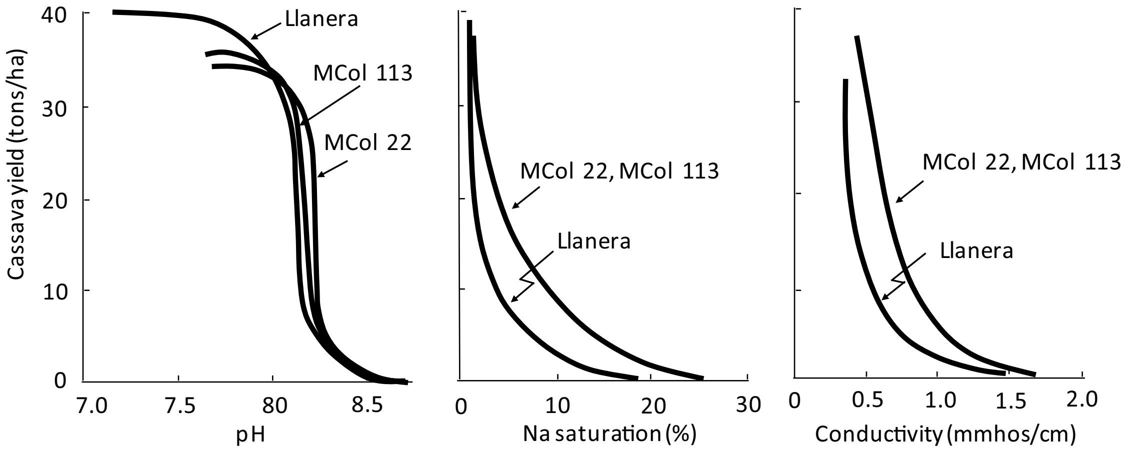

Figure 11. *Relation between the root yield of three cassava varieties and soil pH, percent Na saturation, and soil solution conductivity in a saline-alkaline soil at CIAT- Colombia.*

Source: *CIAT, 1977.*

Problems of soil salinity-alkalinity are very costly to resolve. Yield can be improved by applying 1–2 t/ha of elemental S or 1–2 t/ha of H_2SO_4 (CIAT, 1977), but this is seldom justified economically. Large varietal differences in tolerance have been observed, and the use of tolerant varieties is probably the most practical solution.

CHAPTER 10

ARE THERE BIOLOGICAL WAYS TO IMPROVE THE SOIL AND INCREASE CASSAVA YIELD?

In many parts of the world, crops are still grown without application of chemical fertilizer, either because this fertilizer is not available or it is considered too costly. This is especially true for cassava because the crop is often grown by subsistence or smallholder farmers who live in isolated places and often don't have money to buy this input. In that case, farmers usually try to maintain the fertility of the soil through various biological means, which may include shifting cultivation, agro-forestry, crop rotations, green-manuring, mulching, cover cropping, alley cropping, and intercropping, as well as the application of animal manure or compost. Most of these systems have advantages and disadvantages, and farmers have to decide which systems are most suitable for their own particular conditions. In general, these systems are most suitable in areas where labor is available and rather cheap, while purchased inputs such as fertilizer are unavailable or very expensive. The various biological methods can also be used to supplement the application of chemical fertilizer, mainly to increase the organic matter content of the soil, which will improve the soil structure, soil aggregate stability, water- and nutrient-holding capacity, and drainage.

Many of these biological systems have been tested in experiments to determine their effect on soil productivity and cassava yield.

SHIFTING CULTIVATION

In many areas in the tropics, farmers try to maintain soil fertility through shifting cultivation, also known as "slash-and-burn" systems, in which, after several years of cropping, the land is returned to bush fallow or forest for 10–20 years to let the soil rest and to replenish the nutrients that were lost during the cropping cycle with those in the ash of the burned forest. However, because of rapid population growth and the consequent increase in land pressure, the fallow period has steadily been shortened while the cropping cycle and intensity have increased.

a. Shifting cultivation in Cauca Department of Colombia

In the early 1980s, a study was undertaken in the mountainous cassava growing region of Cauca Department in Colombia to determine the effect of the length of the fallow period on the yield of subsequently grown cassava, and whether longer fallows could actually replace the use of chemical fertilizer. In this area of very poor and eroded soils, cassava is the main crop used for home consumption and for sale to small cassava starch factories. Farmers were interviewed about their cassava cropping practices and asked about the length of the fallow periods of their plots. These plots were then separated into four groups that had had fallow periods of 1−2, 4−5, 7−10, and >15 years. Simple on-farm trials were established on each of these four categories of length-of-fallow plots with seven fertilizer treatments: no fertilizer, three amounts of P fertilizer without N and K, and the same three P treatments combined with N and K. The trials were continued for three consecutive cropping cycles (CIAT, 1988a).

Figure 1 shows that the length of the fallow period had no consistent effect on cassava yield, with the shorter fallow period often producing higher yield than the longer periods. Application of only P fertilizer in general had a marked positive effect on cassava yield, but, in a few cases, this effect was minor or even negative. The application of all three nutrients, however, was very effective in increasing yield, and this effect was independent of the length of the previous fallow period.

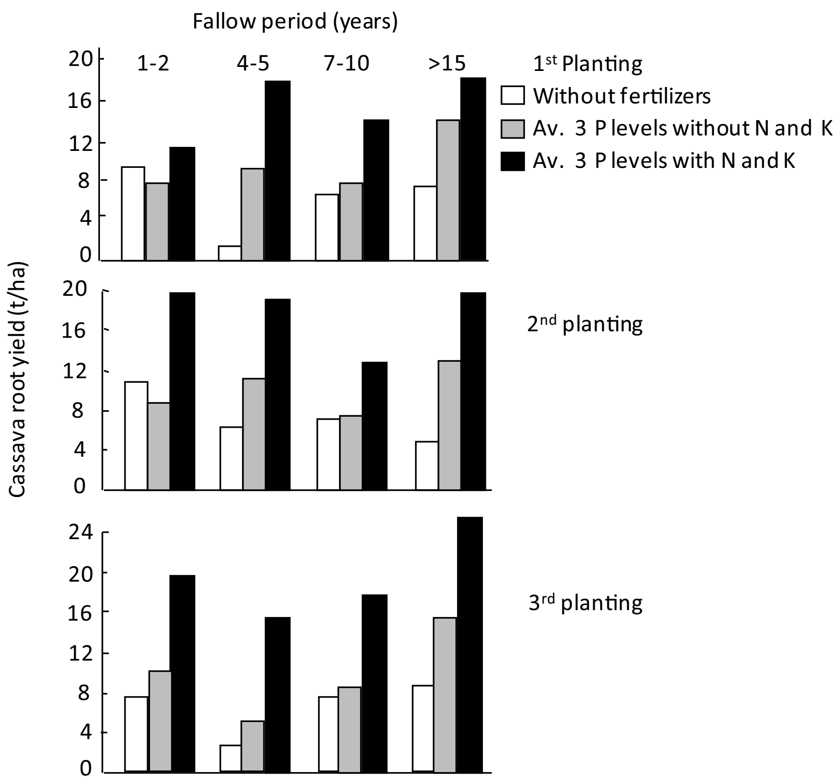

Figure 1. *Effect of the length of fallow period on the yield of three consecutive cassava crops grown with various fertilizer treatments in farmers' fields near Mondomo, Cauca, Colombia.*
Source: *CIAT, 1988a.*

Thus, it is clear that, in these very poor and degraded soils, even long periods of bush fallow were not able to fully restore soil fertility, and cassava yield remained below 8−10 t/ha. In contrast, with the application of N, P, and K in chemical fertilizer, cassava yield could double or triple, surpassing 24 t/ha in the third consecutive planting. In this and many similar situations, farmers could greatly increase their income if they would grow cassava on a more permanent basis on the best and flattest land, using chemical fertilizer, while leaving the steeper and more degraded fields in permanent pasture, or planting coffee, fruit trees, or forest. Unfortunately, in many of these areas, fertilizer is not readily available or the farmers don't have the knowledge or financial resources to buy it.

In other areas of the world where soils may be more fertile, less acid, and less eroded, the forest vegetation may grow back faster and more vigorously, resulting in more biomass production, better nutrient recycling, and more effective soil fertility restoration. However, when slash-and-burn systems are practiced on steep slopes, such as in Lao PDR and parts of western Vietnam, after burning of the forest during the dry season, much of the resulting ash is washed down-slope with the first rains of the wet season and before the crops can be planted, making the system ineffective in replenishing soil fertility. The result is a steady decline in soil fertility and decreasing crop yield.

A good example is Thailand, where the cassava growing area in the early 1980s expanded rapidly into the northeastern part of the country; this was achieved mainly by cutting and burning the native forest vegetation. Average cassava yield for the country was initially quite high at 18.65 t/ha in 1983, but fell to 12.66 t/ha in 1986 due to decreasing soil fertility. Yield remained at 13−15 t/ha until about 1995, when farmers started to adopt higher yielding varieties and the use of chemical fertilizer, which resulted in steadily increasing yield, reaching 22.67 t/ha in 2009.

The steady yield decline in the absence of fertilizer is also clearly shown in on-farm trials conducted in Thailand in three soil series. Yield of the plots—not in the same fields every year—without fertilizer application decreased gradually from about 28 t/ha to only 12−13 t/ha due to decreasing soil fertility (**Figure 2**).

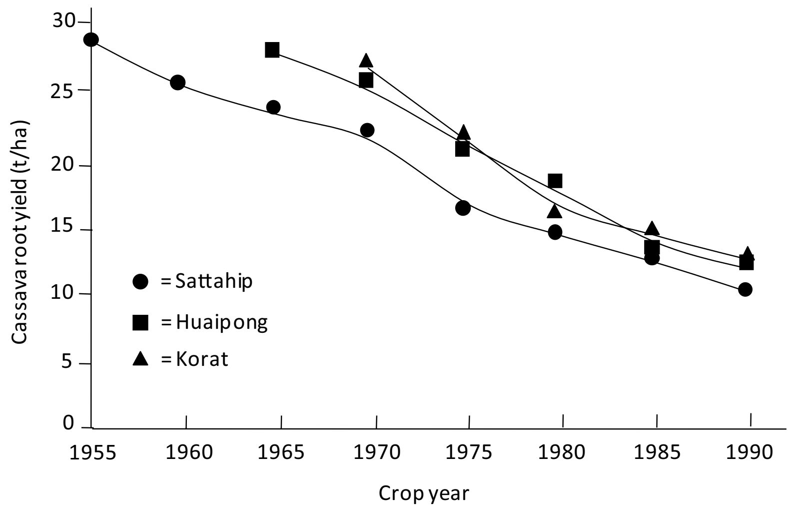

Figure 2. *Decline in fresh root yield due to cassava cultivation without fertilizer in on-farm trials conducted in three soil series in Thailand.*
Source: *Sittibusaya, 1993.*

AGRO-FORESTRY

Various agro-forestry systems are practiced in many parts of the world with different objectives. In Indonesia, it is quite common to see many trees in and around fields with crops. These may be teak trees that were planted mainly to make use of any available piece of land to plant trees as a long-term investment to eventually sell the wood or use the wood to build a new house. These trees are often planted along footpaths or along field borders. The falling leaves may help to improve the soil, mainly by increasing organic matter, but the roots of the trees also compete with crops for nutrients and water, and the shade of the trees may reduce crop yield.

Many fast-growing leguminous trees are often planted in or around fields with the objective to provide construction material or fuel wood, or the young branches are pruned regularly to supply fodder to feed cattle or goats during the dry season. The trees may also fix nitrogen and recycle nutrients from the subsoil to the topsoil in fallen leaves, which can improve the nutrient supply to the crop.

ALLEY CROPPING

This is a variation on the agro-forestry system mentioned above, but with the main objective of improving the nutrition of the crops and in some cases reducing erosion. The term refers to the practice of planting crops in the alleys between rows of fast-growing leguminous trees. The space between hedgerows can be varied, but is usually 4−5 meters, so that less than 20% of the total land area is occupied by the hedgerows. The trees are cut back regularly to about 50 cm above the ground and the prunings are either incorporated into the soil of the alleys before the crop is planted or are mulched on the soil surface to supply nutrients (especially N), and to control weeds and erosion.

The benefit of the trees is that they can fix considerable amounts of N, which is added to the soil in the alleys through the decomposing prunings. In addition, the trees are deep-rooted and are able to take up nutrients from the deeper soil layers and recycle these to the topsoil, where they become available to the crops after decomposition of the tree prunings. Also, because the trees are deep-rooted, they compete less for water and nutrients than fast-growing intercrops. The trees will need to be pruned regularly, but do not require replanting for many years, and thus do not require the annual purchase of seed.

a. Adaptation of leguminous shrub and tree species in Rayong, Thailand

Various leguminous shrubs were tested in Rayong, Thailand, to determine their general adaptation, ease of establishment, productivity of leaf/stem biomass, resistance to regular pruning, and drought tolerance. **Table 1** shows that several species of *Sesbania* were highly productive in the first year, but did not resist regular pruning. Perennial pigeon pea *(Cajanus cajan)* varieties were easy to establish, were highly productive and drought tolerant, but they lasted only a few years. *Leucaena leucocephala, Gliricidium sepium,* and *Cassia siamea* were more difficult and slow to establish, but, once established, they were highly productive, resistant to pruning, and very persistent. *Cassia siamea* is a non-N-fixing legume tree and serves mainly to produce biomass as mulch, to recycle nutrients, and to protect the soil from erosion. Other species such as *Flemingia macrophylla* and *Tephrosia candida* have been used successfully in other countries. Farmers are adopting hedgerows consisting of a mixture of fast-growing pigeon pea with a slower growing but more persistent tree species such as *Leucaena leucocephala* in northern Thailand (Boonchee et al., 1997).

Table 1. Total dry weight of prunings at three harvests as well as total nutrient content of the prunings of alley crop hedgerow species grown at Rayong Field Crops Research Center, Rayong, Thailand, in 1990/91.

	Total dry matter (t/ha)					
	Months after planting			Total nutrient content (kg/ha)[1)]		
Alley crop hedgerow species	3	6	13.5	N	P	K
Leucaena leucocephala	0	0.55	11.97	-	-	-
Gliricidia sepium	0.10	0.02	0.68	19.81	1.63	28.19
Cassia siamea	0.18	1.22	25.40	525.69	37.25	668.12
Sesbania grandiflora	1.08	0.42	0.32	48.94	3.31	51.12
S. sesban	2.97	2.52	0	79.00	8.12	115.56
S. aculeata	4.81	1.31	0.39	130.12	12.37	125.75
S. javanica	1.63	0.67	0.36	52.50	3.93	52.12
S. rostrata	3.67	1.17	0	77.19	5.25	73.31
Pigeon pea from the U.S.	2.30	3.69	14.99	388.25	26.37	480.12
Pigeon pea ICP 8094	3.74	2.68	12.44	345.43	22.62	403.00
Pigeon pea ICP 8860	3.63	4.55	14.64	383.75	28.19	527.06
Pigean pea ICP 11890	3.96	3.20	20.94	517.25	33.44	564.75

[1)] Sum of nutrients in leaves and stems from three harvests.
Source: *Howeler, 2012b.*

b. Alley cropping of cassava with leguminous shrubs in Malang, Indonesia

The use of hedgerows of *Flemingia macrophylla* and *Gliricidia sepium* in cassava fields was investigated for five years on 5% slope in Malang, Indonesia. The experiment had eight treatments without replication. Eroded soil was collected in concrete channels below each plot. The two hedgerow species were initially difficult to establish and during the first three years they had no beneficial effect on cassava yield or erosion (Wargiono et al., 1998). However, in the fourth year, when cassava in other plots suffered from severe N deficiency after intercropping with maize, the cassava plants in the alley-cropped treatments were tall and had dark green leaves, indicating that the prunings of the hedgerows had supplied considerable amounts of N.

Table 2 indicates that, during the fourth year, the two alley-cropped treatments produced high cassava yield and the lowest erosion (by enhanced early canopy cover). **Table 2** also shows that cover cropping with *Mimosa envisa* reduced cassava yield slightly in the first 2 years, but markedly in the subsequent 2 years.

In a previous experiment at the same site, hedgerows of *Leucaena leucocephala* and *Gliricidia sepium* also produced the highest cassava yield and lowest erosion during the fourth year of consecutive planting; these two treatments also resulted in the highest soil OM, the lowest bulk density, and the highest water infiltration rates and soil aggregate stability (Wargiono et al., 1995). Thus, once well-established, hedgerows of leguminous shrubs significantly enhanced soil fertility and improved the soil's physical characteristics. However, in less fertile soils or in areas with a long dry season, the hedgerows can severely compete with neighboring cassava for water and nutrients (Jantawat et al., 1994); they also require additional labor to keep them properly pruned to prevent light competition.

Table 2. Effect of various crop and soil management practices on soil loss due to erosion and on cassava and maize yield during four consecutive cropping cycles on 5% slope at the Jatikerto Experiment Station in Malang, Indonesia.

Crop/soil management treatm.	Dry soil loss (t/ha)					Cassava root yield (t/ha)					Maize yield (t/ha)		
	91/92	92/93	93/94	94/95	95/96	91/92	92/93	93/94	94/95	95/96	91/92	92/93	93/94
C + M[1)], no fertilizer, no ridges	58.3	49.3	55.7	8.5	8.5	16.3	15.8	5.1	6.6	5.8	-	-	0
C + M[1)], no fertilizer, contour ridges	43.0	36.9	36.7	2.8	5.7	25.4	23.2	5.1	13.3	11.8	-	-	0
C + M, with fertilizer, contour ridges	39.2	24.8	28.1	3.8	4.9	20.4	20.5	17.8	16.7	13.3	1.98	2.27	2.88
C + M, with fertilizer, contour ridges, elephant grass hedgerows	36.9	19.8	20.8	2.4	3.0	18.4	17.4	11.8	19.3	16.9	1.36	1.42	1.96
C + M, with fertilizer, contour ridges, *Gliricidia* hedgerows	43.2	22.3	20.9	2.2	4.1	16.3	18.0	16.1	20.7	19.3	1.16	1.28	2.80
C + M, with fertilizer, contour ridges, *Flemingia* hedgerows	41.3	17.7	17.3	1.0	2.7	17.2	18.1	14.2	21.6	21.4	1.26	1.46	3.20
C + M, with fertilizer, contour ridges, *Mimosa* cover crop	38.4	18.3	24.7	2.4	3.8	17.1	18.2	12.2	9.9	14.3	1.44	1.63	3.36
C + M[1)], with fertilizer, contour ridges, peanut intercrop	36.4	21.7	26.3	4.5	3.5	23.7	23.7	19.9	25.3	23.0	-	-	2.10

1) During the first two years, there was no intercropped maize in treatments 1, 2, and 8; no maize yield data for 1994/95 and 1995/96; C+M = cassava intercropped with maize.

Source: *Wargiono et al., 1998.*

COVER CROPPING

Cover crops are usually perennial forage legumes that are planted to fix N and recycle soil nutrients in order to improve soil fertility, and to prevent serious soil erosion on sloping land. Annual crops may be planted in individual planting holes or in strips where the cover crop has been incorporated or killed with herbicides. Several experiments have been conducted in Colombia and Thailand to see whether cover crops can improve cassava yield and/or reduce erosion when cassava is grown on slopes.

a. Cover cropping of cassava with forage legumes in Santander de Quilichao, Colombia

Two experiments were established side by side on nutrient-depleted soil at Santander de Quilichao, with one receiving no fertilizer and the other receiving a band application of 500 kg/ha of 10-20-20 fertilizer. Weeds were removed by hoe and two cassava varieties, MCol 1684 and CM507-37, were planted without further land preparation at a spacing of 0.8 × 0.8 m; six forage legumes were interplanted between cassava. Besides the check plot without cover crops, there were two additional treatments, one in which native weeds were slashed and mulched on the soil surface, and one in which the weeds were sprayed with Paraquat. In both cases, cassava was planted in the mulch of weeds.

Except for *Arachis pintoi*, all cover crops germinated well and had established full soil cover at 3−4 months after planting. *Arachis pintoi* established more slowly. After the harvest of the first cassava crop, all cover crops or weeds were slashed back and mulched, while a second crop of cassava was planted in manually prepared planting holes.

Table 3 shows the yield of CM507-37 for the two crop cycles, in both the experiments, with and without fertilizer.

In the check plots without cover crops or mulch, fertilizer application nearly doubled cassava yield in the first year and tripled yield in the second year. Only cover cropping with *Macroptilium* increased cassava yield significantly in the second year in the absence of fertilizer, while all cover crops reduced yield in the presence of fertilizer. Yield reductions were most marked for *Desmodium ovalifolium* and *Arachis pintoi,* and were more serious in the second year than in the first year of establishment. Fertilizer application stimulated the growth of forages, resulting in strong competition with cassava, mainly for soil water. Besides this strong competitive effect of the cover crops, it is possible that *Desmodium* and *Arachis* had an allelopathic effect (CIAT, 1993), as both cassava cultivars were seriously stunted in these treatments. MCol 1684 is less vigorous and has a less extensive root system than CM507-37 (CIAT, 1985b). This resulted in lower yield and more stunted growth due to competition from the cover crops (CIAT, 1993). Thus, some cassava varieties are more suitable for cover cropping than others, but most varieties will suffer from severe competition when associated with vigorously growing perennial forage legumes.

Table 3 also shows that cassava yield increased significantly by mulching the native weeds, either by cutting the weeds or by spraying them with Paraquat. Yield increased in both the absence and presence of chemical fertilizer. The weed mulch not only supplied nutrients to the crop but also increased soil moisture and decreased the surface soil temperature (Cadavid et al., 1998). Thus, mulching of native weeds combined with minimum tillage (hand preparation of planting holes) produced much better results than intercropping with leguminous cover crops.

Table 3. Effect of various cover crops and weed mulch on the yield of cassava cv. CM507-37 grown during two cropping cycles with and without fertilizer application at CIAT-Quilichao, Colombia, in 1987/88 and 1988/89.

Cover crop treatments	Fresh root yield (t/ha) 1987/88		Fresh root yield (t/ha) 1988/89	
	W/out fert.	With fert.	W/out fert.	With fert.
Sole cassava (no cover crop), weeds removed	29.6 bc[2]	51.8 abc	17.1 c	56.2 ab
C + *Zornia latifolia* CIAT 728	22.7 cd	50.4 abc	19.7 bc	42.7 cd
C + *Desmodium ovalifolium* CIAT 13089	19.2 d	48.1 bcd	5.9 d	17.0 e
C + *Arachis pintoi* CIAT 17434	26.9 bcd	45.9 bcd	7.1 d	29.5 d
C + *Centrosema acutifolium* CIAT 5277	23.5 cd	44.1 cd	18.3 c	43.2 bc
C + *Pueraria phaseoloides*	30.9 bc	39.0 d	21.6 abc	35.1 cd
C + *Macroptilium atropurpureum* CIAT 535	26.7 bcd	40.9 cd	25.4 ab	32.5 cd
Sole cassava, weeds cut and mulched	39.6 a	60.9 a	21.9 abc	61.6 a
Sole cassava, weeds sprayed[1] and mulched	33.8 ab	56.1 ab	27.0 a	45.3 bc
F-test:	fertilizer effect ** cover crop effect ** fertilizer × cover crop *		fertilizer effect ** cover crop effect ** fertilizer × cover crop **	

[1] Weeds sprayed with Paraquat

Note: Data within a column followed by the same letter are not significantly different at P=0.01

Source: *CIAT, 1993.*

b. Cover cropping of cassava with forage legumes in Pluak Daeng, Thailand

After evaluating a large number of forage species for adaptation to soil and climatic conditions in Thailand, some species were identified as potential cover crops for use with cassava. These were tested in Pluak Daeng, Rayong Province. Nine leguminous species were planted in double rows in between rows of cassava cv. Rayong 1, spaced at 1.80 × 0.55 m. Cassava received 156 kg/ha of 15-15-15 fertilizer. All forage species established well, resulting in complete soil cover in 3–4 months after planting, except for *Arachis pintoi* and *Stylosanthes hamata,* which established more slowly. In the first year, the cover crops were not cut back, resulting in competition with cassava, for both light and soil moisture during the dry season. After the first cassava harvest, all cover crops were slashed back and mulched. The plots were subdivided and cassava was replanted at a spacing of 1.10 × 0.90 m in 60-cm-wide strips prepared either with a hand tractor or by spraying the cover crops with Paraquat. The same methodology was used in the third year. In the second and third year, cover crops were regularly slashed back at 20 cm above the ground to reduce competition with cassava. Nevertheless, **Table 4** shows that cassava yield was low and severely affected by competition from the cover crops. Most competitive was *Stylosanthes guianensis,* followed by *Centrosema pubescens. Stylosanthes hamata* and *Arachis pintoi* were not very competitive during the first year of establishment, but became very competitive in subsequent years. Least competitive was *Centrosema acutifolium,* but this was partly due to less vigorous growth resulting in only partial soil cover (Tongglum et al., 1992).

Table 4. Effect of intercropping cassava with leguminous cover crops on the yield of cassava cv. Rayong 1 during 3 consecutive years of cropping in Pluak Daeng, Thailand.

Cover crop treatments	DM of cover crops (t/ha)		Cassava fresh root yield (t/ha)[1]		
	1988/89[2]	1990/91[3]	1988/89	1989/90	1990/91
Sole cassava (no cover crop)	-	-	11.68 a	7.79 a	19.62 a
C + *Stylosanthes hamata*	1.74 d	1.68 ab	10.27 ab	3.91 c	4.45 de
C + *S. guianensis*	9.22 a	2.19 a	3.21 d	6.56 ab	0.83 e
C + *Arachis pintoi*	0.87 d	-	8.46 bc	6.56 ab	9.71 cd
C + *Centrosema acutifolium*	2.17 bcd	0.93 bc	7.66 bc	6.69 ab	15.33 ab
C + *C. pubescens*	1.04 d	1.34 bc	7.51 bc	5.60 bc	6.17 d
C + *Mimosa envisa*	1.97 cd	1.36 bc	7.49 bc	6.48 ab	13.33 bc
C + *Desmodium ovalifolium*	3.81 b	0.68 c	7.26 bc	6.78 ab	13.46 bc
C + *Macroptilium atropurpureum*	2.19 bcd	0.78 c	6.61 c	7.70 a	8.96 cd
C + *Indigofera* sp.	3.25 bc	1.27 bc	3.05 d	6.36 ab	8.50 c
F-test	**	**	**	*	**

[1] Cassava received 25 kg N, 25 P_2O_5, and 25 K_2O/ha; data for 1989 and 1990 refer to those plots with tractor preparation of cassava planting strips.

[2] At 10 months after planting.

[3] At 3 months; average of mechanical and chemical land preparation treatments.

Note: Data within a column followed by the same letter are not significantly different

A similar experiment was conducted in an adjacent field. In the main plots, two cassava plant spacings were used, 1.0 × 1.0 m and 1.50 × 0.67 m, both giving a plant population of 10,000 plants/ha. In the subplots, various forage species were planted in between cassava rows. Cassava received 156 kg/ha of band-applied 15-15-15 fertilizer. After the first cassava harvest, the cover crops were slashed back and cassava was replanted in 60-cm-wide strips prepared with a hand tractor. In the second year, all cover crops were well established and competed strongly with cassava, mainly for soil moisture during cassava establishment. **Table 5** shows that there were no significant differences in cassava yield due to plant spacing, but that nearly all cover crops reduced cassava yield, and some by more than 50%. Most competitive were *Indigofera* and *Mimosa envisa*, which were also among the most productive forage species tested. Less productive and thus less competitive were *Zornia glabra, Alysicarpus vaginales*, and *Arachis pintoi,* although the latter still caused a marked yield reduction in the second year.

From these three cover crop experiments, we can conclude that cassava is a weak competitor and yield declines markedly if the plants have to compete with deep-rooted and well-established forage legumes used as a cover crop. This competition is particularly strong during cassava plant establishment, especially when this coincides with a period of drought. Thus, cover cropping with most forage legumes would not be practical since it tends to reduce cassava yield and it requires considerable additional labor. Ruppenthal (1995) also reported yield reductions of more than 40% when forage legumes were grown as cover crops under cassava in Santander de Quilichao and Mondomo, both in Cauca, Colombia. Ruppenthal et al. (1997) also showed that cover crops, once well established, were very effective in reducing soil erosion, but that erosion can be controlled more effectively and with less reduction in cassava yield with the use of contour hedgerows of vetiver grass *(Vetiveria zizanioides).*

Table 5. **Dry matter production of various cover crops and their effect on the yield of cassava cv. Rayong 1 planted at either 1.0 × 1.0 m or 1.5 × 0.67 m at Pluak Daeng, Thailand. Data are average values for the two plant spacings.**

	DM of cover crops (t/ha)		Cassava fresh root yield (t/ha)	
Cover crop treatments	1991/92	1992/93	1991/92	1992/93
Sole cassava (no cover crops)	-	-	18.61 a	7.14 a
C + *Indigofera* sp.	6.55	3.15	8.33 c	4.19 abc
C + *Zornia latifolium* CIAT 9199	1.08	1.14	16.34 ab	3.94 bc
C + *Zornia glabra* CIAT 8283	0.47	1.68	22.23 a	5.44 ab
C + *Alysicarpus vaginales*	1.37	0.27	17.19 ab	6.70 ab
C + *Mimosa envisa*	4.61	2.96	12.71 bc	2.15 c
C + *Stylosanthes hamata*	3.21	5.23	13.61 bc	2.12 c
C + *Arachis pintoi*	0.26	0.42	15.97 b	2.30 c
F-test for cassava yield: Cassava spacing (S):			NS	NS
Cover crops (C):			**	**
S x C:			NS	*

Note: NS = not significant; * = significant at P=0.05; ** significant at P= 0.01
Data within a column followed by the same letter are not significantly different at P=0.01
Source: *Tongglum et al., 1992.*

GREEN MANURING

This usually refers to the practice of growing a grain- or forage-legume on the land for several months prior to planting the main crop.The green manure is generally cut after 2−3 months of growth and either incorporated into the soil or mulched on top of the soil before planting the following crop. This will improve the soil's fertility, especially that of N. However, the green manure can also be planted as an intercrop within the main crop and slashed back and mulched after 2−3 months of growth; or it is planted as narrow strips alternating with strips of the main crop. These practices have been widely researched and promoted by soil scientists but have not been widely adopted by farmers.

Many green manure species have been tested to see their effect on the following cassava crop, in both Colombia and Thailand (Howeler, 2012b).

a. Green manuring of cassava with grain and forage legumes in Santander de Quilichao, Colombia

An experiment began in 1983 to see whether green manure, with or without fertilizer, could restore soil productivity in a soil that had previously been cropped with cassava for five years without fertilizer inputs. Three grain legumes and five forage legumes were planted after the application and incorporation of 1 t/ha of lime; they also received 250 kg/ha of banded 10-30-10 fertilizer. The check plot without green manure did not receive this basal fertilizer application. The grain legumes, cowpea *(Vigna unguiculata)*, peanut *(Arachis hypogaea)*, and pigeon pea *(Cajanus cajan)*, were harvested after four months, and the forage legumes were cut at six months, followed by incorporation of the forages and crop residues into the soil. One month later, two cassava varieties were planted, both with and without band application of 500 kg/ha of 10-30-10 fertilizer. After the cassava harvest at 12 MAP, a second cassava crop was planted, again with and without fertilizer, to measure the residual effect of the green manure.

Table 6 shows the dry matter production of the green manures and their effect on soil fertility parameters before the first and second cassava crops, as well as the yield of cassava (only cv. MCol 1684) in both crop cycles. Velvet bean *(Mucuna pruriens)* and pigeon pea produced the greatest amount of DM, followed by *Indigofera hirsuta* and peanut. Incorporation of the green manures had only a minor effect on soil fertility, except that kudzu *(Pueraria phaseoloides)* increased both soil P and K, while peanut increased mainly soil K. Some of the increase in soil P and K was due to the band application of 250 kg/ha of 10-30-10 at the time of planting the green manures; this was not applied to the check plots without green manures.

Table 6. **Dry matter production of various green manures and the effect of their incorporation on soil fertility (A); and on the yield of cassava cv. MCol 1684 grown with or without the application of chemical fertilizer [1] (B) in 1983 and 1984 in Santander de Quilichao, Colombia.**

A.	DM of green manures	Soil fertility in 1983 [2]				Soil fertility in 1984 [2]	
Green manure treatments	(t/ha)	pH	OM (%)	P (ppm)	K (meq/100 g)	P (ppm)	K (meq/100 g)
1. No green manure	-	4.1	5.5	3.8	0.10	3.6	0.08
2. Cowpea	0.45	4.0	5.5	5.2	0.12	5.5	0.08
3. Peanut	1.75	4.1	5.9	5.1	0.14	6.2	0.09
4. Pigeon pea	1.95	4.1	6.0	4.6	0.13	6.6	0.07
5. Velvet bean	1.95	4.1	5.6	5.5	0.12	5.8	0.08
6. *Zornia latifolia*	0.55	4.1	5.6	5.2	0.12	5.1	0.07
7. *Centrosema pubescens*	0.90	4.1	5.9	4.6	0.11	5.0	0.08
8. *Indigofera hirsuta*	1.90	4.1	5.8	5.5	0.13	6.7	0.08
9. *Pueraria phaseoloides*	1.00	4.1	5.6	7.7	0.15	5.4	0.08

B.	Cassava fresh root yield (t/ha)			
	1983/84		1984/85 [3]	
Green manure treatments	Without fertilizer	With fertilizer	Without fertilizer	With fertilizer
1. No green manure	16.9 c	31.9 abcd	13.6 b	31.4 bcd
2. Cowpea	18.9 bc	26.5 cd	19.5 ab	32.2 abcd
3. Peanut	29.3 a	39.0 a	24.6 a	30.0 cd
4. Pigeon pea	28.6 a	33.8 abc	18.8 ab	38.9 a
5. Velvet bean	19.9 bc	23.6 d	18.9 ab	31.9 abcd
6. *Zornia latifolia*	24.1 abc	41.1 a	22.3 ab	28.6 d
7. *Centrosema pubescens*	25.1 abc	36.7 ab	15.2 ab	40.0 a
8. *Indigofera hirsuta*	25.7 ab	29.7 bcd	12.6 b	34.8 abcd
9. *Pueraria phaseoloides*	26.9 ab	40.4 a	13.7 b	37.3 abc
Average	**23.9 b**	**33.6 a**	**17.7 b**	**33.9 a**

[1] Band application of 500 kg/ha of 10-30-10 (N-P_2O_5-K_2O) fertilizer with both cassava crops.
[2] Average of with and without fertilizer.
[3] Residual effect of green manures planted in 1983 on cassava yield in 1984/85.
Note: Data within a column followed by the same letter are not significantly different

During the first cassava cycle, all green manures increased yield when no fertilizer had been applied to cassava, while some green manures increased and others decreased yield when fertilizer had been applied. Peanut, pigeon pea, and kudzu were the most effective in the absence of fertilizer, while kudzu and peanut were the most effective in the presence of fertilizer. Application of fertilizer in the absence of green manures increased cassava yield from 16.9 to 31.9 t/ha, while the incorporation of green manures increased cassava yield at most to 29.3 t/ha with the use of peanut. Velvet bean and cowpea were not very effective in increasing yield in the absence of fertilizer, and actually decreased yield in the presence of fertilizer. In the case of velvet bean, cassava growth was clearly stunted, possibly due to an allelopathic effect. Soil analyses before the second cassava crop indicate that the fertilizer applied to cassava had little residual effect on soil fertility, possibly because of the high cassava yield (up to 41 t/ha) obtained. Peanut and *Indigofera* had increased soil P, while soil K was very low for all treatments. There was no apparent residual effect of the green manures on soil K.

In the second cassava crop, fertilizer application in the absence of green manures increased yield from 13.6 to 31.4 t/ha. In the absence of fertilizer, peanut and *Zornia* increased yield markedly, but only that of peanut was statistically significant. In the presence of fertilizer, the effect of green manures was statistically significant. *Centrosema* and pigeon pea increased cassava yield significantly, while *Zornia* and peanut slightly decreased yield.

From this experiment, we can conclude that cassava yield increased most markedly with the application of fertilizer, but incorporation of green manures also helped to increase yield, especially when no fertilizer was applied to cassava. Peanut was among the most effective species, but *Zornia latifolia*, *Pueraria phaseoloides,* and *Centrosema pubescens* were also very effective, especially in the presence of fertilizer.

b. Green manuring of cassava with grain and forage legumes in Media Luna, Colombia

Another experiment was planted in Media Luna on the north coast of Colombia, in very sandy soils low in OM and nutrients. Since previous trials had shown that responses to chemical fertilizer were not as great as might be expected, a green manure trial was established to determine whether green manures could increase yield in both the presence and absence of chemical fertilizer. The green manures were cut and mulched after three months and two cassava cultivars, MVen 25 and MCol 2215, were planted, either without or with band application of 500 kg/ha of 15-15-15 fertilizer. One check plot with weeds removed and one with native weeds cut and mulched was also included. The native weeds consisted mainly of tall grasses and creeping legumes.

Table 7 shows that peanut, *Indigofera*, and native weeds had the highest DM yield, while *Crotalaria juncea* was the least productive and had only a minor effect on soil fertility. Green manures (including native weeds) slightly increased soil OM. Mulching of *Canavalia* resulted in the highest soil P, Ca, and K, while native weeds also increased Ca and Mg, but had little effect on P and K.

Application of 500 kg/ha of 15-15-15 fertilizer in the absence of green manures increased cassava yield from 19.5 to 34.3 t/ha. Similar yield was obtained by the mulching of native weeds or *Canavalia* without application of fertilizer. All green manures markedly increased cassava yield when no fertilizer was applied, but *Crotalaria juncea* was the least effective. In the presence of fertilizer, green manuring had no beneficial effect (CIAT, 1988a).

Table 7. Dry matter production of native weeds and green manures and the effect of mulching on soil fertility and on the yield of cassava cv. MVen 25 grown without and with application of fertilizer in sandy soils of Media Luna, Colombia.

Green manure treatments	DM of green manures (t/ha)	At time of planting cassava: pH	OM (%)	P (ppm)	Ca (meq/100 g)	Mg (meq/100 g)	K (meq/100 g)	Cassava root yield (t/ha): Without fertilizer	With fertilizer [1)]
1. No green manures	-	5.2	0.70	6.4	0.43	0.11	0.04	19.5	34.3
2. Native weeds	4.73	5.5	0.82	4.6	0.54	0.18	0.06	34.4	30.7
3. Cowpea	2.93	5.3	0.77	5.9	0.52	0.16	0.07	27.6	32.5
4. Peanut	6.56	5.3	0.97	6.1	0.45	0.13	0.07	32.0	24.8
5. Pigeon pea	3.93	5.1	1.15	8.4	0.54	0.17	0.07	30.2	29.7
6. Velvet bean	2.50	5.5	0.80	5.1	0.47	0.13	0.05	31.9	34.8
7. *Crotalaria juncea*	1.71	5.3	0.85	5.7	0.46	0.13	0.06	24.6	32.6
8. *Canavalia ensiformis*	3.29	5.0	0.85	8.0	0.56	0.17	0.09	34.0	32.9
9. *Indigofera hirsuta*	6.00	5.2	0.82	6.1	0.49	0.14	0.06	30.9	34.8
Average								**29.4**	**32.3**

1) With 500 kg/ha of band-applied 15-15-15 fertilizer.

Thus, we can conclude that, in the sandy soils of Media Luna, application of 3–6 t/ha of dry mulch of green manures had beneficial effects similar to the application of chemical fertilizer. Of the green manures tested, *Canavalia ensiformis* and native weeds were the most effective, while *Crotalaria juncea* was the least productive and least effective in increasing cassava yield. Since cassava produced high yield when mulched with 3–6 t/ha of weeds or green manures even though the soil-K remained far below the critical level of 0.15 meq/100 g, it appears that K, leached down the profile from the decomposing mulch, was immediately absorbed by cassava roots without increasing the amount of exchangeable K in the soil. In addition, the mulch may have had other beneficial effects.

c. Green manuring with vegetable cowpea at CTCRI in Kerala, India

In India, the standard recommendation is to apply 100 kg N, 50 kg P_2O_5, and 100 kg K_2O/ha as chemical fertilizer, together with 12.5 t/ha of farmyard manure (FYM). Since FYM is expensive and cumbersome to transport and apply, a long-term experiment was conducted from 1990 to 2004 to determine whether green manuring with vegetable cowpea could reduce the need for FYM and/or reduce the high amounts of chemical fertilizer input. Vegetable cowpea was planted during premonsoon rains in February and, after the harvest of green pods, the total crop biomass was incorporated into the soil before planting cassava in May. The effect of incorporating the crop residues of cassava back into the soil after harvest was also investigated. **Figure 3** shows that,during the first 11 years of cropping, both the annual incorporation of the *in situ* cowpea biomass and the incorporation of the cassava residues from the previous crop produced cassava yield similar to that with the application of 6.25 t/ha of FYM, and slightly lower yield than the application of 12.5 t/ha of FYM (Susan John et al., 2005). Only when the Southwest monsoons were delayed or rainfall was insufficient did the planting of cowpea to serve as green manure seriously delay the planting of cassava, which resulted in low cassava yield. It was found that, by practicing green manuring with *in situ* cowpea, the application of FYM as well as that of N and P could be reduced to only 50% of the recommended rates, while the annual incorporation of cassava crop residues could completely replace the application of 12.5 t/ha of FYM as long as the recommended rates of N, P, and K were applied (Susan John et al., 2005; Nayar et al., 2007). At the end of the experiment, the average cassava root yield over the 14-year cropping cycle was 26.13 t/ha when 12.5 t/ha of FYM had been applied, 23.92 t/ha with the application of 6.25 t/ha of FYM, 23.11 t/ha with the incorporation of cassava crop residues without FYM, and 21.34 t/ha with the incorporation of *in situ* grown cowpea biomass and without FYM, and only 50 kg N, 25 kg P_2O_5, and 100 kg K_2O/ha as chemical fertilizer. These yields were not statistically significantly different. The first three treatments also received 100 kg N, 50 kg P_2O_5, and 100 kg K_2O/ha as chemical fertilizer.

Soil analyses at the start of the experiment and after each successive crop indicate that the application of FYM, as well as the incorporation of cowpea biomass and cassava crop residues, markedly increased the organic C, available P, and exchangeable K content of the soil during the 14-year period.

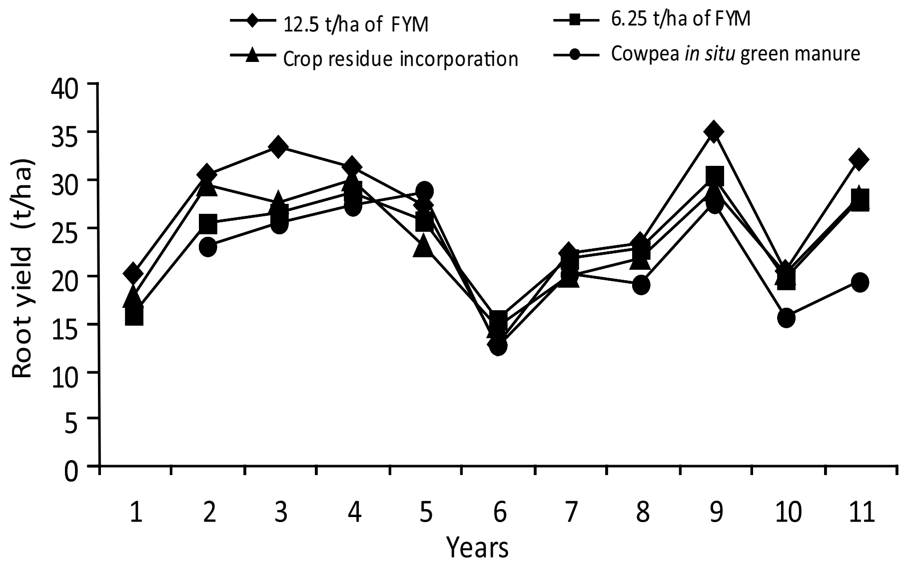

Figure 3. *Influence of application of farmyard manure and the incorporation of cowpea green manure or cassava crop residues on cassava root yield during 11 years of continuous cropping at CTCRI, Kerala, India. All plots received annually 100 kg N, 50 kg P_2O_5, and 100 kg K_2O/ha except for the cowpea green manure plots, which received 50 kg N, 25 kg P_2O_5, and 100 kg K_2O/ha as chemical fertilizer.*

Source: *Nayar et al., 2007.*

d. Green manuring of cassava with leguminous species in Khon Kaen, Thailand

Three green manures were tested in a long-term trial conducted in Khon Kaen, Thailand. The green manures were planted annually in the early part of the rainy season and were incorporated into the soil at 60 days after planting; after that, cassava was planted and was harvested after ten months. **Table 8** shows that, averaged over five years, incorporation of the residues of cowpea variety Vita-3 increased cassava yield significantly. *Crotalaria juncea* also increased yield, but not significantly, while pigeon pea had little beneficial effect (Sittibusaya et al., 1995). Cowpea produced more biomass, and thus had a higher nutrient content, especially of N and cations, such as K, Ca, and Mg, which are very important for cassava production in light-textured soil. In addition, this improved some physical conditions of the soil, such as bulk density and water infiltration rate.

Table 8. Cassava root yield (t/ha) as affected by the annual incorporation of different green manures before planting cassava (Rayong 3) at the Agricultural Development Research Center (ADRC) in Khon Kaen, Thailand, from 1985 to 1989.

	Crop year					
Green manure	1	2	3	4	5	Average
Cowpea	10.23	17.58	16.24	19.14	14.64	15.57
Pigeon pea	5.44	12.91	14.16	13.25	14.18	11.99
Crotalaria juncea	5.88	13.43	14.94	17.21	15.20	13.33
No green manure	4.43	13.99	14.13	12.07	13.97	11.72
F-test	**	NS	NS	NS	NS	**
CV (%)	23.6	29.7	23.9	11.5	32.7	10.7

Note: NS = not significant; ** = significant at P=0.01

Source: *Paisancharoen* et al., 1990.

e. Green manuring of cassava with forage legumes in Pluak Daeng, Thailand

An experiment on the use of forage legumes as green manures to maintain soil fertility in sandy clay soils was also conducted in Pluak Daeng in Rayong Province of Thailand in 1988/89. The green manures were planted in the beginning of the wet season (May/June) and after 3–4 months the above-ground parts were cut and incorporated into the soil before planting cassava in the mid to late wet season (Aug./Sept.). Cassava did not receive any fertilizer, except in one of the two treatments without green manures, which received 100 kg N and 50 K_2O/ha. Cassava was harvested after about 8 months at the start of the next wet season. The experiment was repeated in a similar fashion in 1989/90 and 1990/91.

Table 9 shows the productivity of the green manures and their effect on cassava yield during the three years of testing. There was a significant effect of green manure application on cassava yield in the first two years, but the effect was not significant in the last year. *Crotalaria juncea* and *Canavalia ensiformis* were the most productive species and the most effective in recycling nutrients (Tongglum et al., 1992), while incorporation or mulching of *Crotalaria juncea* usually resulted in the highest cassava yield; this yield was similar to that obtained with chemical fertilizer. Another promising species was *Mucuna fospeada.* Nevertheless, in the first two years, cassava yield was extremely low because cassava could be planted only late in the rainy season after the green manures had been incorporated or mulched. Therefore, cassava suffered from drought stress during much of the growth cycle. In the third year, cassava was not harvested until August 1991 (11 months), resulting in much higher yield, but there was no significant response to green manure applications.

Table 9. **Green manure productivity and its effect on cassava yield in three experiments conducted in Pluak Daeng, Rayong, Thailand, from 1988/89 to 1990/91.**

Green manure treatments [1]	DM of green manures (t/ha)			Cassava fresh root yield (t/ha)		
	1988/89	1989/90	1990/91	1988/89	1989/90	1990/91
No green manure, no fertilizer	-	-	-	3.21 cd	5.75 bcd	16.36
Sesbania rostrata	9.71 b	3.46 b	9.91 b	9.29 a	5.37 bcd	15.04
S. speciosa	2.58 ef	2.15 b	9.73 b	5.61 abcd	4.46 cd	17.52
S. aculeata	4.20 dc	2.54 b	7.58 b	5.19 bcd	4.42 cd	13.23
Crotalaria juncea	13.46 a	6.88 a	24.79 a	9.04 ab	8.83 a	17.29
C. mucronata CIAT 7790	6.77 c	2.86 b	10.36 b	6.71 abc	5.17 bcd	11.77
C. spectabilis	5.49 cd	2.98 b	12.75 ab	5.81 abcd	3.96 d	17.64
Canavalia ensiformis	6.63 c	6.96 a	24.79 a	5.37 bcd	7.00 abc	14.67
Indigofera	6.36 c	3.21 b	10.94 b	5.37 bcd	5.08 bcd	16.61
Mucuna fospeada	5.66 cd	2.70 b	10.74 b	5.21 bcd	6.08 abcd	16.45
Pigeon pea (from ICRISAT)	2.11 f	3.46 b	2.29 b	2.06 d	4.50 cd	14.79
No green manure, with fertilizer [2]	-	-	-	8.75 ab	7.71 ab	17.04
F-test	**	**	**	**	*	NS

[1] Green manures were planted in May/June, cut in August/September, and cassava was planted in October and harvested after 8–9 months in the first 2 years and after 11 months in the third year.
[2] 100 kg N and 50 K_2O/ha; no fertilizer to cassava in the green manure treatments.

Analyses of soil samples taken before planting and after harvest of cassava indicate that green manures had no significant effect on pH, OM, and available P or exchangeable K (CIAT, 1992). In all treatments, soil pH gradually decreased from 6.6 to 5.5, OM decreased slightly from 1.0% to 0.8%, soil available P was quite variable, while exchangeable K decreased markedly from 0.24 to 0.08 meq/100 g.

A similar experiment was conducted for three years (1991−94) in an adjacent field in Pluak Daeng using six green manure species. These were again planted in the early wet season (May/June), cut after three months, and (in subplots) either mulched on the soil surface or incorporated into the soil with a hand tractor. In the mulched subplots, cassava was planted without further land preparation. Cassava was planted in the mid to late rainy season (Aug./Sept.) and harvested after 9−10 months. For comparison, two additional plots without green manures were planted at the more traditional planting time at the start of the rainy season (May/June); these were also harvested after 9−10 months. At both planting times, one of the two check plots without green manures received 94 kg N and 50 kg K_2O/ha.

Table 10 shows that planting in the early rainy season resulted in much higher cassava yield than planting toward the end of the rainy season. Application of NK fertilizer increased yield, but not significantly. Among the six green manures, *Crotalaria juncea* was consistently the most productive species, while *Sesbania rostrata* was the least productive. *Crotalaria juncea*, when either mulched or incorporated, also produced the highest cassava yield. Although this yield was higher than that of the crop planted in September with fertilizer, it was not significantly different from yield obtained without fertilizer when cassava was planted in the early wet season, and it was considerably lower than the yield obtained with fertilizer and planting in May/June.

Soil analyses again indicate that incorporation or mulching of green manures had no significant effect on soil fertility parameters. This indicates that nutrients leached down from the decomposing green manures were directly absorbed by cassava roots without having a long-term effect on soil fertility.

Table 10. **Effect of cassava planting time, fertilization, and green manuring on green manure production and cassava yield in Pluak Daeng, Thailand. Data are average values for three cropping cycles, 1991/92, 1992/93, and 1993/94.**

Green manure treatments	DM of green manures (t/ha)		Cassava fresh root yield (t/ha)		
	Incorporated	Mulched	Incorp.	Mulched [1]	Average
No green manure, June planting, no fertilizer	-	-	11.06	9.13	10.09 ab
No green manure, June planting, with fertilizer [2]	-	-	13.69	13.17	13.43 a
No green manure, Sept. planting, no fertilizer	-	-	5.76	4.45	5.11 cd
No green manure, Sept. planting, with fertilizer [2]	-	-	6.49	5.57	6.03 cd
Sesbania rostrata, Sept. planting no fertilizer	0.84	1.11	5.25	3.63	4.44 d
Mucuna fospeada, Sept. planting, no fertilizer	3.08	3.78	7.44	9.41	8.42 bc
Crotalaria juncea, Sept. planting, no fertilizer	6.22	6.92	9.92	10.47	10.20 ab
Canavalia ensiformis,Sept. planting, no fertilizer	3.27	3.64	6.83	6.94	6.88 bcd
Cowpea, Sept. planting, no fertilizer	2.10	2.97	7.40	4.61	6.00 cd
Pigeon pea, Sept. planting, no fertilizer	3.10	3.57	9.31	6.17	7.74 bcd
Average	**3.10**	**3.66**	**8.32 A**	**7.36 A**	

F-test for cassava yield: main plots (A) NS; green manure treatments (B) **; A × B NS

[1] Cassava planted without land preparation.
[2] 94 kg N and 50 kg K_2O/ha.
Note: NS = not significant; ** = significant at P=0.01; data within a column followed by the same letter are not significantly different.

From these two experiments conducted in Pluak Daeng, we concluded that, among the green manures tested, *Crotalaria juncea* was the most productive and the most effective in increasing cassava yield; that incorporation of the green manures resulted in slightly higher yield than mulching (not statistically significant); and that some green manures were as effective as or even more effective than chemical fertilizer in increasing yield. However, under the climatic conditions of Thailand, which has a 6-month dry season, the traditional use of green manures is impractical, since the better part of the rainy season is used for the production of green manures, while the following cassava crop produces low yield due to drought stress in the dry season. For that reason, green manuring is seldom adopted by Thai cassava farmers.

f. Alternative management of green manures in Rayong, Thailand

To overcome some of the above-mentioned constraints, alternative management practices were tested in a green manure experiment conducted at Rayong Field Crops Research Center in Rayong, Thailand, from 1994 to 1999, using *Crotalaria juncea, Canavalia ensiformis*, pigeon pea, and cowpea as the green manures. Three methods of green manure management were tested: (a) green manures were intercropped with cassava, pulled out at two months after planting (MAP), and mulched between cassava rows; (b) green manures were interplanted into a mature cassava stand at seven MAP; they were pulled up and mulched at the time of the next cassava planting; or (c) green manures were grown as a conventional green manure crop before being pulled up at 3−4 MAP and mulched, after which cassava was planted without further land preparation and left to grow for 18 months. The last method resulted in a 21-month crop cycle.

The results **(Table 11)** indicate that *Crotalaria juncea* usually had the highest DM production, followed by pigeon pea or cowpea. Pigeon pea was particularly productive as a green manure crop when interplanted at seven MAP, in which case the green manure remained in the field during the dry season. Because of their high DM production, *Crotalaria* and pigeon pea were the most effective in recycling nutrients.

In the first cycle, almost all green manure treatments increased cassava yield compared with the check without green manure (T1); however, this yield was still below that obtained with a higher fertilization rate (T2). In the second and third cycles, intercropping or interplanting of the green manures still had no significant effect on cassava yield, which was again considerably below that obtained with a higher rate of fertilization (T2). Letting cassava grow for 18 months after a conventional green manure crop (T11–T14) resulted in very high cassava yield while having little effect on root starch content. This may be an effective way for farmers to reduce production costs, since land preparation, weeding, and harvesting are done only once in two years, while total production from three 21-month cycles was similar to or higher than that of five 1-year cycles (**Table 11**). However, using a higher rate of fertilization without green manures still produced the highest cassava yield.

Again, there were no consistent effects of any of the green manure treatments on soil pH, OM, available P, or exchangeable K. Thus, while green manuring may have short-term benefits in terms of crop productivity, the long-term effects on soil fertility are not very clear. Whenever labor is scarce, such as in Thailand, farmers will probably prefer to maximize their yield through the use of chemical fertilizer.

Nevertheless, Paisancharoen et al. (1990) reported that incorporation of vegetative cowpea (Tita-3) significantly increased the yield of the following cassava crop during five consecutive years in Khon Kaen in northeast Thailand. Incorporation of *Crotalaria juncea* also increased yield, but not significantly, while pigeon pea had little beneficial effect (Sittibusaya et al., 1995) (see **Table 8** above).

Table 11. Effect of fertilizer application, three alternative green manure practices, and four different species on green manure production and nutrient content, as well as on the yield of cassava cv. Rayong 90 grown for three consecutive cropping cycles at Rayong Field Crops Research Center in Thailand from 1994 to 1999.

Treatments[1)]	DM of green manures (t/ha)		Nutrient content of green manures (kg/ha)						Cassava yield (t/ha)				
			N		P		K						
	1st[2)]	2nd	1st	2nd	1st	2nd	1st	2nd	1st cycle	2nd cycle	3rd cycle	Av.	Σ5 years[3)]
1. Cassava without GM, 156 kg/ha 13-13-21	-	-	-	-	-	-	-	-	17.56	30.06	14.39	20.67	103.3
2. Cassava without GM, 467 kg/ha 13-13-21	-	-	-	-	-	-	-	-	29.78	40.39	21.42	30.53	152.6
3. C+*Crotalaria juncea,* mulched at 2 months	1.92	4.74	44.7	94.9	3.0	12.7	27.6	31.1	23.75	29.19	14.02	22.32	111.6
4. C+*Canavalia*, mulched at 2 months	0.94	1.84	20.1	51.7	2.4	6.6	14.6	25.9	26.94	27.75	15.50	23.40	117.0
5. C+pigeon pea, mulched at 2 months	1.09	2.09	27.0	48.7	2.2	6.7	12.5	19.0	21.39	26.97	14.47	20.94	104.7
6. C+cowpea, mulched at 2 months	-	2.77	-	53.7	-	7.2	-	27.1	20.28	18.75	11.31	16.78	83.9
7. C+*Crot. juncea,* planted at 6–7 months	9.89	1.15	262.1	21.7	23.7	4.6	102.9	7.4	8.75	31.44	14.97	18.39	91.9
8. C+*Canavalia*, planted at 6–7 months	1.54	0.65	36.6	16.0	4.1	3.1	28.0	8.2	22.83	24.17	12.94	19.98	99.9
9. C+pigeon pea, planted at 6–7 months	8.92	2.32	221.7	45.5	20.0	7.3	108.8	15.9	15.86	28.81	14.27	19.65	98.2
10. C+cowpea, planted at 6–7 months	-	0.72	-	14.2	-	2.9	-	7.6	17.25	27.02	14.77	19.68	98.4
11. *Crot.juncea* GM, cut at 2–3m, C 18 months	1.44	4.36	39.9	79.9	3.6	17.7	14.7	31.6	46.17	49.04	36.94	44.05	132.1
12. *Canavalia* GM, cut at 2–3m, C 18 months	0.93	1.41	18.4	45.7	2.3	7.2	15.8	17.2	42.98	43.81	34.14	40.31	120.9
13. Pigeon pea GM, cut at 2–3m, C 18 months	1.05	2.68	25.6	68.7	2.3	13.2	12.8	21.7	38.81	45.97	37.00	40.59	121.8
14. Cowpea GM, cut at 2–3m, C 18 months	-	2.92	-	68.2	-	12.6	-	31.0	38.86	46.32	30.22	38.47	115.4

1) C = cassava; GM = green manure.
In T3–T14, cassava received 156 kg 13-13-21/ha (like T1).
In T3–T6, cassava was intercropped with one row of green manure, which was pulled out and mulched at 2 MAP; cassava was harvested at 11 months for a total crop cycle of 12 months.
In T7–T10, the green manures were interplanted in the cassava stand at 7 MAP; they remained after the cassava harvest and were pulled up and mulched at the time of the next cassava planting; cassava was harvested at 11 months for a total crop cycle of 12 months.
In T11–T14, the green manures were planted, pulled out, and mulched at 3–4 months, after which cassava was planted and remained in the field for 18 months for a total crop cycle of 21 months.
In the first cycle, T6, T10, and T14 had *Mucuna pruriens* as the GM, but this species did not germinate well and was replaced by cowpea in the second and third cycle.

2) 1st and 2nd refer to the first two cropping cycles.

3) For T1–T10, estimated from the average yields in the first three years; for T11–T14, actual yields during the three crop cycles completed in slightly over 5 years.

g. *Long-term economic effect of green manures in Khaw Hin Sorn, Thailand*

A new trial was started at Kasetsart University's Khaw Hin Sorn station in Chachoengsao Province of Thailand in 2002 in order to determine the potential benefits of green manures planted as intercrops between cassava rows. In this case, the green manures were planted one month after the planting of cassava (to give cassava a competitive edge) and were pulled out and mulched two months later. **Table 12** shows the effect of annual planting of green manures on cassava yield during five consecutive cropping cycles. Although the planting of some green manures produced slightly higher cassava yield in some years, on average, none had a beneficial effect on yield. It was expected that green manures would improve both the physical and chemical characteristics of the soil, resulting in higher cassava yield, especially in these very light-textured soils that have little organic matter (1−2%). However, the data indicate that, even after five years, there was still no beneficial effect of green manuring (as an intercrop) on cassava yield. *Canavalia ensiformis* and mungbean were less competitive than *Mucuna* sp. and *Crotalaria juncea. Mucuna* tends to climb on top of cassava plants, and is therefore not suitable as an intercropped green manure. The highest yields were obtained with the application of the high rate of 469 kg/ha of 15-7-18 fertilizer and without green manures.

Table 12. Effect of green manures and/or chemical fertilizer on the root yield of cassava cv. KU 50 planted for five consecutive years at Khaw Hin Sorn Research Station in Chachoengsao, Thailand, from 2002/03 to 2006/07.

	Cassava yield (t/ha)					
Treatment [1]	1st year	2nd year	3rd year	4th year	5th year	Av.
1. Check without GM; 25 kg/rai 15-7-18	46.45	26.28	32.48	36.08	18.86	**32.03**
2. *Crotalaria juncea;* 25 kg/rai 15-7-18	36.58	20.83	29.26	31.19	19.03	**27.38**
3. *Canavalia ensiformis;* 25 kg/rai 15-7-18	40.35	27.07	31.16	29.79	19.00	**29.47**
4. Pigeon pea ICPL 304; 25 kg/rai 15-7-18	38.23	24.18	31.86	30.79	19.64	**28.94**
5. Cowpea CP 4-2-3-1; 25 kg/rai 15-7-18	38.54	21.66	32.12	32.06	20.76	**29.03**
6. *Mucuna;* 25 kg/rai 15-7-18	36.73	21.17	28.58	32.09	16.45	**27.00**
7. Mungbean; 25 kg/rai 15-7-18	40.07	25.08	33.49	36.38	16.51	**30.31**
8. Check without GM; 75 kg/rai 15-7-18	43.44	32.16	37.78	34.51	27.56	**35.29**

[1] GM = green manures; 1 ha = 6.25 rai.
Source: *S. Jantawat, personal communication.*

Although intercropped green manures may actually reduce cassava yield by competing with cassava for light, water, and nutrients, they also compete with the local weeds, thus reducing competition from weeds. This will reduce the normal cost of weed control. During the fifth year, this reduced cost of weed control more than compensated for the additional costs of the green manure seed and the labor involved in planting and cutting back the green manures, as shown in **Table 13**. Thus, the use of green manures actually reduced the total cost of production compared with the check without green manures. **Table 14** shows the average root yield and starch content, as well as the gross income, production costs, and net income. The highest net income was obtained with the use of the high rate of chemical fertilizer, followed by the lower rate, both without green manures.

Table 13. Estimated cost of production of treatments in the green manure experiment conducted at Khaw Hin Sorn Research Station in Chachoengsao, Thailand, in 2006/07 (fifth year).

	Production costs for 5th year (baht/rai) [1]							
Treatment [1]	Land prepar.	Planting cassava	Fert.+ applic.	Weed control	GM planting+ harvest	GM seed	Cassava harvest + transport	Total
1. Check without GM; 25 kg/rai 15-7-18	450	200	400	620	-	-	1,147	2,817
2. *Crotalaria juncea;* 25 kg/rai 15-7-18	450	200	400	220	220	150	1,157	2,797
3. *Canavalia ensiformis;* 25 kg/rai 15-7-18	450	200	400	220	220	150	1,155	2,795
4. Pigeon pea ICPL 304; 25 kg/rai 15-7-18	450	200	400	220	220	150	1,194	2,834
5. Cowpea CP 4-2-3-1; 25 kg/rai 15-7-18	450	200	400	220	220	170	1,262	2,922
6. *Mucuna;* 25 kg/rai 15-7-18	450	200	400	220	220	150	1,000	2,640
7. Mungbean; 25 kg/rai 15-7-18	450	200	400	220	220	120	1,003	2,613
8. Check without GM; 75 kg/rai 15-7-18	450	200	1,000	620	-	-	1,676	3,946

[1] Costs:

land preparation :	baht 400/rai	herbicide application:	baht	100/rai
planting cassava:	200/rai	hand weeding (2x):		400/rai
15-7-18 fertilizer:	600/50 kg	planting + harvesting GM:		220/rai
fertilizer application:	100/rai	harvest cassava:		180/ton
Glyphosate (500 mL/rai):	120/rai	transport cassava:		200/ton
US$1 is about 40 Thai baht		1 ha = 6.25 rai		

Table 14. Effect of green manures and/or chemical fertilizer on the average root yield and starch content of cassava cv. KU 50 as well as gross and net income during five consecutive years of cassava cropping at Khaw Hin Sorn Research Station in Chachoengsao, Thailand, from 2002/03 to 2006/07.

Green manure treatment [1]	Root yield (t/ha)	Starch content (%)	Gross income	Production costs (000 baht/ha)	Net income
1. Check without GM; 25 kg/rai 15-7-18	32.03	24.2	37.68	17.94	19.94
2. *Crotalaria juncea;* 25 kg/rai 15-7-18	27.38	23.7	32.28	16.38	15.90
3. *Canavalia ensiformis;* 25 kg/rai 15-7-18	29.47	24.2	34.86	16.94	17.92
4. Pigeon pea ICPL 304; 25 kg/rai 15-7-18	28.94	23.6	34.04	16.83	17.21
5. Cowpea CP 4-2-3-1; 25 kg/rai 15-7-18	29.03	23.2	34.08	17.02	17.06
6. *Mucuna;* 25 kg/rai 15-7-18	27.00	24.3	32.14	16.23	15.91
7. Mungbean; 25 kg/rai 15-7-18	30.31	23.9	35.86	17.00	18.86
8. Check without GM; 75 kg/rai 15-7-18	35.29	24.4	42.39	22.04	20.35

[1] GM = green manure; all green manures were planted between cassava rows one month after planting cassava and were pulled out or cut off two months later and mulched; 1 ha = 6.25 rai.

From these various green manure trials, we can conclude that the planting of green manures can increase cassava yield in areas with a relatively long wet season or with a bimodal rainfall distribution, especially when no fertilizer is applied. However, in areas with a single and relatively short wet season, the planting of green manures before incorporation or mulching, and before cassava planting, may actually decrease cassava yield due to inadequate rainfall during the cassava growth cycle. In that case, leaving cassava in the ground for another year may be the most economical solution. Interplanting the green manures within a mature cassava stand at 7−8 MAP and incorporating them before the next cassava planting may be another solution, while intercropping at the time of cassava planting, or shortly thereafter, could result in excessive competition with cassava.

h. Use of off-site green manures in DR Congo

Another alternative is to collect green manures off-site. Some species, such as *Chromolaena odorata*, a common weed in many fields, or *Tithonia diversifolia,* a weed found growing along roadsides, are high-quality green manures. *Tithonia* is particularly high in N and K, while *Chromolaena* is high in N and intermediate in K. However, their nutrient contents will vary with the location where they are collected (**Table 15).**

Table 15. Dry matter and nutrient content of *Tithonia diversifolia* and *Chromolaena odorata* green manures collected at two sites in the Bas-Congo region of DR Congo.

	Tithonia diversifolia		*Chromolaena odorata*	
	Kiduma	Mbuela	Kiduma	Mbuela
DM (% of fresh weight)	28		19	
N (% of dry matter)	4.66	2.96	4.56	3.16
P (% of dry matter)	0.24	0.17	0.26	0.17
K (% of dry matter)	4.71	1.64	1.85	1.28

Source: *Pypers et al., 2012.*

Research reported by Pypers et al. (2012), conducted at two sites in western DR Congo, indicates that, when 2.5 t DM/ha of these two green manures were incorporated in the soil before planting cassava, the yield of cassava increased markedly, similar to that obtained with the application of low to moderate NPK compound fertilizer, that is, 283 and 850 kg 17-17-17/ha, respectively. When the two green manures were applied in combination with the low or moderate amounts of fertilizer, cassava yield increased more, even beyond that obtained with the high rate of 1,417 kg/ha of 17-17-17 fertilizer. *Tithonia* was more effective in increasing cassava yield than *Chromolaena* in Kiduma, but not in Mbuela, due to the much lower nutrient content of *Tithonia* collected at the latter site. Application of chemical fertilizer in low, moderate, and high amounts increased cassava yield significantly at both sites and also had significant residual effects in the following cassava crop. Incorporation of *Tithonia* and *Chromolaena* increased cassava yield significantly in Kiduma, but not in Mbuela, and neither green manure had a residual effect in the following cassava crop (**Table 16**). In spite of the high cost of fertilizer, the net economic benefits increased with fertilizer application, up to the highest rate in Kiduma and up to the moderate rate in Mbuela; however, the benefit/cost ratio and marginal rate of return were highest for *Tithonia*.

Thus, in areas where chemical fertilizer is either not available or very costly, cassava yield can be markedly increased by incorporating local weeds such as *Tithonia* or *Chromolaena*. However, these may not always be available and are cumbersome to collect and transport at the high rates of application used in these experiments (8.93 t fresh matter of *Tithonia* and 13.16 t/ha of *Chromolaena*).

Table 16. Effect of the application of various rates of chemical fertilizer and incorporation of green manure species *Tithonia diversifolia* and *Chromolaena odorata* on cassava fresh root yield (t/ha) during two cropping cycles at two sites in the Bas-Congo region of DR Congo.

	Fertilizer rate [1] (kg/ha)	Cassava fresh root yield (t/ha)			
		First crop		Second crop	
		Kiduma	Mbuela	Kiduma	Mbuela
Fertilizer response					
No green manure	0	12.7	10.5	10.1	5.4
No green manure	283	23.7	14.9	14.9	7.4
No green manure	850	31.4	19.6	17.6	9.0
No green manure	1,417	39.6	18.6	33.1	18.0
Green manure					
Tithonia	0	32.8	18.1	12.7	6.4
Tithonia	283	37.6	23.5	17.8	8.7
Tithonia	850	41.5	21.7	20.2	8.2
Chromolaena	0	19.9	18.2	12.2	7.3
Chromolaena	283	29.5	21.1	18.4	8.5
Chromolaena	850	35.2	23.4	18.6	9.0

[1] Fertilizer 17-17-17 expressed as N-P_2O_5-K_2O.
Source: *Pypers et al., 2012.*

The effectiveness of particular green manure species seems to vary a lot depending on their adaptation to particular soil and climatic conditions. Among the best grain legumes were peanut, pigeon pea, and cowpea, and among forage legumes the most effective were *Crotalaria juncea* (mainly in slightly acid to neutral soils) and *Canavalia ensiformis, Zornia latifolia*, and *Pueraria phaseoloides* (mainly in acid soils). Also, within each species are many different ecotypes, which may vary in their particular adaptation and productivity. In some cases, the mulching of native weeds may be as effective as planting green manures.

In practically all the trials, the highest cassava yield was obtained by using chemical fertilizer rather than green manures, and, in many cases, this would be the most economical practice. In the absence of fertilizer, green manures may increase cassava yield, but they seldom seem to have a long-term beneficial effect on soil fertility.

MULCHING

In many of the green manure experiments mentioned above, the biomass of the green manure species was either incorporated into the soil or was mulched on top of the soil. Mulching the biomass on top of the soil has the advantage that the mulch will protect the soil from the direct impact of raindrops, resulting in less erosion. Moreover, the mulch will reduce weed growth, will preserve soil moisture, and reduce diurnal temperature fluctuations in the soil. The practice of mulching the biomass also eliminates the need for the additional work of incorporation or one additional pass with the tractor. If the soil is loose and well aggregated, the cassava stakes can be planted directly through the mulch into the soil. This method of minimum or zero-tillage in itself tends to have many advantages, mainly in improving the organic matter and structure of the soil.

Although mulching seems to have many benefits, in only a few experiments was the biomass both mulched and incorporated. In the second green manure experiment in Pluak Daeng, Thailand, described above, the green manure biomass was both mulched and incorporated. The data in **Table 10** indicate that cassava yield was slightly but not significantly higher when the green manure biomass was incorporated rather than mulched.

a. Mulch of dry grass in Media Luna, Colombia

In another experiment on sandy soils in Media Luna, on the north coast of Colombia (CIAT, 1994; 1995; 1996; Cadavid et al., 1998), the long-term effect of zero-tillage, application of mulch, and the use of chemical fertilizer (50 kg/ha of N, P_2O_5, and K_2O) on cassava yield was investigated. The results **(Table 17)** indicate that application of large amounts (12 t/ha) of dry mulch of guinea grass not only supplied plant nutrients, mainly K, Ca, Mg, and inorganic-N, but also helped to maintain soil moisture and reduce the temperature of the surface soil.

Table 17. Effect of fertilizer application, mulching, and tillage on the average cassava root yield, root DM, and HCN content during eight years of cropping in Media Luna, Colombia.

	With fertilizer [1]			No fertilizer		
Main treatments	Root yield (t/ha dry weight)	Root DM (%)	Root HCN (mg/kg dry weight)	Root yield (t/ha dry weight)	Root DM (%)	Root HCN (mg/kg dry weight)
Conventional tillage	5.51	30.2	158	2.19	30.1	227
Conventional tillage + mulch	5.92	30.9	146	4.66	30.6	149
Zero-tillage	4.42	29.5	150	1.93	29.2	224
Zero-tillage + mulch	6.11	31.0	140	4.66	30.4	158
Average	**5.49**	**30.4**	**148**	**3.36**	**30.1**	**189**
LSD 5% for comparison among fertilizer treatments	0.26	NS	12			
LSD 5% for comparison among main treatments	0.77	0.88	18	0.35	0.77	0.32

[1] With fertilizer is 50 kg/ha each of N, P_2O_5, and K_2O.
Source: *Cadavid et al., 1998.*

Mulch application during eight consecutive years significantly increased cassava root and top biomass, increased root dry matter content while reducing its yearly variation, and decreased root HCN, particularly in the absence of fertilizer. Cassava yield declined over the years in the absence of fertilizer and mulch, but increased when either mulch alone or mulch and fertilizer were applied. Over the years, both the application of mulch and that of fertilizer increased the soil P and K, whereas, without mulch, soil pH decreased. The effect of fertilization was more pronounced in the absence of mulch.

b. Application of rice straw mulch in Dong Nai Province of southern Vietnam

On a rather infertile sandy loam soil in Traco Village of Thong Nhat District in Dong Nai Province of Vietnam, the application of 3 t/ha of dry rice straw increased cassava yield, but not significantly, while fertilizer application had a more significant positive effect **(Table 18)**.

Table 18. Effect of mulching and rates of applied chemical NPK fertilizer on the average fresh root yield of cassava grown on an Haplic Acrisol in Traco Village of Dong Nai Province in southern Vietnam in 1994/95 and 1995/96.

	Fresh root yield (t/ha)		
Fertilizer treatment	No mulch	With rice straw mulch[1]	Average
No fertilizer	17.84 d	18.68 d	**18.26**
30-30-45 kg N-P_2O_5-K_2O/ha	21.39 c	22.23 bc	**21.81**
60-60-90 kg N-P_2O_5-K_2O/ha	22.04 c	22.88 bc	**22.46**
120-120-180 kg N-P_2O_5-K_2O/ha	24.32 ab	25.16 a	**24.74**
Average	**21.40**	**22.23**	

[1] 3 t/ha of dry rice straw.
Note: Data in the same column followed by the same letter are not significantly different
Source: *Cong Doan Sat and P. Deturck, 1998.*

CROP ROTATION

In most parts of Asia, cassava is grown on the same fields year after year. This is mainly because cassava is often grown in areas where other crops will not grow well because of soil or climatic constraints. A good example is the northeast of Thailand, where cassava is the main upland crop because maize, soybean, and mungbean yields are very low. Cassava is sometimes rotated with sugarcane when the sugar support price is high even though sugarcane yields in the area are usually below the world average. Still, there is no doubt that rotating cassava with other crops can reduce pest and disease problems, and could increase soil fertility and cassava yield. Especially in areas with heavy soils and poor internal drainage, where root rots are frequently observed, farmers are often advised to rotate cassava with other crops, especially cereals and grasses, in order to reduce the soil inoculum of the causal agent, *Phytophthora* spp. With the recent appearance of a type of witches' broom disease, mainly in Vietnam, Thailand, and Cambodia, caused by a phytoplasma, it is probably advisable to rotate cassava with other crops to prevent the spread of the disease through infected crop residues left from the previous cassava crop.

Another reason for crop rotations is to increase farmers' income. Although cassava is usually grown for 10−11 months per year, some short-duration varieties can produce a reasonably high yield when harvested after 7−8 months. In that case, another short-duration crop can be grown during the same year, thus increasing farmers' income. In Lampung Province of Indonesia, upland rice is often planted in the early rainy season and harvested after 4 months, after which a short-duration cassava variety, such as UJ-3 (Rayong 60), is planted and harvested after eight months toward the end of a short dry season.

a. *Sequential cropping systems in lowland areas of Kerala, India*

In Kerala State of India, more and more cassava is now grown in lowland areas where short-duration cassava varieties are often planted after the harvest of a short-duration rice crop. Under those conditions, the yield of cassava is substantially higher than in the traditional upland areas. Even higher income can be obtained when cassava follows a crop of vegetable cowpea or when a peanut crop follows cassava under lowland rice field conditions in Kerala, India **(Table 19)**.

Table 19. Average yield and economics of three cassava-based sequential cropping systems under lowland conditions at CTCRI, Kerala, India, during three planting seasons from 1986 to 1988.

Crop sequence	Average yield (t/ha)	Average gross income (Rs/ha)	Average cost of cultivation (Rs/ha)	Average net income (Rs/ha)
1. Rice-cassava				
Rice	2.16	6,765	5,300	1,465
Straw	3.28	-	-	-
Cassava roots	47.56	24,540	9,300	15,240
Total	-	**31,305**	**14,600**	**16,705**
2. Vegetable cowpea-cassava				
Veg. cowpea	4.63	8,834	3,300	5,534
Cassava roots	51.12	26,380	8,100	18,280
Total	-	**35,214**	**11,400**	**23,814**
3. Cassava-peanut				
Cassava roots	49.61	25,590	9,300	16,290
Peanut	0.94	5,264	3,700	1,564
Total	-	**30,854**	**13,000**	**17,854**

Source: *Mohankumar and Nair, 1990.*

b. *Crop rotation in three soil series in cassava-growing areas in Thailand*

A crop rotation experiment was conducted in three major soils in northeast Thailand from 1975 to 1984. Cassava was grown either in continuous monoculture, with and without chemical fertilizer (50 kg/ha each of N, P_2O_5, and K_2O), or rotated yearly with peanut followed by pigeon pea or by mungbean followed by pigeon pea in the same year.

The results indicate that, although the rotation system did not have much effect on soil properties, the system increased farmer income over continuous cassava cropping, especially when cassava was rotated with peanut followed by pigeon pea (Chaiwanakupt and Sittibusaya, 1985, as quoted by Paisancharoen et al., 2010).

c. *Crop rotation and intercropping in Khon Kaen, Thailand*

A long-term cropping systems experiment was started at the Khon Kaen Field Crops Research Center in 1980 and was continued for 22 years until 2001/02. Continuous cassava monoculture was compared with cassava intercropped with peanut, and a third treatment in which cassava monoculture was rotated yearly with the sequential cropping of peanut followed by pigeon pea in the same year. These three cropping systems were each combined with four methods of soil improvement: (1) no fertilizer; (2) chemical fertilizer (50 kg N, P_2O_5, and K_2O/ha); (3) soil amendments of 1.25 t/ha of lime plus 1.25 t/ha of phosphate rock and 12.5 t/ha of compost applied only in the first, fifth, and ninth year; and (4) chemical fertilizer plus soil amendments. The peanut in the rotation treatment was fertilized with 19 kg N + 57 kg P_2O_5 + 32 kg K_2O/ha, while the pigeon pea did not receive any fertilizer. All crop residues were incorporated into the soil before the next planting.

Figure 4 indicates that, averaged over the four soil improvement treatments, cassava yield in the crop rotation system tended to increase over the years, whereas, in the two cropping systems of cassava monoculture and intercropped with peanut, yield declined, especially for the intercropping treatment. However, when in the later years of the experiment the planting of peanut was delayed until 4 weeks after the planting of cassava, cassava yield increased, possibly due to the reduced early competition from peanut.

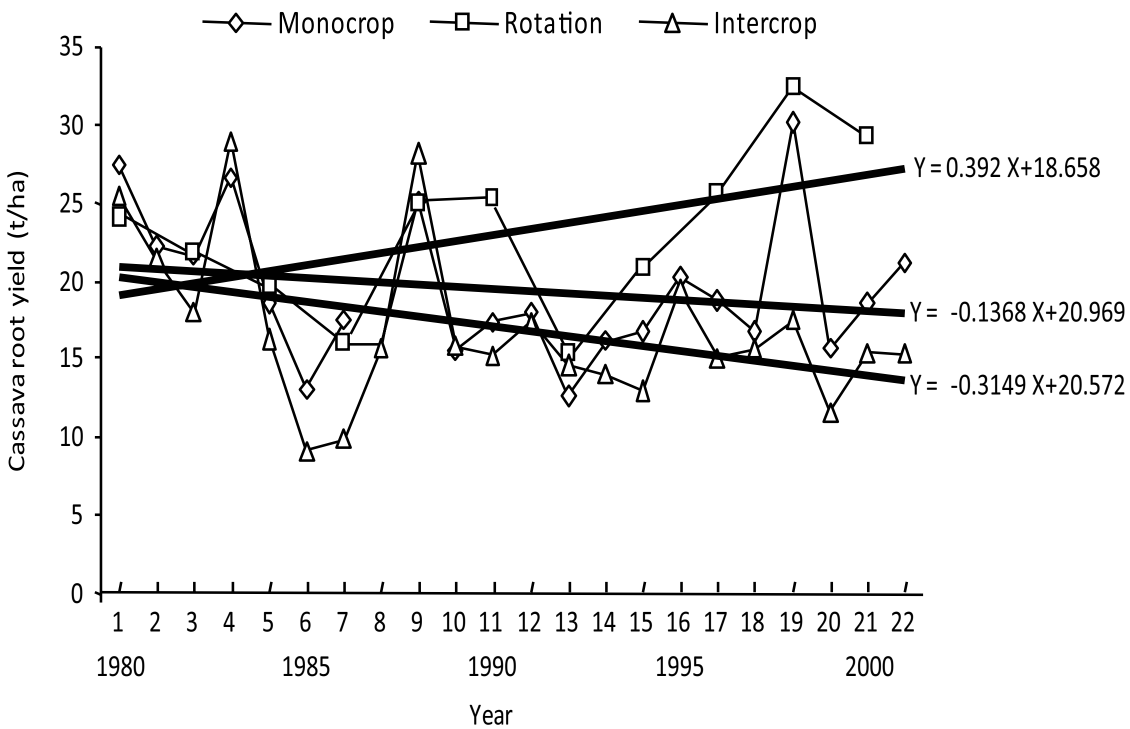

Figure 4. *The effect of crop rotation and intercropping with leguminous species on fresh cassava root yield during 22 years of continuous cropping at Khon Kaen Field Crops Research Center in Khon Kaen, Thailand, from 1980 to 2001.*

Source: *Wongwiwatchai et al., 2001; 2007.*

These results clearly indicate that rotating cassava with well-adapted grain legumes, such as peanut and pigeon pea, had long-term advantages over continuous cassava production, which is the common practice among farmers in northeast Thailand (Wongwiwatchai et al., 2001).

INTERCROPPING

Intercropping cassava with short-duration crops is a common practice among smallholder farmers in many tropical countries. These intercrops are useful because they supply either food or additional income, especially at times when the cassava crop cannot yet be harvested; they may fix N and supply other nutrients to the topsoil; they may protect the soil from the direct impact of rainfall, and may reduce the speed of runoff water when the cassava canopy is not yet closed, thus reducing soil erosion; and they may reduce weed growth during the early stages of cassava development. However, intercrops need to be carefully managed in order to reduce the competition with cassava for light, water, and nutrients. This is usually done through modifications of the plant spacing or planting pattern of both crops, by adjusting the relative time of planting, and by fertilizing each crop adequately to maximize yield.

1. Advantages and Disadvantages of Intercropping

Intercropping is usually practiced by smallholder farmers who have only small areas of land from which to feed or sustain a family. In this case, land and capital are the major constraints while labor may be rather abundant. These farmers have to maximize the total productivity of the land by optimizing growth factors such as light, water, and nutrients. Growing two or more crops together has the following advantages:

- The different crops provide a greater food variability such as carbohydrates from grain and root or tuber crops, protein from grain legumes, and vitamins and fiber from vegetables
- Increased yield stability or income and reduced risk of total crop failure
- Reduced incidence of pests and diseases
- Reduced weed competition
- Reduced soil loss by erosion by providing an early ground cover between the rows of the slow-growing long-duration crop
- More efficient use of land and labor, the latter being needed for different operations throughout the year
- Increased yield and total net income per unit area of land

However, intercropping also has certain disadvantages:

- It reduces the possibility of using mechanization for planting, weeding, and harvesting, as well as the use of certain herbicides to control weeds, and the application of fertilizer
- It may complicate the management of each crop individually
- It requires more labor per unit area
- Intercrop competition is likely to reduce the yield of each individual crop, although this is generally compensated for by an increase in the total value of all crops included in the system

Intercropping systems must be designed to maximize the total net income of the system, to increase the various advantages, and to decrease the disadvantages mentioned above. This will require the careful selection of the various crops to be planted, the most suitable varieties of each crop, the most effective plant densities and planting arrangements, appropriate relative time of planting each crop, and the most effective fertilization, amounts and balance of nutrients and times of application, as well as their distribution among the various crops.

2. Commonly Used Intercropping Systems in Asia

Intercropping systems vary markedly from country to country as well as among different regions within the same country, depending on the soil and climatic conditions, especially the length of the rainy and dry seasons. The most commonly used systems are shown in **Table 20.**

Table 20. Commonly used intercropping systems with cassava in Asia.

Country	Associated crops
Cambodia	Upland rice, maize, cashew nut, rubber
China	Maize, watermelon, sweet potato, peanut, rubber
Timor-Leste	Maize, peanut, vegetables, banana
India	Maize, cowpea, vegetables, coconut
Indonesia	Upland rice, maize, soybean, cowpea, mungbean, peanut, coconut, rubber
Lao PDR	Upland rice, maize, Job's tear, peanut
Myanmar	Maize, peanut, common bean, banana
Philippines	Maize, peanut, sweet potato
Thailand	Maize, rubber, coconut, cashew nut
Vietnam	Maize, upland rice, peanut, black bean, rubber, cashew nut, coffee, tea

Source: *Aye and Howeler, 2012.*

Probably the most intensive intercropping systems are found in the wetter zones of West Java and Sumatra of Indonesia. There, cassava is intercropped with simultaneously planted upland rice between cassava rows and maize between plants in the cassava row. Once the upland rice and maize are harvested at about four months after planting, a short-duration grain legume, such as mungbean, soybean *(Glycine max)*, cowpea, or peanut, is planted in the interrow space previously occupied by rice. If rainfall permits, a fourth intercrop, such as mungbean *(Vigna radiata)* or peanut, is planted in the space previously occupied with the harvested grain legume. In East Java, on the other hand, the dry season is longer and cassava cannot be intercropped with more than one crop, usually maize.

In southern Vietnam, cassava is often intercropped with maize or planted among young rubber or cashew trees, while in northern Vietnam the crop is often intercropped with peanut or black bean *(cowpea)*.

In Guangxi Province of China, cassava is often intercropped with maize, peanut, sweet potato *(Ipomoea batatas)*, or watermelon, while in Hainan Province the crop is often interplanted among young rubber trees or bananas.

In Thailand, cassava is only occasionally intercropped with maize or grain legumes due to the lack of labor, but the crop is sometimes planted for a few years among young rubber or coconut trees.

3. Improvements in Cassava Intercropping Systems

Several factors should be considered in the selection of crops and management practices to maximize the outputs of intercropping systems.

a. Plant type and/or growth habit

Cassava varieties may differ in their growth habit, some having vigorous early growth and early branching, while others are more erect with medium to late branching. This may also vary with fertility of the soil; in soils low in K, plants tend to be short and highly branched, showing a prostrate growth habit, while plants growing in soils high in N are tall and show vigorous early growth. To minimize the shading of low-growing grain legumes by cassava, the latter should have an erect and late-branching growth habit, but, to avoid the shading of cassava by fast-growing intercropped maize, the former should have a vigorous early growth with medium to late branching.

b. Relative time of planting

The intercrops can be planted at the same time as cassava or one or more weeks before or after planting cassava, depending on the vigor of each crop as well as on the relative income expected from each crop. When the income from the intercrop is expected to be high, these crops can be favored by planting before the planting of cassava, and vice versa. However, in general, the greatest total yields are obtained when both crops are planted at the same time or with a difference in planting date of only 1–2 weeks **(Figure 5)**.

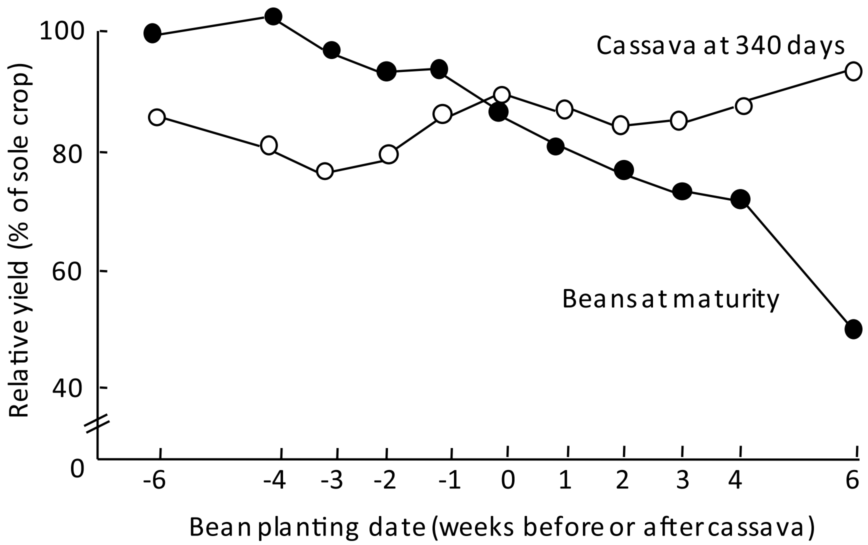

Figure 5. *Relative yield of cassava and common beans (Phaseolus vulgaris) grown in association according to their relative planting times.*
Source: *Thung and Cock, 1979.*

c. Planting density

In general, the optimum monocrop planting density can also be used when cassava is grown in association with other crops without causing a serious yield reduction of the associated crop. However, if the cassava variety is very vigorous, it may be necessary to reduce its plant density in order to maximize total yield. With late-branching and less vigorous cassava varieties, the best yield was achieved with an intermediate plant density of about 10,000 plants per hectare.

d. Planting pattern

The choice of spatial arrangement of each crop is important in reducing competition and maximizing total yield, as different arrangements affect the efficiency of the use of light and space. In many cases, a normal square planting arrangement of cassava with one row of grain legume or maize between cassava rows gives the maximum yield and income from both crops. However, to favor the growth of intercrops, a wider between-row spacing of cassava and shorter interplant spacing in the row are often preferred. This arrangement may allow the planting of two or more rows of intercrops between cassava rows. In Indonesia, cassava is often planted with a between-row spacing of 1.8–2.0 m and interplant spacing of 0.5 m, which allows the planting of four to five rows of upland rice or peanut planted between rows in addition to one hill of maize between cassava plants in the row. After the harvest of upland rice and maize, there is still enough light between rows for planting a second intercrop of a short-duration grain legume between the cassava rows. Alternatively, cassava can be planted in double rows spaced at 0.8×0.8 m in each double row, with 1.9–2.0 m between the double rows. This will allow the planting of several rows of intercrops between each double row of cassava. By varying the between-row and interplant spacing, a cassava plant density of about 10,000 plants/ha can be maintained. Within limits, whether cassava is planted in a square or rectangular planting pattern has little effect on cassava yield **(Table 21)**.

Table 21. Effect of various spatial planting arrangements on the yield of cassava at a constant plant density at three locations in Colombia.

Locality	Variety	Spatial arrangement (m)	Density (plants/ha)	Fresh root yield (t/ha)
CIAT-Palmira[1)]	MMex 52	1.0 × 1.0	10,000	25.0
		2.0 × 0.5	10,000	22.0
CIAT-Palmira	MCol 22	1.0 × 1.0	10,000	35.0
		2.0 × 0.5	10,000	37.0
Caribia	MCol 22	1.0 × 1.0	10,000	17.1
		1.8 × 0.6	9,259	17.6
Media Luna	Secundina	1.0 × 1.0	10,000	15.0
		1.6 × 0.6	10,416	14.1

1) At CIAT-Palmira, the effect of spatial arrangements on cassava yield was statistically not significant. No statistical analyses were performed for the other two locations.

Source: *CIAT, 1979 and 1980.*

The spacing of the intercrops planted between the cassava rows depends on the growth habit of the crop. Most grain legumes should be planted at least 50−70 cm from the nearest cassava row to prevent excessive competition from cassava. Within the remaining interrow space, two to three rows of legumes can be grown at 30−50 cm between rows. When intercropping cassava with common beans in Colombia, the arrangement of three rows of beans (spaced at 30 cm between rows) planted between cassava rows (spaced at 1.8 m between rows) produced the highest total yield and income (**Figure 6** on right). However, in northern Vietnam, the planting of two rows of peanut between cassava rows (spaced at 1 m between rows) was most profitable (Le Sy Loi, 2000).

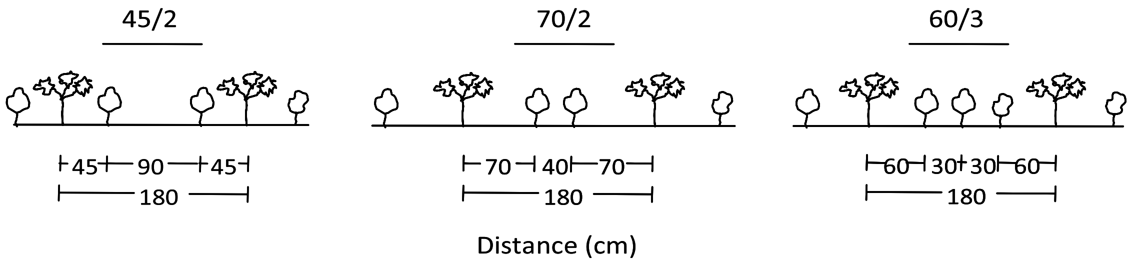

Figure 6. *Various spatial arrangements for cassava in association with legumes, planted on flat land.*
Source: *CIAT, 1979.*

e. *Fertilization*

Crops grown in association tend to cause less loss of nutrients through erosion and leaching but more loss of nutrients removed in the harvested products. Intercropping represents an intensification of the demand for nutrients, particularly when each associated crop is planted at its normal density. In this case, the removal of nutrients from the soil is higher than when cassava is grown in monoculture **(Table 22)**.

Table 22. Removal of soil nutrients by the products (roots and grains) harvested in a cassava/ mungbean intercropping system compared with removal by cassava planted in monoculture.

	Nutrients removed (kg/ha)					
Cropping system	N	P	K	Ca	Mg	S
Cassava in monoculture	40	5	78	19	8	6
Cassava/mungbean intercropping	90	11	84	18	10	9

There is little or no information about the optimum rates and balance of N, P, and K fertilization for each crop in an intercropping system because this is highly dependent on the fertility of the soil, the nutritional requirements of each crop, their competitive interaction, and growth duration. Whether most fertilizers should be applied to cassava or to the intercrop also depends on the expected income to be derived from each crop. In general, cassava should be fertilized as if it were planted in monoculture, usually requiring relatively high N and K, while cereal crops require mostly N and P, and grain legumes P and K.

f. *Weed control*

Intercropping cassava tends to reduce the growth of weeds between cassava rows, but it also makes weeding by mechanical means more difficult. One hand weeding with a hoe at 3−4 weeks after planting is often practiced, after which the canopy cover from both cassava and the intercrop will generally prevent further weed growth.

Weed competition can also be reduced by applying preemergence herbicides. However, some herbicides that are selective for cassava may not be selective for the intercrop. Thus, care should be taken in the selection and dosage of the appropriate herbicides, as discussed in **Chapter 12**.

4. Experimental results

Many experiments have been conducted to determine the best plant spacing and planting patterns, and comparing different intercrops to identify those that maximize yield and income. Only a few examples are shown below.

a. *Intercropping cassava with maize and several legumes in southern Vietnam*

In Vietnam, many smallholder farmers intercrop cassava to maximize their food production or income from a small area of land. An intercropping trial was therefore conducted at Hung Loc Agricultural Research Center in southern Vietnam to determine the best intercrop and planting arrangement for this system. **Figure 7** shows that the single-row planting of cassava at 1.0 × 1.0 m produced higher cassava yield and net profit than the double-row system for all intercrops except maize. All intercrops reduced cassava yield, especially intercropping with the long-duration *Canavalia ensiformis*. Net profit was also highest for planting cassava in monoculture, whereas, among the intercrops, peanut produced the highest total net profit in both single- and double-row systems.

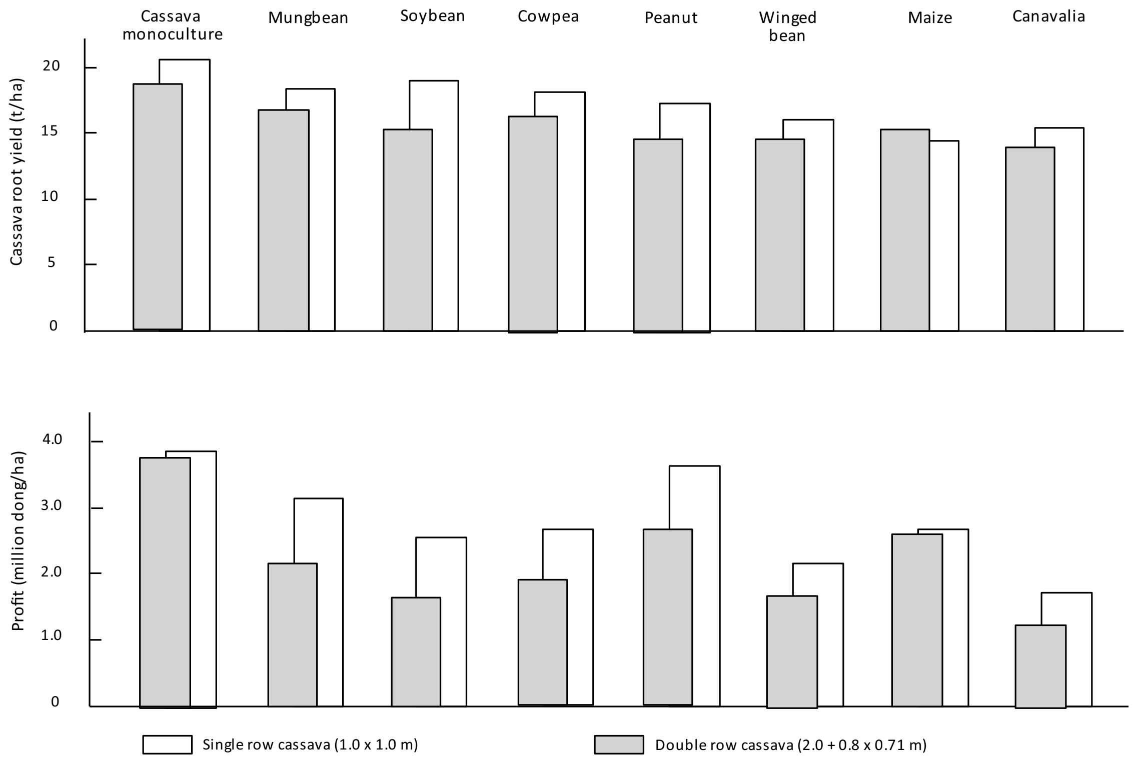

Figure 7. *Average effect of various intercropping systems on cassava yield (top) and on total net income (bottom) when cassava was planted in single rows at 1.0 × 1.0 m or in double rows at 2.0 + 0.8 × 0.71 m at Hung Loc Center in southern Vietnam from 1989 to 1992.*

Source: *Nguyen Huu Hy et al., 1995.*

b. Intercropping cassava with maize and several grain legumes in North Vietnam

In North Vietnam a similar intercropping experiment was conducted for three years from 1990 to 1992. **Table 23** shows that only the intercropping with cowpea and maize reduced cassava yields significantly; intercropping with peanut, soybean and mungbean reduced cassava yields only slightly and intercropping with peanut resulted in the highest total crop value.

Table 23. Average yield of cassava and intercrops as well as the corresponding total crop value in various intercropping systems planted during three years in Thai Nguyen, northern Vietnam, from 1990 to 1992.

Cropping system	Cassava yield (t/ha)	Intercrop yield (kg/ha)	Total crop value (000 dong/ha)
Cassava monoculture	21.8	-	4,905
Cassava + peanut	20.5	719	6,841
Cassava + cowpea	16.0	501	5,353
Cassava + mungbean	21.5	136	5,313
Cassava + soybean	21.0	227	5,633
Cassava + maize	18.4	1,283	5,551

Peanut was also the most productive intercrop in several other experiments conducted in North Vietnam, especially when planting double rows between single rows of cassava spaced at 1 m (Le Sy Loi, 2000; Trinh Phuong Loan, personal communication)

c. Intercropping cassava with cereal and legume crops in Indonesia

Farm size in Indonesia is extremely small while labor is quite abundant in most areas, especially on Java island. For that reason, most cassava is grown with at least one and sometimes up to four intercrops in order to maximize food production to feed the family and for sale. In southern Sumatra, where rainfall is rather abundant with only a 3−4-month dry season, farmers often intercrop cassava with upland rice between cassava rows and maize between cassava plants in the row. After the harvest of rice and maize at 3−4 MAP, they may plant peanut or mungbean between cassava rows, followed by cowpea if rainfall permits. In East Java, where the dry season extends to 5−6 months, cassava is generally only intercropped with maize, planted in single rows alongside the cassava rows.

An intercropping experiment was conducted from 1987 to 1990 in Tamanbogo in Lampung Province of southern Sumatra to determine the best plant spacing and planting pattern of cassava when intercropped with various combinations of three to four crops, that is, rice, maize, peanut, mungbean, and cowpea. Cassava was planted at three spacings, 1.0 × 1.0 m, 2.0 × 0.5 m, and the double-row system of 2.73 + 0.6 × 0.6 m, which all resulted in a cassava plant population of 10,000 plants/ha. Upland rice and maize were planted at the same time as cassava in the early part of the rainy season (October/November), while peanut or mungbean was planted between the cassava rows after the harvest of rice, and cowpea was planted after the harvest of the peanut or mungbean crop. **Table 24** shows the contribution of cassava and the first, second, and third intercrops to the total gross income in each cropping system. When planted in monoculture, cassava obviously contributed 100% to the total gross income. In monoculture, the highest yield was obtained with the square planting arrangement of 1.0 × 1.0 m, while there was no difference in yield between the wide-row spacing and the double-row arrangement. When intercropped, cassava contributed only 45−58% to the total gross income, while the remaining income came from the various intercrops. Averaged over the three planting patterns, the system of cassava intercropped with peanut followed by mungbean and cowpea produced the highest gross income. Averaged over the four intercropping systems, the highest gross income was obtained with the square planting pattern (1.0 × 1.0 m), which was slightly higher than that obtained with the wide-row spacing (2.0 × 0.5 m), while the double-row spacing produced the lowest gross income (Wargiono et al., 1995). In a similar trial conducted in Yogyakarta in 1987 and 1988, square planting at 1.0 × 1.0 m again produced the highest total crop value in two intercropping systems (Wargiono et al., 1992).

Table 24. The effect of cassava cropping system and planting arrangement on total gross income and the relative contribution of each crop to total gross income in Tamanbogo, Lampung, Indonesia. Data are average values for 3 years (1987−1990).

Cassava plant spacing/ cropping system [1]	Total gross income (000 Rp/ha)	Relative contribution to income (%)			
		First intercrop(s)	Second intercrop	Third intercrop	Cassava
1.0 × 1.0 m					
Cassava monoculture	1,386	-	-	-	100
C+M+R-P-CP	1,466	37	14	2	47
C+M-P-CP	1,406	25	19	3	53
C+R-P-CP	1,581	32	15	3	50
C+P-MB-CP	1,577	35	6	3	56
2.0 × 0.5 m					
Cassava monoculture	1,242	-	-	-	100
C+M+R-P-CP	1,550	36	18	3	42
C+M-P-CP	1,378	23	23	3	51
C+R-P-CP	1,607	33	17	3	47
C+P-MB-CP	1,464	35	5	3	57
2.73 + 0.6 × 0.6 m					
Cassava monoculture	1,240	-	-	-	100
C+M+R-P-CP	1,486	39	13	3	45
C+M-P-CP	1,299	25	21	3	51
C+R-P-CP	1,477	27	17	2	53
C+P-MB-CP	1,666	32	6	4	58

[1] C = cassava, M = maize, R = upland rice, P = peanut, MB = mungbean, CP = cowpea.
Source: *Wargiono et al., 1995.*

From these various experiments, we can conclude that intercropping tends to decrease cassava yield, but the yield of the intercrops will often more than compensate for the loss in cassava yield, and will provide farmers with additional food or cash long before the cassava is ready for harvest. However, unless the intercrops are well fertilized, incorporation of their residues will generally have little long-term effect on soil fertility.

Among the various intercrops tested, peanut seems to be most compatible with cassava as it can grow in relatively acid and low-fertility soils and does not compete as much with cassava as most other crops. Upland rice and maize are also successfully intercropped with cassava, mainly in Indonesia.

d. Long-term intercropping experiments in Rayong, Thailand

Although intercropping cassava is not widely practiced in Thailand, many intercropping experiments have been conducted over the years (Tongglum et al., 2001; Wongwiwatchai et al., 2007; Paisancharoen et al., 2010). One intercropping trial conducted at the Rayong Field Crops Research Center continued for 24 years, from 1975 to 1999. Cassava was grown in monoculture as well as intercropped with sweet corn, mungbean, peanut, or soybean. After every 5-year cycle of intercropping, cassava was grown for one year in monoculture in all treatments to observe the effect of intercropping on the subsequent cassava yield in monoculture. After the second 5-year cycle in 1987, cassava yield in plots previously used for intercropping with sweetcorn, soybean, and peanut was significantly higher than in plots used for continuous monoculture. This was still the case after the third 5-year intercropping cycle in 1993, with the highest cassava yield obtained after intercropping with peanut and soybean. Soil analyses during 24 years of cropping indicated that the amount of organic matter in plots intercropped with peanut or soybean had increased from the original 1.0% to 1.2−1.3%, while organic matter in plots under continuous monoculture had decreased slightly to 0.9%. **Table 25** shows the average yield of cassava and intercrops as well as the average gross income of the cropping systems during 21 years of continuous cropping. On average, the cassava yield under monoculture was slightly higher than under intercropping, especially when intercropped with soybean or peanut, but the annual gross income was highest for the intercropping system with sweet corn followed by that with peanut.

Table 25. Cassava and intercrop yield and gross income in a long-term intercropping experiment at Rayong Field Crops Research Center from 1975 to 1998. Data are average values of 21 cropping cycles on the same plots.

Intercropping system	Yield (t/ha)		Annual gross income (US$/ha)		
	Cassava	Intercrops	Cassava	Intercrops	Total
Cassava monoculture	20.15	-	345	-	345
Cassava + sweet corn [1]	19.92	20.20	341	531	872
Cassava + mungbean	19.18	0.59	328	140	468
Cassava + peanut	17.96	1.08	307	284	591
Cassava + soybean	17.50	0.76	299	160	459

[1] Sweet corn yield in '000 cobs/ha.
Source: *Tongglum et al., 2001.*

e. Long-term intercropping experiment in Khon Kaen, Thailand

Another long-term intercropping experiment was conducted at Khon Kaen Field Crops Research Center from 1987 to 1995. The three treatments consisted of cassava monoculture, cassava intercropped with cowpea, and cassava intercropped with sword bean *(Canavalia ensiformis)*. During the first four cropping cycles, the intercrops were planted at the same time as cassava, while in the following five years they were planted 2−3 weeks after cassava in order to reduce the competition on the cassava. **Figures 8** and **9** show the change in annual cassava yield as well as the yield during the first four and last five years of cropping, both with and without application of chemical fertilizer (47-47-47 kg/ha of N, P_2O_5, and K_2O). Without fertilizer, cassava yield gradually decreased from 24 t/ha in 1987 to only 7 t/ha in 1995, for both cassava monoculture and intercropped. With fertilizer, yield also decreased but not as drastically, from about 28 t/ha to 16 t/ha. During the first four years, when cassava and the two intercrops were planted at the same time, the yield of monoculture cassava was significantly higher than when intercropped, especially with the longer duration sword bean. But, when the intercrops were planted 2−3 weeks after cassava, the yield of intercropped cassava was slightly higher than that of the monoculture crop, indicating that the time of planting of each crop in an intercropping system can markedly change their competitive effects and thus their relative yield (Paisancharoen et al., 1996; 2002).

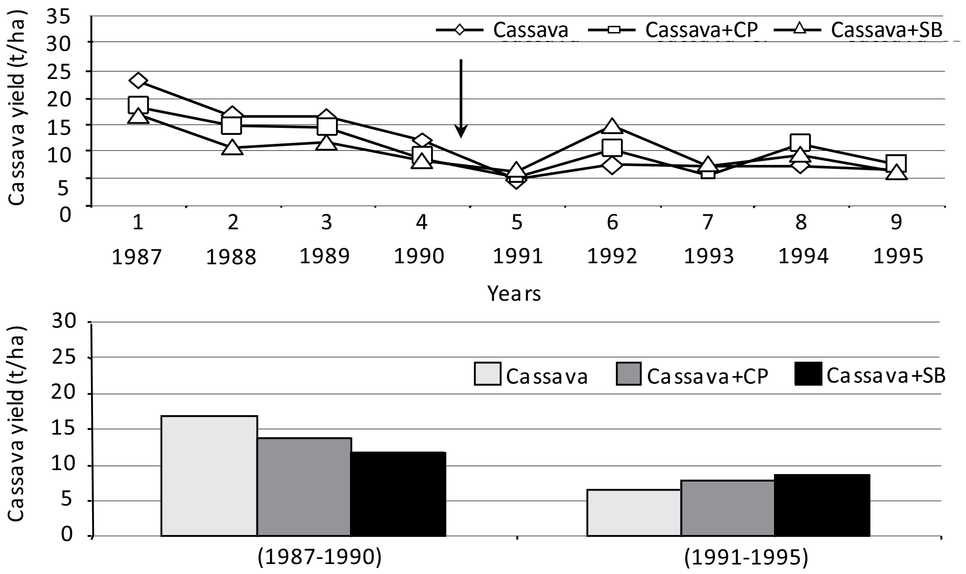

Figure 8. *Effect of cassava intercropping with cowpea (CP) or sword bean (SB) on the fresh root yield of cassava during nine consecutive years of cropping without application of chemical fertilizer at Khon Kaen Field Crops Research Center from 1987 to 1995.*

Source: *Paisancharoen et al., 2002 as quoted by Wongwiwatchai et al., 2007.*

Paisancharoen et al. (2002) also conducted a nutrient balance study of different cropping systems in farmers' fields in three important cassava-growing provinces in northeast Thailand. They reported that the K balance was negative in all three provinces in both monoculture and intercropping systems, indicating that the K removal in the harvested roots was greater than the K input in fertilizer or manure. For N, the inputs and outputs were more or less in balance, whereas, for P, the inputs far exceeded the outputs, resulting in a positive balance in all three provinces. In monoculture cassava, rather large amounts of nutrients were removed, while the inputs were relatively small, resulting in slightly positive balances of N and P and a considerably negative balance for K. In contrast, in the intercropped cassava fields, the K balance was only slightly negative while the N and P balances were quite positive due to the incorporation of the intercrop residues.

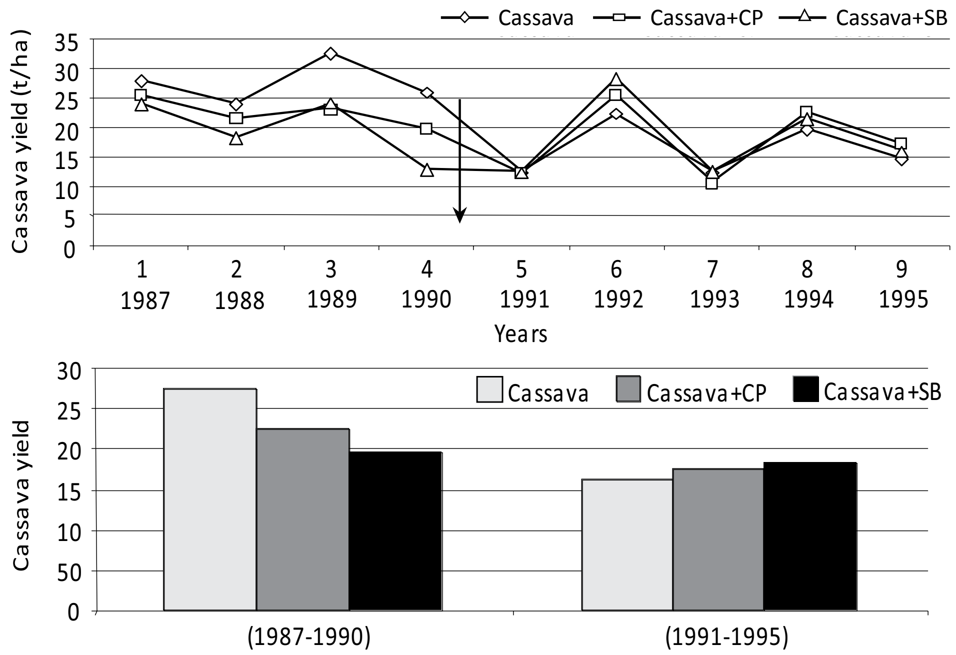

Figure 9. *Effect of cassava intercropping with cowpea (CP) or sword bean (SB) on the fresh root yield of cassava during nine consecutive years of cropping with application of 47-47-47 kg/ha of* $N-P_2O_5-K_2O$ *at Khon Kaen Field Crops Research Center from 1987 to 1995.*

Source: *Paisancharoen et al., 2002 as quoted by Wongwiwatchai et al., 2007.*

From these various intercropping experiments, we can conclude that, when well-managed, the intercropping of cassava with short-duration food crops will generally result in slightly lower cassava yield, but will increase the total income obtained from the various crops. Moreover, intercropping will help to reduce weed growth and reduce soil loss by erosion due to a more rapid canopy development, while the incorporation of the intercrop residues will tend to increase soil organic matter and may contribute more N fixed from the air by intercropping with grain legumes. To maintain high yield of both cassava and the intercrops, both crops should be adequately fertilized.

f. Long-term effect of intercropping, green manuring, and alley cropping on cassava yield, net income, and soil fertility in southern Vietnam

A long-term experiment was started in 1992 at Hung Loc Agricultural Research Center in southern Vietnam to determine the best cropping system to maintain high cassava yield and/or improve soil fertility. The eight treatments included cassava monoculture, two intercropping, three green manure, and two alley cropping systems, as indicated in **Tables 26** and **27**. During the first seven years, all plots received a uniform fertilizer application, which obscured the effect of the various cropping systems; in years 8, 9, and 10, no chemical fertilizer was applied, which resulted in a significant drop in cassava yield. As of the 11th crop, all plots were split, with half being fertilized every year and half remaining unfertilized. Cassava cv. KM 60 was planted every year at a spacing of 1.0 × 1.0 m, and the various intercrops and green manures were planted at the same time and in between the cassava rows. For the two alley cropping treatments, each fifth row of cassava was replaced by one row of the hedgerow species; these were planted from seed only in the first year. The hedgerows were pruned every year before planting cassava and the prunings were mulched between the four cassava rows nearby. Soil samples were taken nearly every year after land preparation and before the next cassava planting. **Table 26** shows the results of soil analyses after the third and after the 15th year of continuous cassava cropping. Fifteen years of continuous cassava cropping had decreased the soil pH in all treatments, but especially when no fertilizer was applied and in both alley cropping treatments. There was also a significant reduction in soil OM, but less so when fertilizer had been applied and in the two alley cropping treatments. Yearly application of 80 kg N, 40 kg P_2O_5, and 80 kg K_2O/ha usually increased available P, had little effect on Ca and Mg, but actually decreased exchangeable K, probably due to increased K removal with the higher root yield obtained. Although most intercrop and green manure treatments had little effect on soil fertility characteristics, the soil in the two alley cropping treatments had markedly lower pH and higher OM, P, Ca, Mg, and K. Thus, of the various biological soil improvement treatments, alley cropping was the only system that actually had a long-term beneficial effect on soil fertility, although not quite enough to maintain the original soil fertility characteristics after 15 years of continuous cassava cropping, even in combination with some fertilizer.

Table 26. Effect of planting intercrops, green manures, and alley crops, with or without fertilizer, on soil fertility characteristics after 15 years of continuous cassava cultivation at Hung Loc Agricultural Research Center in Dong Nai, Vietnam, in 2007/08 (before the 16th crop planting).

	pH		OM(%)		P(ppm)		Al(meq/100g)		Ca(meq/100g)		Mg(meq/100g)		K(meq/100g)	
Treatments[1)]	-fert	+fert	-fert	+fert	-fert	+fert	-fert	+fert	-fert	+fert	-fert	+fert	-fert	+fert
3rd year (1994)	4.4		3.1		9.4		1.00		1.66		0.57		0.32	
16th year (2007)														
1. C monoculture[1)]	4.11	4.38	2.24	2.35	15.73	13.96	2.80	2.91	0.63	0.64	0.16	0.15	0.16	0.13
2. C+pigeon pea GM	4.09	4.43	2.46	2.52	14.53	16.31	2.96	2.81	0.58	0.63	0.15	0.14	0.13	0.15
3. C+*Mucuna* GM	4.12	4.34	2.35	2.46	14.33	13.08	2.81	2.76	0.72	0.66	0.22	0.17	0.14	0.10
4. C+peanut IC	4.06	4.35	2.48	2.59	18.86	26.39	3.07	2.86	0.55	0.71	0.16	0.14	0.13	0.12
5. C+cowpea IC	4.11	4.28	2.36	2.07	17.70	19.23	2.91	2.70	0.49	0.67	0.17	0.14	0.22	0.13
6. C+*Crotalaria* GM	4.14	4.30	2.44	2.56	15.00	16.26	2.81	2.76	0.66	0.62	0.15	0.16	0.16	0.13
7. C+*Leucaena* AC	3.97	4.21	2.82	3.08	18.26	28.82	2.86	2.55	0.76	0.82	0.25	0.26	0.23	0.18
8. C+*Gliricidia* AC	3.98	4.20	2.51	2.62	15.33	21.77	2.86	2.76	0.78	0.63	0.25	0.17	0.22	0.14
Average	**4.07**	**4.31**	**2.46**	**2.53**	**16.22**	**19.47**	**2.74**	**2.76**	**0.65**	**0.67**	**0.19**	**0.17**	**0.17**	**0.14**

1) Cassava variety is KM 60; -fert. = without fertilizer; +fert. = with annually 80 kg N, 40 kg P_2O_5, 80 kg K_2O/ha. GM = green manure, IC = intercrop, AC = alley crop.

Table 27 shows the effect of the various treatments on the yield of cassava, root starch content, and gross and net income during the 16th year of cropping. The highest cassava yield, starch content, and gross and net income were obtained with the two alley cropping treatments, with hedgerows of *Leucaena leucocephala* usually being more effective than *Gliricidia sepium*, in spite of the very low soil pH. The beneficial effect of the two alley cropping treatments became apparent only during the 8th cropping

cycle, but has been consistent ever since, most markedly in the unfertilized treatments. Among the two intercrops, peanut was better than cowpea, while the three green manures had a beneficial effect on cassava yield only in the absence of chemical fertilizer (CIAT, 2008).

Table 27. Effect of planting intercrops, green manures, and alley crops, with or without fertilizer, on cassava and intercrop yield, as well as gross and net income obtained when cassava cv. KM 60 was grown for the 16th consecutive year at Hung Loc Agricultural Research Center in Dong Nai, Vietnam, in 2007/08.

	Root yield (t/ha)		Starch content (%)		Gross income[2)] (000 dong/ha)		Product. costs[3)] (000 dong/ha)		Net income (000 dong/ha)	
Treatments[1)]	+fert	-fert	+fert	-fert	+fert	-fert	+fert	-fert	+fert	-fert
C monoculture	17.44	4.81	23.28	21.28	20,405	5,628	6,008	3,800	14,397	1,828
C+pigeon pea GM	15.62	6.75	23.60	21.70	18,275	7,898	8,108	5,900	10,167	1,998
C+*Mucuna* GM	17.82	8.56	24.45	22.35	20,849	10,015	8,108	5,900	12,741	4,115
C+peanut IC[4)]	20.41	8.62	25.35	24.08	24,824	10,085	8,108	5,900	16,716	4,185
C+cowpea IC	19.44	7.44	24.92	22.65	22,745	8,705	8,108	5,900	14,637	2,805
C+*Crotalaria* GM	18.75	8.50	24.95	21.72	21,938	9,945	8,108	5,900	13,830	4,045
C+*Leucaena* AC	20.68	13.39	25.52	24.40	24,196	15,666	7,708	5,500	16,488	10,166
C+*Gliricidia* AC	19.30	16.75	26.32	24.95	22,581	19,597	7,708	5,500	14,873	14,097
Average	**18.68**	**9.35**	**24.80**	**22.89**	**21,977**	**10,942**	**7,745**	**5,538**	**14,231**	**5,404**

1) C = cassava, GM = green manure, IC = intercrop, AC = alley crop.

2) Prices: cassava dong 1,170/kg fresh roots; peanut 8,000/dry pods

3) Costs:

land preparation	900,000/ha	cassava planting	700,000/ha
fertilizer (80:40:80 kg/ha)	1,983,000/ha	weeding	2,200,000/ha
- urea (46% N)	5,500/kg	intercrop planting	500,000/ha
- SSP (17% P_2O_5)	1,700/kg	intercrop harvest	1,200,000/ha
- KCl (60% K_2O)	4,700/kg	seed of intercrops or GM	400,000/ha
fertilizer appl. (5 person-days/ha)	225,000/ha	cost of labor	45,000/pers-day

4) Peanut yield with fertilizer: 118 kg dry pods; without fertilizer: 0 yield

Note: US$1 = 17,000 dong in 2008.

Source: *Nguyen Huu Hy, personal communication.*

From these various experiments mentioned above, and many more reported in the literature, we can conclude that cassava is a very weak competitor and suffers serious setbacks if it has to compete with weeds, intercrops, or cover crops, especially at the early stage of establishment, due to its slow initial rate of growth. Thus, most perennial cover crops will strongly compete with cassava at the early stages of growth, resulting in low cassava yield. Most intercropped green manures or long-duration intercrops will also tend to reduce cassava yield. Most beneficial are some of the green manures when they are grown and incorporated before planting cassava, but only in areas with a long wet season that provides sufficient soil moisture during most of the cassava growth cycle; their beneficial effect is most pronounced when no chemical fertilizer is applied.

Among the various biological solutions mentioned above, alley cropping seems to have the greatest long-term beneficial effect on cassava yield and soil fertility, but more so in the absence than in the presence of chemical fertilizer. Once established, the hedgerows require little maintenance besides regular pruning and they can survive for at least 15−20 years without the need for replanting. Besides improving soil fertility, the prunings, when mulched on the soil surface, will help to control weeds and erosion, reduce soil surface temperature, and increase soil moisture. Similar beneficial effects of mulching have also been obtained when native weeds were cut and mulched before planting cassava with minimum tillage.

CHAPTER 11

IS SOIL EROSION A PROBLEM?

Soil erosion is indeed a problem: a big problem, especially in Asia and especially for cassava! **Table 1** and **Figure 1** indicate that soil losses due to erosion in Asia are much more serious than in either Africa or Latin America. Names such as "Red River" and "Yellow River" in Asia are indicative of the huge amounts of soil sediments these rivers carry off to sea. Milliman and Meade (1983) calculated that the annual discharge of sediments from the major river systems in continental Southeast Asia amounts to about 3.2 billion tons, while that of insular Southeast Asia is almost equally high at 3.0 billion tons. In fact, the rivers of tropical Asia discharge about four times more sediments than those of tropical America, and more than ten times as much as those of Africa. Some of this erosion is due to natural processes, especially in the rather unstable and geologically young Himalayan Mountain ranges, but much of it is directly due to, or accelerated by, human activity through deforestation, the intense cultivation of hillsides, and the opening of roads in unstable mountain areas. It is also because rainfall is rather high in Southeast Asia, whereas, because of population pressure, even rather steep slopes are intensively cultivated and forests are disappearing at alarming rates.

Table 1. Rates of erosion of the continents.

Continent	Area (10^6 km^2)	Mechanical denudation rate (t/km^2/year)
Africa	29.81	7.0
Asia	44.89	166.0
Australia	7.96	32.1
Europe	9.67	43.0
North and Central America	20.44	73.0
South America	17.98	93.0

Source: *Modified from data in Strakhov, 1967, cited by Chorley, 1969.*

In addition, many of the light-textured soils used for cassava production in Asia, particularly in Thailand, parts of Vietnam, and on Bohol Island of the Philippines, are very susceptible to erosion. The highest erosion losses in cassava trials in Asia have been measured on Hainan Island of China, where intensive rainfall in early spring coincides with the stage of slow early growth of cassava, when much soil is exposed to rainfall impact. **Table 2**, which summarizes the results of many cassava erosion control trials conducted in Asia and in Colombia, shows that soil losses measured in Asia tend be much higher than in Colombia, even though slopes were generally steeper in the latter. Thus, because of a combination of high-intensity rains and erodible soils, soil losses due to erosion can be a serious problem in Asia. Unless measures are taken to reduce erosion, future soil productivity will be affected.

Table 2. Average dry soil losses due to erosion measured in cassava trials in various countries in Asia as well as in Colombia, South America.

Country	Site	Slope (%)	Soil texture	OM[1] (%)	Dry soil loss (t/ha)
China	Xhi Fang, Hainan	8	Sandy clay loam	2.4	154
	CATAS, Hainan	15	Clay	1.8	128
	CATAS, Hainan	25	Clay	2.0	144
	Nanning, Guangxi	12	Clay	1.7	16
Indonesia	Malang, E. Java	8	Clay	1.5	42
	Tamanbogo, Lampung	5	Clay	1.8	47
	Umas Jaya, Lampung	3	Clay	2.7	19
Malaysia	MARDI, Serdang	6	Clay	-	10
Philippines	Baybay, Leyte	25	Clay loam	1.9	54
Thailand	Sri Racha, Chonburi	8	Sandy loam	0.6	15
	Sri Racha, farmer's field	8	Sandy loam	0.5	18
	Pluak Daeng, Rayong	5	Sandy loam	0.7	21
Vietnam	Thai Nguyen Univ.	5	Sandy clay loam	1.6	23
	Thai Nguyen Univ.	10	Sandy clay loam	1.6	39
	Thai Nguyen Univ.	15	Sandy clay loam	1.6	105
Colombia	Mondomito, Cauca	27	Clay	4.7	45
	Mondomito, Cauca	30	Clay	-	2
	Las Pilas, Mondomo, Cauca	40	Clay loam	11.0	3
	Agua Blanca, Cauca	42	Clay loam	5.1	18
	Popayán, Cauca	15	Loam	24.8	15
	Popayán, Cauca	25	Loam	24.8	7

[1] OM = soil organic matter.
Source: *Howeler, 1994.*

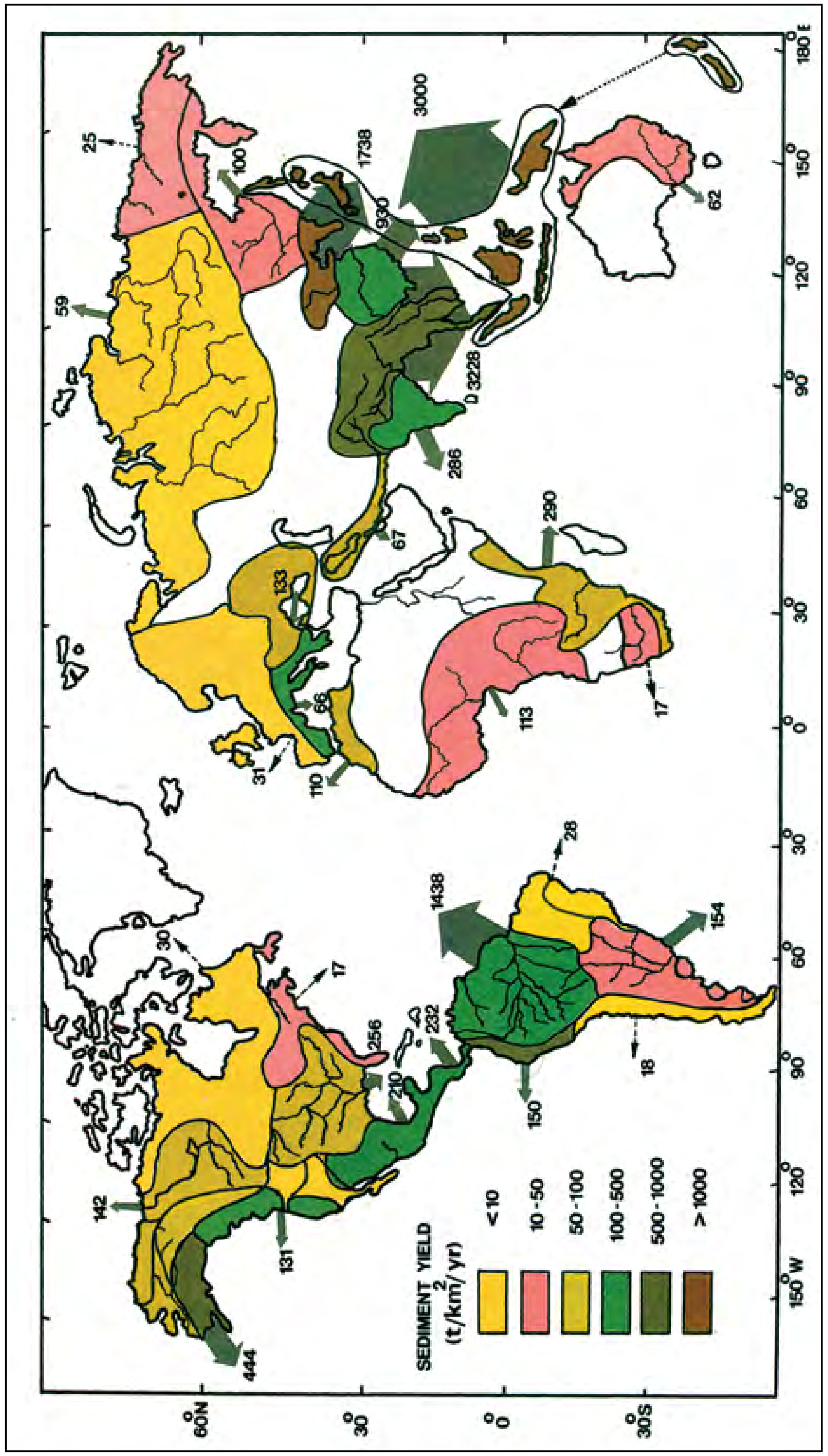

Figure 1. *Annual discharge (millions of tons) of suspended sediments from various drainage basins of the world. The width of the arrows corresponds to relative discharge. The direction of the arrows does not indicate direction of sediment movement.*
Source: *Milliman and Meade, 1983.*

1. The Erosion Process

When raindrops fall at high speed on unprotected soil, they tend to break the soil aggregates into smaller units and disperse the individual clay or sand particles. Soils differ in their susceptibility to erosion (erodibility factor) in having various degrees of resistance to breakdown, or aggregate stability, depending mainly on the texture and soil organic matter (OM) content. Thus, soils of intermediate texture, having a large proportion of silt and fine sand particles, have little aggregate stability, and are the most susceptible to erosion. Similarly, soils with little OM and/or low biological activity, or those with a low content of free oxides of Fe and Al, are the most erodible. Once the aggregates are broken down, the smaller particles may be carried away by runoff water, causing inter-rill (or sheet) erosion.

When the runoff water collects and concentrates into small rivulets, the force of the running water can detach particles, and this may result in rill erosion, which may progress into the formation of gullies. The objectives of most soil conservation techniques are (1) to protect the soil from direct rainfall impact by the establishment of either live or dead (crop residue or mulch) vegetative cover, which can absorb the energy of the impact of raindrops; and (2) to reduce the quantity and slow the speed of the runoff water by improving water infiltration into the soil, and to reduce the length or steepness of the slope by contour cultivation, contour ridging, contour grass barriers or hedgerows, and terracing or bunding.

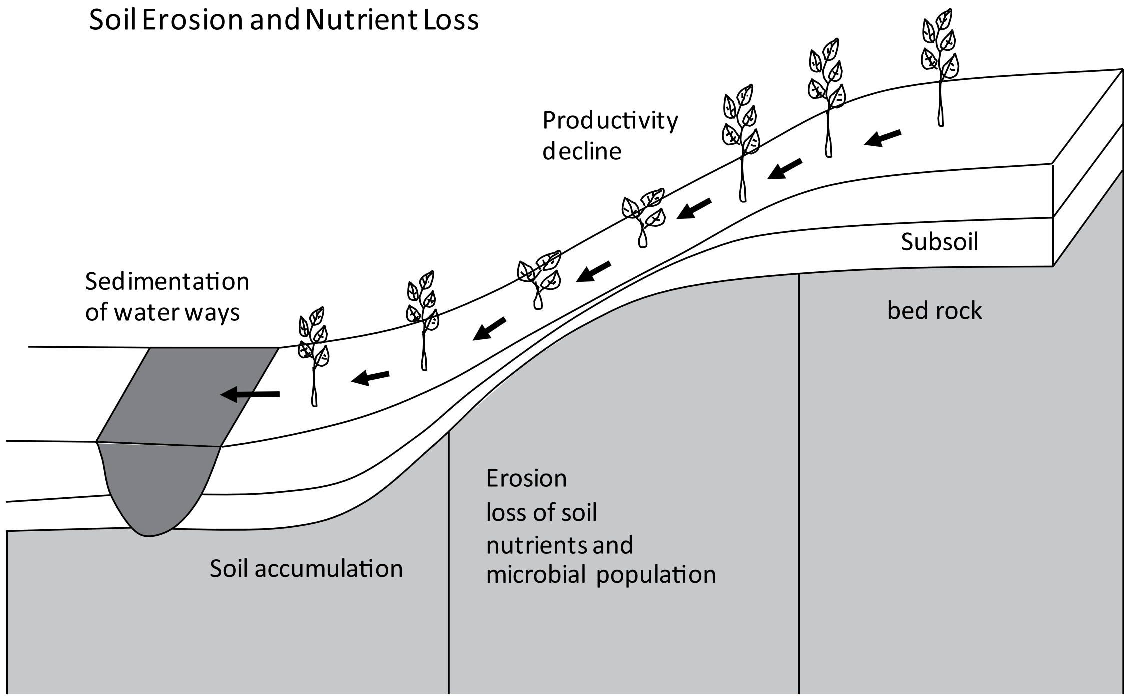

Figure 2. *Conceptual representation of the differential effects of erosion in various parts of the landscape on soil depth, nutrient distribution, and growth of crops.*

The erosion process selectively removes mainly the organic matter and certain clay fractions, which provide the soil with its water and nutrient-holding capacity. Thus, surface runoff results in a direct loss of potentially soil-stored water as well as nutrients, especially from fertilizer, while soil loss due to erosion removes mainly the most productive part of the soil containing a considerable amount of nutrients, especially organic N, P, and S, as well as very important microorganisms, such as N-fixing bacteria and VA mycorrhizae. The loss of clay and OM also results in a lower cation exchange capacity (CEC) as well as a lower water-holding capacity. Finally, the physical removal of part of the topsoil reduces the effective rooting depth to underlying bedrock or subsoil layers. This also reduces the water storage capacity of the soil and further exacerbates rainfall runoff and erosion **(Figure 2).**

2. Nutrient Losses in Eroded Sediments and Runoff and their Effects on Yield

Little information exists about the amounts of nutrients lost in eroded sediments and runoff. In most cases where sediments have been analyzed, results are reported as total N (organic + inorganic N), available P, and exchangeable K, Ca, and Mg. The total loss of P, K, Ca, and Mg in the sediment could be an order of magnitude higher than the "available" or "exchangeable" fractions reported. **Table 3** shows results from cassava experiments conducted in Thailand and Colombia. Nutrient losses were a direct function of the amount of soil eroded: practices that reduced erosion automatically reduced nutrient losses. N losses ranged from 4 to 37 kg/ha, while exchangeable K and Mg losses ranged from 0.13 to 5.1 and from 0.1 to 5.4 kg/ha, respectively. Available-P losses were considerably lower, ranging from 0.02 to 2.2 kg/ha. As mentioned above, total nutrient losses are considerably higher but no data are available from cassava fields.

Table 3. Nutrients in sediments eroded from cassava plots with various treatments in Thailand and Colombia.

Location and treatments	Dry soil loss (t/ha/year)	Nutrient loss (kg/ha/year) N[1]	P[2]	K[2]	Mg[2]
Cassava on 7% slope in Sri Racha, Thailand[3]	71.4	37.1	2.18	5.15	5.35
Cassava on 5% slope in Pluak Daeng, Thailand[4]	53.2	22.3	1.25	3.27	-
Cassava planted on 7−13% slope in Santander de Quilichao, Colombia[5]	5.1	11.5	0.16	0.45	0.45
Cassava with leguminous cover crops in Santander de Quilichao[5]	10.6	24.0	0.24	0.97	0.81
Cassava with grass hedgerows in Santander de Quilichao[5]	2.7	5.8	0.06	0.22	0.24
Cassava planted on 12−20% slope in Mondomo, Colombia[5]	5.2	13.3	1.09	0.45	0.36
Cassava with leguminous cover crops in Mondomo[5]	2.7	6.5	0.04	0.24	0.20
Cassava with grass hedgerows in Mondomo[5]	1.5	3.5	0.02	0.13	0.10

[1] Total N.
[2] Available P, and exchangeable K and Mg.
[3] ***Source:*** *Putthacharoen et al., 1998.*
[4] ***Source:*** *Tongglum et al., 2001.*
[5] ***Source:*** *Ruppenthal et al., 1997.*

Phommasack et al. (1995;1996) reported total nutrient losses in sediments and runoff from maize fields with 25−35% slope in Luang Prabang, Lao PDR: in the second year of cropping, N, P, and K losses in the eroded sediments (9.2 t/ha) were 53.9, 9.3, and 24.0 kg/ha, respectively, while those in the runoff water (2,120 m^3/ha) were 2.3, 0.9, and 26.1 kg/ha, respectively (Howeler and Thai Phien, 2000). Although in this case soil loss and runoff were not particularly high, nutrient losses in the sediments and runoff were substantial, especially those of N and K in the sediments and K in the runoff.

Thus, erosion results in deteriorating soil physical and chemical characteristics, which in turn affect the soil's productive capacity, with shallow soils or those having an unfavorable subsoil being the most affected, and highly demanding crops such as maize and soybean being more susceptible to yield declines than less demanding crops such as rice, cassava, or cowpea. Yield declines due to erosion tend to be greater in Ultisols, Oxisols, and some Alfisols with a high content of clay and Al in the subsoil than in deep and relatively fertile Andosols. Yield is more affected by the loss of the uppermost layer of soil than by the subsequent loss of deeper layers. Thus, yield declined by 3−7% with the loss of the first 1 mm of topsoil, and by 10−25% with the loss of the subsequent 7 mm of soil (Marsh, 1971). In Alfisols of India, with average annual soil losses of 40 t/ha (or 5 mm), yield declined 1.25% per year for the first five years and 0.95% during the subsequent years (Magrath, 1990). In cassava-based cropping systems in Java, annual soil losses of 76−144 t/ha resulted in estimated productivity losses of 3.8−4.7% per year (Magrath and Arens, 1989). Cassava yield in severely eroded soils in Mondomo, Cauca, Colombia, was about 50% of that in adjacent non-eroded soil (Howeler, 1986) **(Figure 3)**.

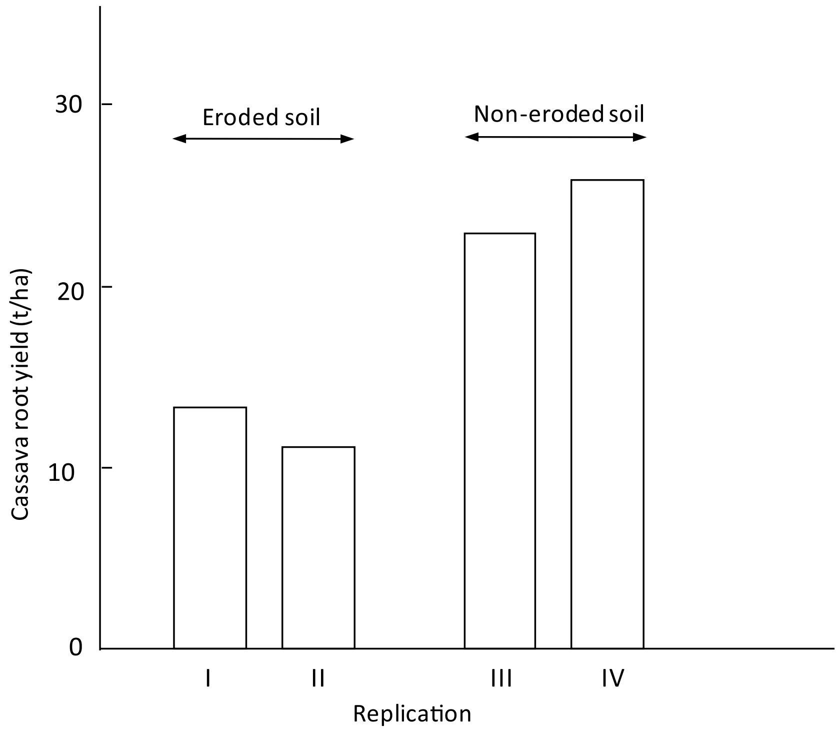

Figure 3. *The average root yields of 18 cassava varieties planted in two replications on eroded soil and two replications on non-eroded soil in Mondomo, Cauca, Colombia.*
Source: *Howeler, 1986.*

3. Effect of Different Crops on Soil Erosion

Cassava is often considered a crop that causes severe erosion when grown on hillsides. Although it is true that the opening of hillsides for the cultivation of annual crops will usually increase erosion by several orders of magnitude compared with undisturbed forest or grassland, whether or not cassava causes more erosion than other food crops depends mainly on the circumstances.

Figure 4 shows a summary by Quintiliano et al. (1961) of the results of 48 erosion control trials conducted at four experiment stations in São Paulo State of Brazil from 1943 to 1959, comparing the effect of different crops and management practices on soil loss by erosion and on runoff.

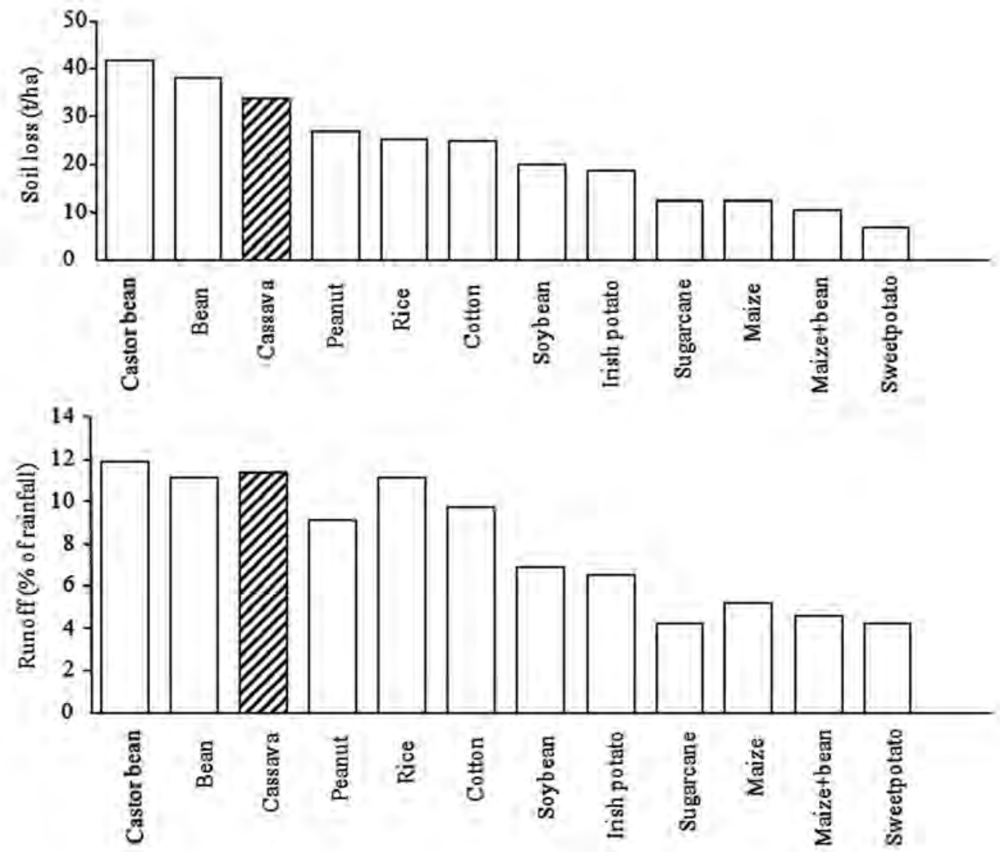

Figure 4. *Effect of crops on annual soil loss by erosion (top) and on runoff (bottom). Data are average values (corrected for a standard annual rainfall of 1,300 mm) from 48* experiments *conducted from 1943 to 1959 on sandy, clayey, and Terra roxa soils in São Paulo State of Brazil with slope of 8.5% to 12.8%.*
Source: *Quintiliano et al., 1961.*

The highest soil losses and runoff were observed in castor bean, common bean *(Phaseolus vulgaris)*, and cassava, followed by peanut, rice, cotton, soybean, potato, sugarcane, maize, and sweet potato. Using relative soil loss as the criterion, with castor bean considered 100, then cassava would have an index of 83, below that of beans (92) but higher than that of peanut (64), rice (60), cotton (60), soybean (48), sugarcane (30), maize (29), and sweet potato (16).

In other trials conducted for ten years on 12% slope on a red-yellow Podzolic soil in Pernambuco, Brazil, Margolis and Campos Filho (1981) reported that cassava on average produced an annual soil loss of 11.0 t/ha compared with 8.3 t/ha for cotton, 3.0 t/ha for maize, 2.8 t/ha for velvet bean (*Mucuna* sp.), and 0.4 t/ha for guinea grass *(Panicum maximum)*, while the soil loss on bare soil was 59.9 t/ha. Although annual soil losses were much lower than those reported by Quintiliano et al. (1961), the crops are listed in a similar order.

Table 4 shows similar data for soil losses in eight crops planted during four years on 7% slope in Sri Racha, Thailand (Putthacharoen et al., 1998). By far, the highest amounts of erosion were observed in cassava for root production (planted at 1.0 × 1.0 m), followed by cassava for forage production (planted at 0.5 × 0.5 m), mungbean, sorghum, peanut, maize, and pineapple. Annual erosion losses for cassava averaged about 75 t/ha, while the average yield was 16 t/ha of fresh roots. Thus, nearly 5 tons of soil were lost for every ton of roots produced. These are extremely high rates of erosion on a slope of only 7%.

Table 4. Total dry soil loss by erosion (t/ha) due to the cultivation of eight crops during four years on 7% slope with sandy loam soil in Sri Racha, Thailand, from 1989 to 1993.

Crop	No. of crop cycles	First period (22 months)	Second period (28 months)	Total (50 months)	Average (t/ha/year)
Cassava for root production	4	142.8 a	168.5 a	311.3	74.7
Cassava for forage production	2	68.8 b	138.5 ab	207.3	49.8
Maize	5	28.5 d	35.5 cd	64.0	15.4
Sorghum	5	42.9 c	46.1 cd	89.0	21.4
Peanut	5	37.6 cd	36.2 cd	73.8	17.7
Mungbean	6	70.9 b	55.3 cd	126.2	30.3
Pineapple[1)]	2	31.4 cd	21.3 d	52.7	12.6
Sugarcane[1)]	2	-	94.0 bc	-	-
F-test		**	**		
CV (%)		11.4	42.7		

[1)] Second cycle is a ratoon crop; sugarcane only during second 28-month period.
Note: Data in each column followed by the same letter are not significantly different at P=0.01
Source: *Putthacharoen et al., 1998.*

Thus, under the soil and climatic conditions of Sri Racha, cassava for root production did cause more severe erosion than most other crops, mainly because the other crops were planted at much higher densities and had a faster early growth; in addition, the rather short rainy season permitted only one crop per year of short-cycle crops such as maize, sorghum, and peanut, while, after the harvest, the soil remained well protected by crop residues and weeds.

However, **Table 5** shows that in Lampung, Indonesia, average soil losses during three years of cassava (planted at 1 × 1 m) were only slightly higher than for upland rice and maize, and similar to those of peanut. Intercropping cassava with upland rice and maize, followed by peanut, reduced soil losses to 42.7 t/ha compared with 49.2 t/ha in cassava monoculture. Intercropping cassava with other crops increased the rate of establishment of vegetative ground cover and generally, but not always, reduced erosion.

Table 5. Effect of cropping systems and cassava row spacing on dry soil loss due to erosion and on total crop value on an Ultisol with 5% slope in Tamanbogo, Lampung, Indonesia. Data are average values for trials planted in 1987, 1988, and 1989.

Cropping system	Soil loss (t/ha) [2)]	Total crop value (000 Rp/ha)
Cassava monoculture, 1.0 × 1.0 m	49.2	1,386
Cassava monoculture, 2.0 × 0.5 m	92.9	1,242
Cassava monoculture, 2.73+0.6×0.6 (double rows)	100.8	1,240
Upland rice followed by cassava (1.0 × 1.0 m)	43.4[2)]	1,193
Maize+rice followed by cassava (1.0 × 1.0 m)	37.4[2)]	943
Peanut+rice followed by cassava (1.0 × 1.0)	50.6[2)]	1,261
Intercropped C+M+R-P[1)] (cassava at 1.0 × 1.0 m)	42.7	1,466
Intercropped C+M+R-P (cassava at 2.0 × 0.5 m)	62.9	1,551
Intercropped C+M+R-P (cassava at 2.73 +0.6 × 0.6 m)	60.1	1,486

[1)] C = cassava, M = maize, R = upland rice, P = peanut.
[2)] About 90% of soil losses occurred during the first crop

When the intercrop competes strongly with cassava, reducing the growth of the latter, erosion can be very severe after the harvest of the intercrop, when much soil between the cassava rows is left exposed to the direct impact of raindrops.

Thus, we can conclude that cassava may sometimes cause more severe erosion than other crops, depending on soil and rainfall characteristics, as well as on the management practices used in each crop. Management practices that minimize soil erosion must be used.

4. Effect of Plant Architecture of Cassava on Soil Erosion

In order to determine the effect of plant architecture on soil erosion, four cassava varieties of distinct growth habit were grown in Pluak Daeng, eastern Thailand, on about 5% slope in 1991/92 and 1992/93. Each cultivar was grown with and without fertilizer at a plant spacing of 0.8×0.8 m, as well as with fertilizer at a wider spacing of 1.0×1.0 m. **Table 6** shows that, in 1991/92, erosion losses were similar for Rayong 1, Rayong 3, and Rayong 90, but slightly lower for the more erect variety Hanatee; erosion losses were much more affected by cultural practices, such as plant spacing and fertilizer application, than by plant architecture. Soil losses were particularly high without fertilizer application.

It was observed that closely spaced cassava without fertilizer had a percent canopy cover similar to that of the wider spaced cassava with fertilizer, but the latter caused significantly less erosion than the former. Thus, canopy cover is important, but it is not the only factor that determines erosion. Having large leaves and good leaf retention, the more erect Hanatee tended to cause less erosion than the highly branched but less vigorous Rayong 3. Thus, overall vigor and good leaf retention seem to be more important than branching habit in reducing erosion. This was also observed in Nanning, China, where a highly branched but less vigorous cultivar (CM513-1) caused more erosion than the erect but vigorous SC201 (Tian Yinong et al., 1995).

Table 6. Effect of plant type, plant spacing, and fertilizer application on total soil losses due to erosion on 5% slope in Pluak Daeng, Rayong, Thailand, in 1991/92.

		Dry soil loss (t/ha)			
Variety	Plant type	1.0 × 1.0 m + fertilizer	0.8 × 0.8 m + fertilizer	0.8 × 0.8 m – fertilizer	Average
Rayong 1	Erect, late branching	4.23	5.72	11.81	**7.25**
Rayong 3	Prostrate, profuse branching	7.93	6.37	8.54	**7.58**
Rayong 90	Prostrate, early primary branch	4.31	4.67	12.57	**7.21**
Hanatee	Erect, no branching	5.11	5.40	6.95	**5.82**
Average		**5.37**	**5.56**	**9.97**	

Source: *Anuchit Tongglum, personal communication.*

5. Effect of Rainfall Distribution on Cassava Yield and Soil Erosion

Table 7 shows the effect of cassava planting dates on root yield and soil loss in an experiment conducted on 4.2% slope at Rayong FCRC in Thailand. The variety Rayong 90 was planted at six different times of the year. Rainfall received in the different planting date treatments varied from 777 to 1,893 mm, while the total dry soil loss ranged from 7.5 to 12.8 t/ha and cassava root yield varied from 15.5 to 46.4 t/ha. The starch content was highest when the crop was harvested in January, in the middle of the dry season.

Table 7. Effect of cassava planting date on total dry soil loss due to erosion, and on the root yield and starch content of Rayong 90 planted at Rayong Field Crops Research Center in Rayong, Thailand, in 1994/95/96.

Planting date (planting to harvest)	Total rainfall received (mm)	Plants harvested (no./ha)	Fresh root yield (t/ha)	Starch content (%)	Total dry soil loss (t/ha)
June' 94 - May' 95	777	9,906	15.47	22.3	7.68
Aug' 94 - July' 95	997	9,906	24.68	20.0	7.47
Oct' 94 - Sept' 95	1,265	9,806	38.09	29.2	7.98
Dec' 94 - Nov' 95	1,749	8,175[1)]	46.44[1)]	28.0	8.14
Feb' 95 - Jan' 96	1,731	9,038[1)]	39.04[1)]	33.0	9.65
Apr' 95 - Mar' 96	1,893	9,806	37.52	28.6	12.76

1) Some irrigation was used to ensure establishment during the dry season.
Source: *Department of Agriculture, Thailand, 1996.*

The greater the amount of effective rainfall, the higher the soil loss. Cassava planted in April, in the early part of the rainy season, received the highest amount of rain, which also caused the greatest soil loss of 12.8 t/ha and resulted in a root yield of 37.5 t/ha. But, the highest root yield was obtained from planting in December and harvesting in November, which also received a lot of rain and caused a considerable

amount of soil loss. The December '94 and February '95 planting dates resulted in a similar starch yield of about 13 t/ha, but the December planting resulted in slightly less soil loss by erosion.

6. Effect of Agronomic Practices on Cassava Yield and Erosion

a. Land preparation

The method of land preparation—ranging from zero-tillage or preparation of only planting holes (minimum tillage) to full preparation using plows, harrows, and ridgers—has a profound effect on cassava yield and the intensity of erosion. Several experiments have been conducted to determine the effect of these different methods of land preparation on cassava yield and soil loss due to erosion, mainly in two locations in China, and in Thailand. **Table 8** shows the average results obtained at CATAS in Danzhou, Hainan, China, from 1989 to 1992.

Table 8. Effect of land preparation methods on the average root yield and dry soil loss due to erosion when cassava was grown for four consecutive years on 25% slope in CATAS, Hainan, China, from 1989 to 1992.

Land preparation treatment	Root yield (t/ha)	Dry soil loss (t/ha)
Zero-tillage, direct planting in small holes	21.9	116.2
Minimum tillage, hand preparation of planting holes 30 × 30 cm	23.8	109.2
One-time plowing	22.4	120.8
Twice plowing, twice disking, no ridging	24.0	182.5
Twice plowing, twice disking, contour ridging	25.2	113.6

Source: *Zhang Weite et al., 1998.*

The highest yields were obtained using the full land preparation methods, including twice plowing and disking followed by contour ridging. This actually produced slightly less erosion than planting directly without any tillage, but produced slightly more erosion than the preparation of only planting holes. The most serious erosion occurred when the land was intensively plowed and disked but cassava was planted without ridging. Planting on contour ridges resulted in a decrease in soil loss of almost 40%.

Table 9 shows the results of experiments conducted in two locations in Thailand. In Sri Racha, in Chonburi Province, zero-tillage produced the highest erosion due to sealing of the surface soil by heavy rain in the early wet season. In contrast, in Pluak Daeng in Rayong Province, zero-tillage produced the lowest erosion. Both locations suffered serious erosion when cassava was planted after conventional preparation of once plowing and disking, without ridging or fertilizer application. This also resulted in the lowest cassava yield. Fertilizer application reduced soil losses by 42% in Sri Racha and by 32% in Pluak Daeng. The combination of contour ridging and fertilizer application was the most effective in reducing erosion when the land was prepared by conventional tillage.

Table 9. Effect of various tillage practices and fertilizer application on the average annual soil loss due to erosion and yield of cassava planted on 5–8% slope in Sri Racha, Chonburi Province, and in Pluak Daeng, Rayong Province, of Thailand.

	Dry soil loss (t/ha)		Cassava yield (t/ha)	
Tillage treatment	Sri Racha ('87-'88)	Pluak Daeng ('89-'90)	Sri Racha ('87-'88)	Pluak Daeng ('89-'90)
No tillage, with fertilizer	49.8	10.7	28.5	17.0
Conventional tillage[1)], with fertilizer	20.8	17.5	28.6	14.4
Conventional with contour ridging, with fertilizer	8.1	13.2	32.6	15.6
Conventional with up-down ridging, with fertilizer	23.6	19.8	29.4	16.1
Conventional tillage, no fertilizer	35.8	25.8	21.5	12.2

1) Conventional tillage is plowing with a 3-disk plow followed by harrowing with a 7-disk harrow.

b. Contour hedgerows

Among the various soil conservation practices used to reduce erosion, the planting of contour hedgerows to slow the flow of runoff water and trap the eroded sediments has been investigated in many locations in Colombia and in Asia, as it was found to be one of the most practical ways to reduce soil loss by erosion.

Two experiments were conducted at the Jatikerto station near Malang, East Java, Indonesia, on 5% slope, one from 1987 to 1990 (4 years) and one from 1991 to 1995 (5 years). The results of the first trial (**Table 10**) indicate that grass or legume tree hedgerows, planted on every sixth contour ridge, did not increase cassava yield during the first 2−3 years of establishment, but the legume trees *Leucaena leucocephala* and *Gliricidia sepium* increased yield during the third year and especially during the fourth year of cropping. During the fourth year, the cassava in all plots looked very N-deficient, except in those plots with the two legume tree hedgerows, in which cassava had dark green leaves and grew more vigorously.

Table 10. Effect of various crop/soil management practices on dry soil loss due to erosion and on cassava root yield during four consecutive cropping cycles on 5% slope at Jatikerto Experiment Station near Malang, Indonesia, from 1987/88 to 1990/91.

	Dry soil loss (t/ha)				Cassava root yield (t/ha)			
Treatment	87/88	88/89	89/90	90/91	87/88	88/89	89/90	90/91
C+M[1)], CR, no HR	97.9	44.9	20.6	18.6	20.6	28.3	22.2	17.8
C+M, CR, elephant grass HR	69.1	20.2	14.3	12.9	25.2	25.9	20.0	18.7
C+M, CR, *Setaria* grass HR	79.9	34.2	15.1	12.6	21.4	19.9	22.5	16.7
C+M, CR, *Gliricidia* HR	91.1	39.0	17.6	7.5	20.5	17.8	24.8	24.6
C+M, CR, *Leucaena* HR	85.5	40.6	16.4	10.9	24.2	24.6	26.8	27.8
C+M, CR, peanut strips	93.5	37.4	16.6	16.5	20.4	18.0	21.5	16.1
C+M, no CR, *Setaria* grass HR	114.6	49.6	29.2	26.5	23.6	26.5	17.8	13.9
C+M, no CR, peanut strips	126.7	53.7	22.9	24.3	22.8	25.1	18.8	13.3
Control of bare soil	224.5	119.0	62.5	-	-	-	-	-

1) C+M = cassava intercropped with maize; CR = contour ridges; HR = hedgerows.

It is clear that the prunings of these trees had contributed considerable amounts of nutrients, especially N. The results also show that all hedgerows reduced soil losses due to erosion starting in the second year, and became increasingly more effective in the following two years; the hedgerows of *Leucaena* and *Gliricidia* were the most effective, followed by the two grass hedgerows, while the peanut strips were slightly less effective. Planting cassava on contour ridges also helped to reduce erosion, while leaving the soil bare without vegetation resulted in the highest soil loss due to serious erosion.

Similar results were obtained in the second experiment conducted on the same plots from 1991/92 to 1995/96. In this case, some plots had hedgerows of elephant grass (*Pennisetum purpureum), Gliricidia sepium*, and *Flemingia macrophylla* or no hedgerows, while other plots had a cover crop of *Mimosa envisa* or a peanut intercrop, with cassava planted on contour ridges, with or without fertilizer application (Howeler, 2012b). The hedgerows were again planted on two contour ridges six meters apart.

Figure 5 shows the relative cassava yield and soil losses by erosion of the three hedgerow treatments as a percent of the yield and soil loss obtained in the treatment without hedgerows (see also **Table 2** of **Chapter 10**).

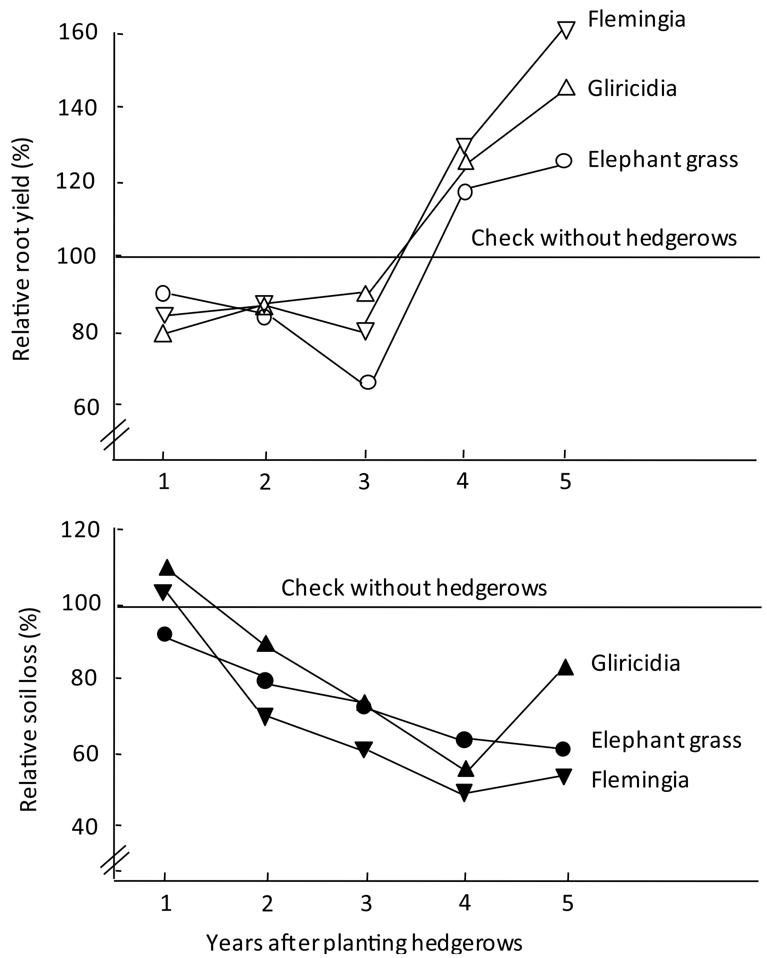

Figure 5. *Trend in relative yield and relative soil loss due to erosion when cassava intercropped with maize was planted with contour hedgerows of elephant grass, Gliricidia sepium and Flemingia macrophylla during five consecutive years of cropping on 8% slope at Jatikerto Experiment Station, near Malang, Indonesia, from 1991/92 to 1995/96.*

During the first 3 years the hedgerows decreased cassava yield by occupying space in the field, but in the fourth and fifth year, they increased yield substantially by contributing nutrients through the decomposition of the leaf prunings. Moreover, starting in the second year, these hedgerows reduced soil loss by erosion by covering the soil with mulch and slowing the flow of runoff water; this resulted in about a 40% reduction in soil loss in the fourth and fifth year.

c. *Various cultural practices*

Many experiments have been conducted using a wide array of cultural practices to determine which practices are most effective in reducing erosion. These experiments usually included treatments of no ridging, contour ridging, and up-and-down ridging, with and without fertilizer, different methods of land preparation, intercropping systems, closer plant spacing, different vegetative barriers, or hedgerows. A few examples of multi-year experiments are shown below:

Table 11 shows that, in an experiment conducted at GSCRI in Nanning, Guangxi, China, vetiver grass contour hedgerows combined with fertilizer application was the most effective in reducing erosion, from 19.9 t/ha to 2.9 t/ha, and increasing yield, from 15 t/ha to 22.8 t/ha. Similarly effective was planting cassava on contour ridges or intercropping with peanut. Fertilizer application and the application of mulch of intercropped *Crotalaria juncea* were also rather effective in reducing erosion and increasing yield.

Table 11. Effect of various cultural practices on the average dry soil loss due to erosion and the root yield of cassava grown on 12% slope at the Guangxi Subtropical Crops Research Institute in Nanning, Guangxi, China, from 1993 to 1995 (3 years).

Treatment	Cassava yield (t/ha)	Dry soil loss (t/ha)
Plowing+disking, no ridges, no fertilizer	15.0	19.9
Plowing+disking, no ridges, with fertilizer	20.8	10.2
Plowing+disking, contour ridges, with fertilizer	22.4	4.2
Plowing+disking, no ridges, with fertilizer, peanut intercrop	22.6	5.6
Plowing+disking, no ridges, with fertilizer, *Crotalaria* intercrop for mulching	21.5	10.2
Plowing only, no ridges, with fertilizer	19.4	10.7
Plowing only, no ridges with fertilizer, vetiver grass hedgerows	22.8	2.9

In contrast, in the experiment conducted on 25% slope in Baybay, in the Philippines **(Table 12)**, the application of fertilizer generally increased yield but resulted in more erosion than any of the other treatments, although no comparable treatment without fertilizer was included. In this case, the annual application of 14.5 t/ha of dried grass mulch was consistently the most effective in reducing erosion and increasing cassava yield. Vetiver grass hedgerows became very effective in reducing erosion, but only in the third year as this grass needs some time to become well established.

Table 12. Effect of various cultural practices on the average dry soil loss due to erosion and the root yield of cassava grown on 25% slope at the Root Crops Research Institute in Baybay, Leyte, Philippines, from 1991 to 1993 (3 years).

Treatment	Cassava root yield (t/ha) 1991	1992	1993	Aver.	Dry soil loss (t/ha) 1991	1992	1993	Aver.
CT [1], with 60-60-60 fertilizer	26.0	25.6	8.4	**20.0**	52.7	39.8	45.0	**45.8**
CT, no fert., lemon grass hedgerows	18.9	12.7	3.5	**11.7**	62.8	21.7	17.9	**34.1**
CT, no fert., vetiver grass hedgerows	18.9	13.1	5.7	**12.5**	70.8	20.7	8.1	**33.2**
CT, no fert., with dried grass mulch [2]	28.1	32.1	14.5	**24.9**	28.0	6.6	10.7	**15.1**
CT, no fert., with *Crotalaria juncea* intercrop for mulch	17.5	17.8	10.7	**15.3**	31.0	30.3	28.5	**29.9**

[1] CT = conventional tillage by clean weeding with hoe.
[2] 14.5 t/ha of dried grass as mulch.

Figure 6 shows that, in an experiment conducted in Thailand, the lack of fertilizer application caused the most serious soil loss by erosion due to the slow establishment and lack of vigor of cassava, which resulted in slow canopy cover. Zero-tillage, subsoiling, and contour ridging were most effective in reducing erosion as soil losses were only about half of those observed with conventional tillage of two passes with a 3-disk plow and 7-disk harrow and without ridging.

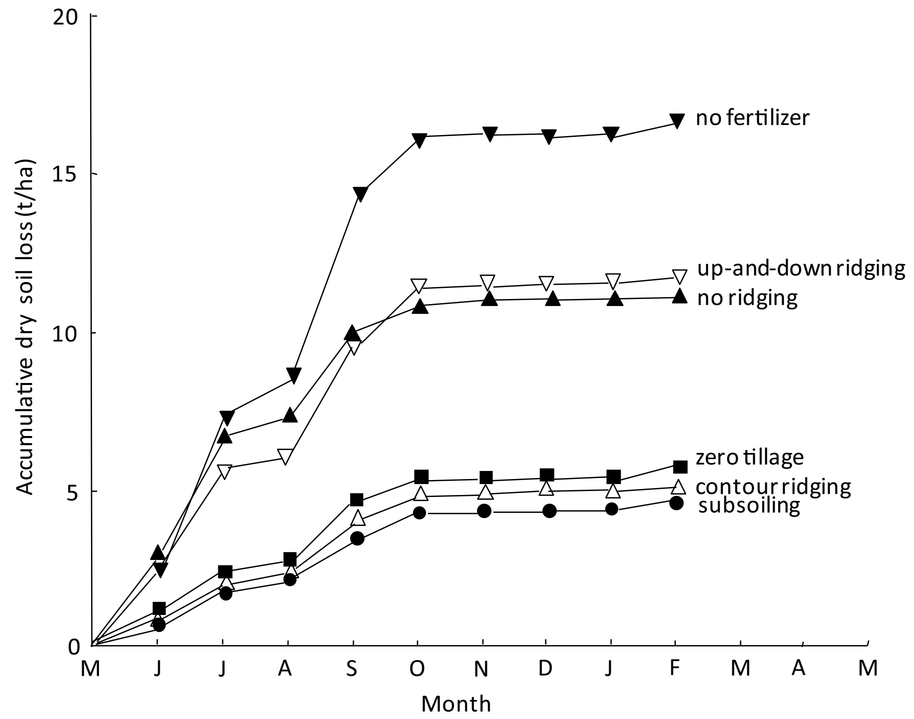

Figure 6. *Effect of various soil/crop management practices on the accumulative dry soil loss by erosion on 7% slope at Sri Racha Experiment Station, Thailand, during a 9-month growth cycle of cassava in 1988/89.*

Most erosion control experiments were continued for 2-3 years in the same location with the same treatments, after which some treatments were discontinued while others were added. However, at the Hung Loc Agricultural Research Center in Dong Nai Province of southern Vietnam, the same treatments were continued for 16 consecutive cropping cycles, from 1997 to 2012. The treatments included intercropping with peanut or mungbean between cassava rows, but the dry peanut pods were harvested, while the mungbean biomass was cut and mulched. Three hedgerows were planted along the contour at 5-m intervals. They were planted only in the first year and pruned or cut back before the planting of each new crop cycle. The prunings were mulched between the cassava rows. If a few plants in the hedgerows had died during the dry season, they were replanted during the following wet season.

Table 13 shows the results of the 16th year of cropping. All intercropping and hedgerow treatments increased cassava yield, mainly by supplying OM and nutrients in the crop residues or prunings. Intercropping with peanut and hedgerows of *Leucaena leucocephala* were the most effective in increasing yield, while vetiver grass was the most effective in reducing erosion, followed by hedgerows of *Leucaena* or *Gliricidia*, intercropping with peanut, and mulching of mungbean biomass. Vetiver grass and *Leucaena* produced the greatest amount of mulching material, while the peanut intercropping and *Leucaena* hedgerow treatments resulted in the highest net income.

Table 13. Effect of various soil and crop management practices on cassava yield and soil loss by erosion, as well as gross and net income obtained when cassava cv. SM 935-26 was grown during the 16th consecutive cropping cycle on 11% slope at Hung Loc Agricultural Research Center in Dong Nai Province of South Vietnam in 2012/13.

Treatment[1)]	Dry soil loss (t/ha)	Root yield (t/ha)	Starch content (%)	Intercrop residue FW yield (t/ha)	Gros income[3)]	Production costs [3)]	Net income
					(000 dong/ha)		
Cassava monoculture	37.79	23.58	25.3	-	23,580	14,114	9,466
C+mungbean GM	30.86	27.27	25.6	1.73	27,270	17,914	9,346
C+peanut[2)] IC	24.89	29.46	26.7	3.13	33,288	18,914	14,374
C+vetiver HR	12.25	28.00	26.7	10.20	28,000	15,314	12,686
C+*Leucaena* HR	16.91	28.85	27.4	9.57	28,850	15,314	13,536
C+*Gliricidia* HR	17.50	27.50	27.1	7.09	27,500	15,314	12,186

1) GM = green manure, IC = intercrop, HR = hedgerows, FW = fresh weight.

2) Peanut yield = 255.2 kg dry pods/ha.

3) Prices: Cassava: dong 1,000/kg fresh roots (includes the cost of harvesting)
Peanut 15,000/kg dry pods

Costs:	Prep. planting material	dong	450,000/ha	Seed peanut	dong	3,000,000/ha
	Land preparation		2,000,000/ha	Fertilizer application		720,000/ha
	Cassava planting		900,000/ha	Urea (46% N)		10,000/kg
	Intercrop planting/management		600,000/ha	SSP (16% P_2O_5)		3,500/kg
	Harvesting peanut/cutting HR		1,200,000/ha	KCl (60% K_2O)		12,000/kg
	Weeding		4,500,000/ha	Basudin		25,000/kg
	Seed mungbean		3,200,000/ha	Labor		120,000/day

US$1 = 21,000 dong

Figure 7 shows the effect of the three hedgerow treatments on relative soil loss due to erosion and relative cassava yield during the first 11 years of continuous cropping. None of the three hedgerow species were effective in controlling erosion during the first year of establishment, but their effectiveness increased over time and in the fifth and subsequent years they reduced soil losses to only 20−50% compared with the plots without hedgerows. Vetiver grass was consistently the most effective in reducing erosion, followed by hedgerows of *Leucaena* and *Gliricidia*. All three hedgerow species increased cassava yield by 10−20%, with *Leucaena* generally being the most effective species. This is similar to results reported in **Table 27** of **Chapter 10**, in which alley cropping with *Leucaena* and *Gliricidia* in another experiment at Hung Loc Center resulted in the highest yield and net income. This also corresponds with data reported in **Table 2** of **Chapter 10** for alley cropping with *Gliricidia*, and *Flemingia* hedgerows at Jatikerto, as well as data shown above in **Table 10** and **Figure 5** for another erosion control trial conducted in Jatikerto, Malang, Indonesia.

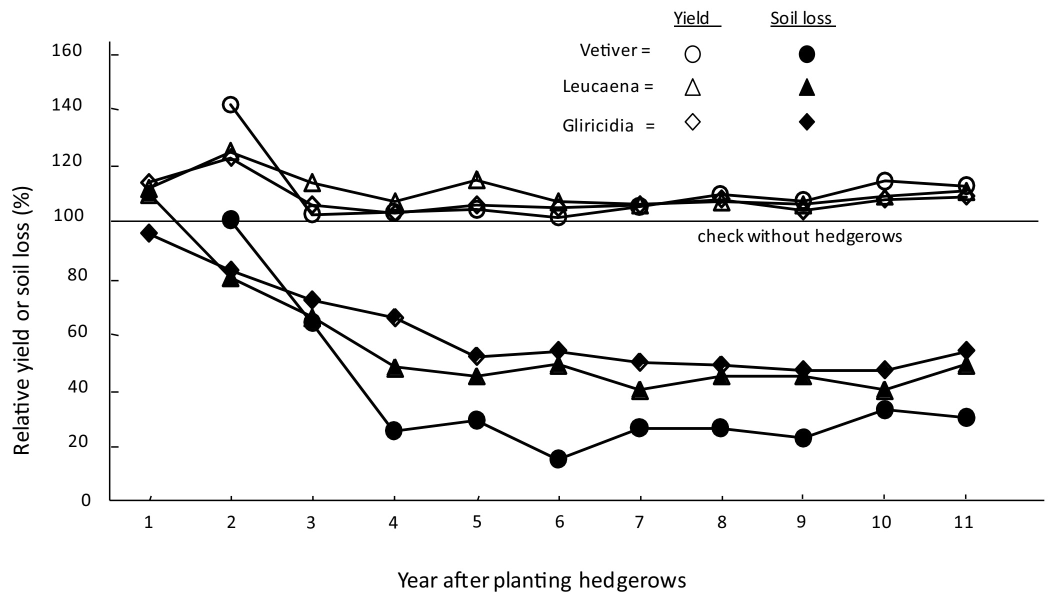

Figure 7. *Trend in relative yield and relative soil loss by erosion when cassava was planted with contour hedgerows of vetiver grass, Leucaena leucocephala or Gliricidia sepium, in comparison with the check without hedgerows during 11 consecutive years in Hung Loc Agricultural Research Center in South Vietnam from 1997/98 to 2007/08.*

Source: *Nguyen Huu Hy et al., 2010.*

7. Enhancing the Adoption of Soil Conservation Practices

From the many experiments conducted by researchers on experiment stations and on-farm, it is clear that many agronomic and soil conservation practices can reduce soil losses by water erosion and even increase yield. This includes planting cassava at a closer plant spacing (at populations of >10,000 plants/ ha), applying fertilizer or manure, planting contour hedgerows of certain grasses or leguminous tree

Table 14. Effect of various soil/crop management practices on erosion and yield, as well as on labor and monetary requirements, and long-term benefits in cassava-based cropping systems.

Erosion control practice	Erosion control	Terrace formation	Effect on cassava yield	Labor require-ment	Monetary cost	Long-term benefits	Main limitations
Minimum or zero-tillage	++	-	-	+	- -	+	Compaction, weeds
Mulching (carry-on)	++++	-	++	+++	+	++	Mulch availability, transport
Mulching (*in situ* production)	+++	-	++	++	+	++	Competition
Contour tillage	+++	+	+	+	+	++	
Contour ridging	+++	+	++	++	++	+	Not suitable on steep slopes
Leguminous tree hedgerows	++	++	+	+++	+	+++ [1]	Delay in benefits
Cut-and-carry grass strips	++	++	- -	+++	+	+++ [1]	Competition, maintenance
Vetiver grass hedgerows	+++	+++	+	+	+	+++	Availability of planting material
Natural grass strips	++	++	-	+	-	++	High maintenance costs
Cover cropping (live mulch)	++	-	- - -	+++	++	+	Severe competition
Manure or fertilizer application	++++	-	+++	+	+++	+++	High cost
Intercropping	++	-	-	++	++	+++	Labor-intensive
Closer plant spacing	+++	-	+	+	+	++	

\+ = effective, positive, or high.

\- = not effective, negative, or low.

1) = value added in terms of animal feed, staking material, or fuel wood.

species, contour plowing and ridging, applying mulch, and intercropping with peanut, melons, or squash, etc. However, most of these practices have certain advantages and disadvantages; some are very effective in reducing erosion, but may also reduce yield, and may be costly or laborious to install or maintain. **Table 14** shows the relative importance of the good and bad attributes of various soil conservation practices.

Since most soil conservation practices have advantages and disadvantages, trade-offs will need to be made. Those are best made by farmers themselves as they will greatly depend on the specific biophysical as well as socioeconomic situations at each site. Thus, farmers were encouraged to conduct simple erosion control and other types of trials in their own fields with guidance from researchers and extension workers. These were called farmer participatory research (FPR) trials. From 1994 to 2004, farmers conducted a total of 1,621 FPR trials in over 100 villages in Thailand, Vietnam, China, and Indonesia, of which 378 were erosion control trials. Some typical examples of these trials are shown in **Tables 15−17**.

During farmer field days at the time of harvest, farmers from the village (participating and nonparticipating) and surrounding villages visited each trial and evaluated and scored each treatment according to their own criteria. Later in the day, the average results of each type of trial were presented for discussion with the farmers; this included estimates of the gross income, total production cost, and net income for each treatment. Farmers were asked to raise their hands to show how they had scored each treatment in order to calculate the farmers' preference, as shown in the last columns of **Tables 15, 16**, and **17**.

Table 15. Effect of various crop management treatments on the yield of cassava and intercropped peanut as well as the gross and net income and soil loss due to erosion in an FPR erosion control trial conducted by six farmers in Kieu Tung Village of Thanh Ba District, Phu Tho Province, Vietnam, in 1997 (3rd year).

Treatment [1]	Slope (%)	Dry soil loss (t/ha)	Yield (t/ha) cassava	Yield (t/ha) peanut [1]	Gross income [2] (mil. dong/ha)	Product. costs (mil. dong/ha)	Net income (mil. dong/ha)	Farmers' ranking
C monocult., with fertilizer, no hedgerows	40.5	106.1	19.17	-	9.58	3.72	5.86	6
C+P, no fertilizer, no hedgerows	45.0	103.9	13.08	0.70	10.04	5.13	4.91	5
C+P, with fertilizer, no hedgerows	42.7	64.8	19.23	0.97	14.47	5.95	8.52	-
C+P, with fertilizer, *Tephrosia* hedgerows	39.7	40.1	14.67	0.85	11.58	5.95	5.63	3
C+P, with fertilizer, pineapple hedgerows	32.2	32.2	19.39	0.97	14.55	5.95	8.60	2
C+P, with fertilizer, vetiver hedgerows	37.7	32.0	23.71	0.85	16.10	5.95	10.15	1
C monocult, with fertilizer, *Tephrosia* hedgerows	40.0	32.5	23.33	-	11.66	4.54	7.12	4

1) Fertilizers = 60 kg N + 40 kg P_2O_5, + 120 kg K_2O/ha; all plots received 10 t/ha pig manure.

2) Prices: cassava (C) dong 500/kg fresh roots
peanut (P) 5,000/kg dry pods
1 US$ = approx. 13,000 dong

Source: *Howeler, 2010c.*

Table 16. Average results of two FPR erosion control trials conducted by farmers in Khook Anu Village, Thep Sathit District, Chayaphum Province, Thailand, in 2001/02.

Treatment	Dry soil loss (t/ha)	Yield (t/ha) Cassava	Yield (t/ha) Intercrop	Starch content (%)	Gross income (baht/ha)	Product. costs[2] (baht/ha)	Net income (baht/ha)	Farmers' preference (%)
Farmers' practice	13.99	12.61	-	20.3	12,736	12,018	718	0
Contour plowing	10.16	8.41	-	20.0	8,410	11,471	−3,061	100
Up-and-down plowing	31.10	12.34	-	18.3	11,970	11,974	−4	0
Mungbean intercrop	10.30	8.70	0.31	24.0	15,516	15,392	124	82
Vetiver grass hedgerows	8.03	13.02	-	22.3	13,619	13,083	536	100
Lemon grass hedgerows	4.53	15.94	-	21.0	16,259	13,550	2,709	0[3]

[1] Prices: cassava baht 1.20/ kg fresh roots at 30% starch
mungbean 20/ kg dry grain
[2] Cost of production without harvest baht 10,000/ha; C+mungbean intercrop baht 14,000/ha
carvest + transport 160/ton; hedgerow planting + maintenance 1,000/ha
contour plowing 125/ha extra
[3] Farmers did not like this treatment as lemon grass planting material is not readily available and plants die during a prolonged drought
Source: *Howeler, 2008.*

Table 17. Average results of five FPR erosion control trials conducted by farmers in Tien Phong and Dac Son villages of Pho Yen District, Thai Nguyen Province, Vietnam, in 1997.

Treatment[1]	Dry soil loss[1] (t/ha)	Yield (t/ha) Cassava	Yield (t/ha) Peanut[2]	Gross income[3] (mil. dong/ha)	Product. costs[4] (mil. dong/ha)	Net income (mil. dong/ha)	Farmers' preference (%)
Farmers' practice	7.73	11.77	-	5.89	4.05	1.84	0
C + P, contour ridges	5.39	17.47	0.36	10.54	5.64	4.90	0
C + P, contour ridges, vetiver hedgerows	3.94	19.05	0.37	11.38	5.92	5.46	67
C + P, contour ridges, *Tephrosia* hedgerows	3.02	19.00	0.39	11.45	5.92	5.53	83
C + P, contour ridges, *Tephrosia* + vetiver hedgerows	2.73	17.92	0.41	11.01	5.92	5.09	3

[1] Farmers' practice: cassava monoculture, 11.4 t/ha of FYM + 68 kg N + 20 kg P_2O_5 + 50 kg K_2O/ha; all other plots received 10 t/ha of FYM + 80 kg N + 40 kg P_2O_5 + 80 kg K_2O/ha.
[2] Dry pods.
[3] Prices: cassava: dong 600/kg fresh roots
peanut: 5,000/kg dry pods
[4] Costs: FYM: dong 100/kg
urea (45%N): 2,500/kg
SSP (17% P_2O_5): 1,000/kg
KCl (60%K_2O): 2,500/kg
peanut seed: 6,000/kg; use 50 kg/ha
labor: 7,500/person-day
US$1 = 11,000 dong
Source: *Nguyen The Dang et al., 2001.*

The average effect of the various soil and crop management practices on cassava yield and on dry soil loss due to erosion was calculated as a percentage of a check treatment without the practice for all erosion control experiments and FPR trials conducted in Thailand and Vietnam. The results are shown in **Tables 18** and **19**. In both countries, contour hedgerows of vetiver grass or *Paspalum atratum* were the most effective in controlling erosion, while in Vietnam hedgerows of *Tephrosia candida, Flemingia macrophylla*, and pineapple were also very effective. In Thailand, these hedgerows reduced yield slightly because they take up some space in the field, but in Vietnam they actually increased cassava yield by 10−15%. Planting cassava at a closer spacing was also quite effective in reducing erosion in Thailand but not in Vietnam; in both countries, closer spacing increased cassava yield. Hedgerows of leguminous tree species such as *Leucaena* or *Gliricidia* were intermediately effective in controlling erosion and increased cassava yield only in long-term trials in Vietnam. The application of fertilizer was one of the most effective ways to increase cassava yield and markedly reduce soil losses by erosion, especially in Vietnam. Intercropping with peanut, melon, or sweet corn did not reduce erosion and decreased cassava yield in Thailand (although they may have increased total income), while intercropping with peanut was intermediately effective in reducing erosion and slightly increased cassava yield in Vietnam.

Table 18. Effect of various soil conservation practices on the average[1] relative cassava yield and dry soil loss due to erosion as determined from soil erosion control experiments, FPR demonstration plots, and FPR trials conducted in Thailand from 1994 to 2003.

Soil conservation practices[2]	Relative cassava yield (%)	Relative dry soil loss (%)
With fertilizer; no hedgerows, no ridging, no intercrop (check)	100	100
With fertilizer; vetiver grass hedgerows, no ridging, no intercrop**	90 (25)	58 (25)
With fertilizer; lemon grass hedgerows, no ridging, no intercrop**	110 (14)	67 (15)
With fertilizer; sugarcane for chewing hedgerows, no intercrop	99 (12)	111 (14)
With fertilizer; *Paspalum atratum* hedgerows, no intercrop**	88 (7)	53 (7)
With fertilizer; *Panicum maximum* hedgerows, no intercrop	73 (3)	107 (4)
With fertilizer; *Brachiaria brizantha* hedgerows, no intercrop*	68 (3)	78 (2)
With fertilizer; *Brachiaria ruziziensis* hedgerows, no intercrop*	80 (2)	56 (2)
With fertilizer; elephant grass hedgerows, no intercrop	36 (2)	81 (2)
With fertilizer; *Leucaena leucocephala* hedgerows, no intercrop*	66 (2)	56 (2)
With fertilizer; *Gliricidia sepium* hedgerows, no intercrop*	65 (2)	48 (2)
With fertilizer; *Crotalaria juncea* hedgerows, no intercrop	75 (2)	89 (2)
With fertilizer; pigeon pea hedgerows, no intercrop	75 (2)	90 (2)
With fertilizer; contour ridging, no hedgerows, no intercrop**	108 (17)	69 (17)
With fertilizer; up-and-down ridging, no hedgerows, no intercrop	104 (20)	124 (20)
With fertilizer; closer spacing, no hedgerows, no intercrop**	116 (10)	88 (11)
With fertilizer; C+peanut intercrop	72 (11)	102 (12)
With fertilizer; C+pumpkin or squash intercrop	90 (13)	109 (15)
With fertilizer; C+sweet corn intercrop	97 (11)	110 (14)
With fertilizer; C+mungbean intercrop*	74 (4)	41 (4)
No fertilizer; no hedgerows, no or up-and-down ridging	96 (9)	240 (10)

[1] Number in parentheses indicates the number of experiments/trials from which the average values were calculated.
[2] C = cassava.
** = Most promising soil conservation practices; * = promising soil conservation practices.
Source: *Howeler, 2008.*

Table 19. **Effect of various soil conservation practices on the average[1] relative cassava yield and dry soil loss due to erosion as determined from soil erosion control experiments, FPR demonstration plots, and FPR trials conducted in Vietnam from 1993 to 2003.**

		Rel. cassava yield (%)		Rel. dry soil loss (%)	
	Soil conservation practices[2]	Cassava monoculture	Cassava + peanut	Cassava monoculture	Cassava + peanut
1.	With fertilizer; no hedgerows (check)	100	-	100	-
2.	With fertilizer; vetiver grass hedgerows**	113 (17)	115 (23)	48 (16)	51 (23)
3.	With fertilizer; *Tephrosia candida* hedgerows**	110 (17)	105 (23)	49 (16)	64 (23)
4.	With fertilizer; *Flemingia macrophylla* hedgerows*	103 (3)	109 (4)	51 (3)	62 (3)
5.	With fertilizer; *Paspalum atratum* hedgerows**	112 (17)	-	50 (17)	-
6.	With fertilizer; *Leucaena leucocephala* hedgerows*	110 (11)	-	69 (11)	-
7.	With fertilizer; *Gliricidia sepium* hedgerows*	107 (11)	-	71 (11)	-
8.	With fertilizer; pineapple hedgerows*	100 (8)	103 (9)	48 (8)	44 (9)
9.	With fertilizer; vetiver+*Tephrosia* hedgerows	-	102 (7)	-	62 (7)
10.	With fertilizer; contour ridging, no hedgerows*	106 (7)	-	70 (7)	-
11.	With fertilizer; closer spacing, no hedgerows	122 (5)	-	103 (5)	-
12.	With fertilizer; peanut intercrop, no hedgerows*	106 (11)	100	81 (11)	100
13.	With fertilizer; maize intercrop, no hedgerows	69 (3)	-	21 (3)	-
14.	No fertilizer; no hedgerows	32 (4)	92 (15)	137 (4)	202 (12)

1) Number in parentheses indicates the number of experiments/trials from which the average values were calculated.

2) ** = Most promising soil conservation practices; * = promising soil conservation practices.

Source: *Howeler, 2008.*

At the end of the project in 2004, an impact assessment was conducted by an outside consultant to determine which practices were most widely adopted by farmers in Thailand and Vietnam. This was done by focus group discussions with farmers that previously had participated in the FPR trials and training courses, as well as with farmers living in nearby villages that had not participated directly in the project. Farmers were also asked to fill out census forms to indicate which practices they had adopted and what their cassava yield was before and after the project. Results (**Table 20**) indicate that, among the participating farmers, 53% in Thailand and 31% in Vietnam were using contour ridging to control erosion. Among nonparticipating farmers, this was only 22% and 29%, respectively, resulting in an overall adoption of about 30% in both countries.

Table 20. **Extent of adoption (percent of households) of soil conservation technologies by participating and non-participating farmers in the Nippon Foundation cassava project in Thailand and Vietnam[1].**

	Participants			Non-participants		
Soil conservation practices	Thailand	Vietnam	Overall	Thailand	Vietnam	Overall
- Contour ridging	53.0	31.3	40.9	22.0	28.9	25.0
- Hedgerows - vetiver grass	61.5	11.6	33.7	9.6	3.7	7.0
- *Tephrosia candida*	0	32.7	18.2	0	6.9	3.0
- *Paspalum atratum*	0.9	11.6	6.8	0	2.0	0.9
- pineapple	0	2.7	1.5	0	0.8	0.4
- sugarcane	1.7	0	0.8	0.6	0	0.4
- other hedgerows	3.4	7.5	5.7	0.3	1.6	0.9
- No soil conservation	20.5	29.3	25.4	70.8	59.3	65.8

1) Data are based on census forms filled out by 417 households in Thailand and 350 in Vietnam, of which 109 and 126 had been participants of the project, respectively.

Source: *Dalton et al., 2007.*

Concerning the adoption of contour hedgerows, it is clear that these were adopted mainly by those farmers that had actively participated in the project. Interestingly, the great majority of farmers in Thailand preferred the planting of vetiver grass, while those in northern Vietnam preferred *Tephrosia candida* and in southern Vietnam *Paspalum atratum*. Other types of hedgerows, such as lemon grass or pineapple, while being quite effective in reducing erosion, were seldom adopted. This clearly indicates that farmers select those practices that fit best into their existing farming practices and are most suitable for their own particular conditions.

In Thailand, vetiver grass is popular because it is recommended by the King and young plants are readily available, usually free of charge. This is not the case in Vietnam, so obtaining vegetative planting material in large quantities is more difficult. Farmers in the north prefer *Tephrosia candida* because it grows well in the cooler climate and as a leguminous species is expected to improve the soil. In the south, farmers prefer *Paspalum atratum* because it provides feed for cattle and buffaloes. Thus, in order to achieve adoption of soil conservation practices, researchers or extension workers should not promote a single technology because it happens to be effective in experiments, but they should let farmers conduct their own soil erosion control trials, and let farmers select those practices that they consider most suitable for their own conditions.

Give farmers a voice and give them a choice!

CHAPTER 12

OTHER AGRONOMIC PRACTICES

Cassava is a popular crop among poor farmers because it requires few inputs besides labor to produce a reasonable yield. Still, to get higher yield and greater economic benefits, the crop should be well managed and some external inputs may be required. Moreover, to sustain high yield in the future, it is important to prevent soil nutrient depletion and soil losses by erosion. This can be achieved through simple agronomic or soil conservation practices.

1. Cassava-based Cropping Systems

Cassava can be planted either as a sole crop in a monoculture system or intercropped with other crops. Farmers that have only small plots of land will generally prefer to intercrop cassava with other crops. In that case, the cassava row spacing is usually widened to allow more space for the intercrop between the cassava rows, while interplant spacing within the row is shortened to maintain a high cassava population.

Numerous experiments have been conducted to determine the best intercrops for cassava, as well as the best planting arrangements and relative time of planting (Leihner, 1983; Aye and Howeler, 2012). In northern Vietnam, the intercropping of cassava with one or two rows of peanut generally resulted in the highest net income (**Table 1**).

Table 1. Average results of four FPR intercropping trials conducted by farmers in Tran Phu commune, Chuong My District, Ha Tay, Vietnam, in 2003.

Treatment	Cassava yield (t/ha)	Intercrop yield (t/ha)	Gross income[1]	Seed costs[2]	Product. costs[2]	Net income
			(000 dong/ha)			
1. Cassava monoculture	24.54	-	9,816	0	5,460	4,356
2. C+1 row peanut	21.93	1.19	14,707	480	8,115	6,592
3. C+2 rows peanut	22.52	2.00	19,008	960	8,595	10,413
4. C+2 rows mungbean	21.42	0	8,568	2,000	9,635	−1,067
5. C+2 rows soybean	21.28	0.16	9,322	800	8,435	887

[1] Prices: cassava dong 400/kg fresh roots
peanut 5,000/kg dry pods
soybean 5,000/kg dry seed

[2] Costs: labor dong = 15,000/person-day
NPK fertilizer = 0.86 mil. dong/ha
peanut seed (80 kg/ha) 12,000 /kg = 0.96 mil. dong/ha for 2 rows
mungbean seed (80 kg/ha) 25,000 /kg = 2.00 mil. dong/ha for 2 rows
soybean seed (80 kg/ha) 10,000 /kg = 0.80 mil. dong/ha for 2 rows
labor for cassava monoculture without fertilizer = 4.5 mil. dong/ha (300 p-d/ha)
labor for cassava intercropping without fertilizer = 6.675 mil. dong/ha (445 p-d/ha)
labor for cassava fertilizer application = 0.10 mil. dong/ha

Source: *Trinh Phuong Loan, personal communication, 2004.*

Intercropping with mungbean or soybean can be successful sometimes, but other times may result in complete crop losses due to drought or severe insect or disease problems. Peanut is a popular intercrop as it can be grown on acid infertile soils similar to those of cassava, it does not suffer severe pest and disease problems, and it protects the soil from rainfall splash, thus reducing erosion (**Table 2**).

Table 2. Effect of intercropping cassava with various grain legumes on the yield of crops, on gross and net income, and on dry soil loss due to erosion when grown on 10% slope at the Agro-forestry College of Thai Nguyen University, Thai Nguyen, Vietnam, in 1997.

Intercropping treatment	Yield (t/ha) Cassava	Yield (t/ha) Intercrop	Gross income[1]	Costs of fert. +seed[1]	Net income	Dry soil loss (t/ha)
			(mil. dong/ha)			
1. Cassava monoculture	18.67	-	7.47	6.22	1.25	31.24
2. C+peanut	16.50	1.08	12.00	8.77	3.23	24.03
3. C+soybean	18.42	0.15	8.27	7.98	0.29	28.50
4. C+mungbean	20.83	0.27	10.49	7.84	2.65	28.61
5. C+black bean	17.92	0.35	9.62	7.94	1.68	28.64
6. C+cuoc bean	17.67	0.17	7.92	7.87	0.05	28.14

[1] Prices: cassava: dong 400/kg fresh roots
peanut: 5,000/kg dry pods peanut seeds: dong 7,000/kg dry pod
soybean: 6,000/kg dry grain soybean seeds: 7,000/kg dry grain
mungbean: 8,000/kg dry grain mungbean seeds: 8,000/kg dry grain
black bean: 7,000/kg dry grain black bean seeds: 7,000/kg dry grain
cuoc bean: 5,000/kg dry grain cuoc bean seeds: 5,000/kg dry grain

Source: *Le Sy Loi, 2000.*

2. Time of Planting and Harvest

The best time to plant cassava depends not only on the climatic conditions at the time of planting but also on climatic as well as marketing conditions at the time of the expected harvest. In those areas where the root price depends on the starch content, farmers want to try to maximize both yield and starch content at the time of harvest. However, prices also depend on market conditions and are usually highest in the off-season, that is, when most farmers do not harvest. Thus, some farmers may want to sacrifice some yield in order to benefit from higher prices in the off-season.

a. Tropical regions

In tropical regions with distinct dry and wet seasons and a monomodal rainfall distribution, the best time to plant is early in the wet season, that is, as soon as enough soil moisture allows for adequate germination of planted stakes. **Figure 1** shows that, in Rayong, Thailand, the highest yield was obtained with planting in May, at the start of the rainy season. In those areas with a bimodal rainfall distribution, such as in Kerala, India, planting at the start of the second rainy season, that is, in August or September, will also result in high yield (George et al., 2001). In the southern hemisphere, the wet and dry seasons are reversed in comparison with the northern hemisphere, and the wet season generally starts in November-December and ends in April-May. In that case, the highest cassava yield is obtained when the crop is planted in December (Wargiono et al., 2001).

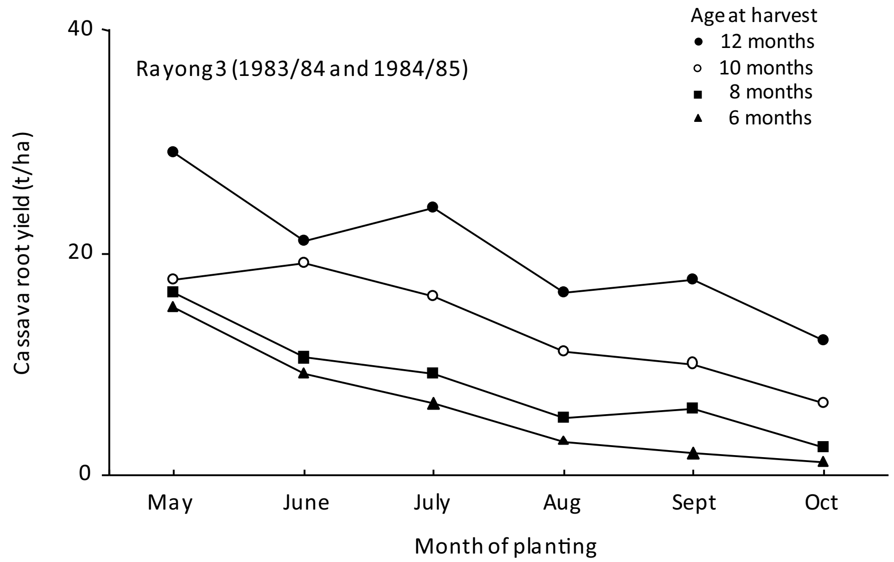

Figure 1. *Effect of month of planting and age at harvest on the average root yields of cassava, variety Rayong 3, planted at Rayong Field Crops Research Center in Thailand in 1983/84 and in 1984/85.*

Source: *Tongglum et al., 2001.*

However, high yield can also be obtained when cassava is planted toward the end of the wet season. **Table 3** shows that the highest yield in Rayong, Thailand, was obtained when cassava was planted in August-November. In this case, plants become well established during the last months of the rainy season, grow slower during the dry season, and have an additional period of fast growth during the following wet season. In this case, weed competition tends to be less severe as plant canopies are already well established during the early part of the second wet season.

Table 3. Average fresh root yield (t/ha) of recommended cassava varieties when planted in different periods of the year at the Rayong Field Crops Research Center, Thailand, in 1987/89 and in 1988/90.

	Cultivars				
Planting period	Rayong 1	Rayong 3	Rayong 60	Rayong 90	**Average**
April-May	18.56	19.94	23.31	24.00	**21.44 c**[1)]
June-July	20.81	24.25	27.63	29.31	**25.50 ab**
August-Sept	22.31	24.44	32.31	27.81	**26.75 a**
Oct-Nov	21.81	26.62	30.19	26.06	**26.19 a**
Dec-Jan	19.38	20.38	29.44	23.87	**23.25 bc**
Feb-March	20.75	20.50	26.25	25.44	**23.25 bc**
Average	**20.62 d**	**22.69 c**	**28.19 a**	**26.06 b**	

1) Mean separation: DMRT, 0.01

Source: *Tongglum et al., 2001.*

b. Subtropical regions

Cassava is also grown in subtropical regions, such as southern China and northern Vietnam. These regions are characterized by cold and dry winters (with occasional frost at higher latitudes) and hot and wet summers with relatively long daylight. **Figure 2** shows that, in Hainan Province of China, cassava yield was little affected by the date of planting when cassava was harvested at 12 months, but that yield declined markedly when the crop was planted in late summer (August-November) and harvested after 8 months in April to July.

When harvested at 8 MAP, both root yield and starch content were lowest when roots were harvested during the hot months of June-July. In that case, root yield was positively and highly significantly correlated with both temperature and rainfall during the third to fifth month after planting, that is, at the time of maximum growth rate of cassava, while starch content was negatively correlated with temperature and rainfall during the last month before harvest (Zhang Weite et al., 1998; Aye, 2012).

We can conclude that the highest yield is generally obtained when cassava is planted as early as possible in the wet season or in early spring, while starch contents are highest when plants are harvested in the middle of the dry season. At planting time, there should be enough soil moisture to get at least 80–90% germination, while soils should not be too wet to prevent adequate aeration and root formation.

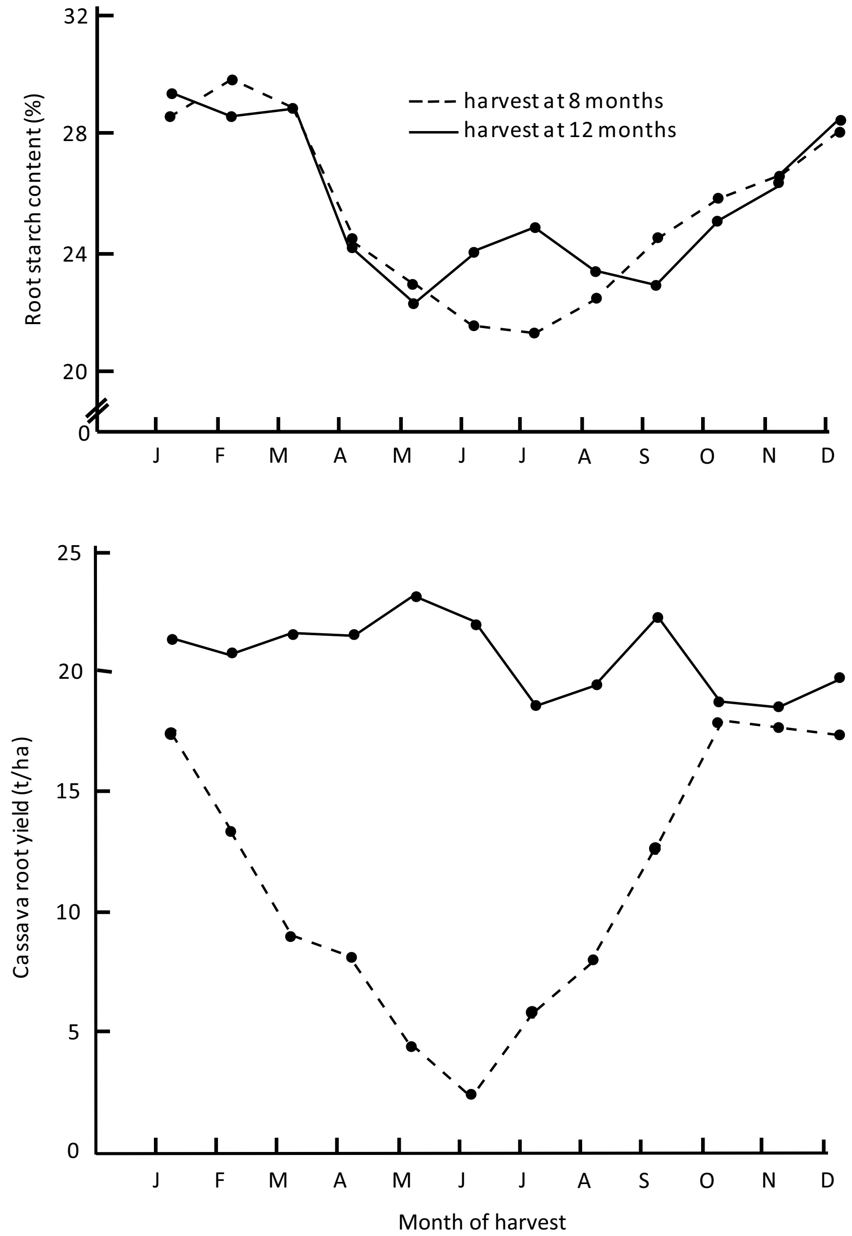

Figure 2. *Cassava root starch content (top) and root yield (bottom) averaged over three varieties and three cropping cycles, when the crop was planted during different months of the year at CATAS, in Danzhou, Hainan, China, and harvested after either 8 or 12 months.*

Source: *Zhang Weite et al., 1998.*

3. Land Preparation

Most farmers prefer to plant cassava in well-prepared loose soil without any weeds. This facilitates vertical or inclined planting and reduces early weed competition. In Thailand, the soil is usually prepared by a hired tractor owner using a 3-disk plow followed by a 7-disk harrow, and sometimes a ridger. The contractor prefers to plow the field in straight lines parallel to roads or plot borders, irrespective of slope direction. This method results in a loose and clean soil surface and high yield, but may cause severe erosion as well as formation of a "plow sole" or compacted layer at 15-20 cm depth. This compacted subsoil impedes free drainage, resulting in poor growth or root rot during the months of heavy rainfall. Moreover, the topsoil is rapidly saturated with water, which is followed by overland runoff and sometimes severe gully erosion. The regular use of a subsoiler will help to break the plow sole and improve internal drainage, which tends to improve plant growth during the height of the rainy season and increase yield (Watananonta et al., 2006). The subsoiler is usually followed by either a 3-disk plow or 7-disk harrow to reduce weed competition and loosen the soil for easy planting.

On steep slopes in Lao PDR and southern China, land is often cleared of vegetation by a machete, followed by burning; land preparation is limited to making individual holes for planting each stake horizontally. In a field with 25% slope at CATAS on Hainan Island of China, hand preparation of only planting holes resulted in similar yield as twice plowing and disking, but markedly reduced soil erosion. Zero-tillage followed by direct planting in small holes reduced yield and slightly increased erosion (Zhang Weite et al., 1998). In Thailand, no-tillage (zero-tillage) and using herbicides to control weeds sometimes resulted in high yield if weed growth was not aggressive (Jongruaysuk et al., 2007). However, in very weedy plots or in compacted soil, zero-tillage generally resulted in lower yield and difficulty in planting, weeding, and harvesting. Therefore, no-tillage systems generally produced low cassava yield but may have improved the soil's physical conditions compared with conventional tillage (**Tables 4** and **5**).

Table 4. Effect of various methods of land preparation on the average fresh root yield and root starch content of Rayong 90 planted for three years at Rayong FCRC in Thailand in 1992/93, 1993/94, and 1994/95.

Land preparation treatment	Fresh root yield (t/ha)	Starch content (%)
No-tillage	13.63 d	26
Two times with 7-disk plow	17.86 b	25
One time with 7-disk plow followed by animal ridging	16.86 bc	26
Two times plowing with 3-disk plow, followed by 7-disk plow	20.43 a	26
Two times of animal ridging	15.22 cd	26
One time of subsoiler followed by 7-disk plow	15.54 cd	25
Cassava harvester followed by 7-disk plow		
F-test	**	NS
CV (%)	14.32	6.74

Note: Data within a column followed by the same letter are not significantly different at P=0.01
Source: *Jongruaysuk et al., 2007.*

Table 5. Effect of various methods of land preparation on the fresh root yield and root starch content of Rayong 5 planted at Rayong FCRC in Thailand in 1995/96.

Land preparation treatment	Fresh root yield (t/ha)	Starch content (%)
No-tillage	19.28 a	21.67
Two times with 7-disk plow	10.66 c	21.22
One time with 7-disk plow followed by animal ridging	14.46 bc	22.25
Two times plowing with 3-disk plow, followed by 7-disk plow	16.31 ab	24.27
Two times of animal ridging	16.06 ab	22.80
One time of subsoiler followed by 7-disk plow	13.63 bc	20.29
Cassava harvester followed by 7-disk plow	15.96 ab	22.15
F-test	*	NS
CV (%)	19.75	9.16

Note: Data within a column followed by the same letter are not significantly different at P=0.05
Source: *Jongruaysuk et al., 2007.*

Most cassava farmers in Thailand now prepare their land by contract plowing with a 3-disk plow followed by a 7-disk harrow, which in turn may be followed by a ridger. An experiment to determine the most effective method of mechanical land preparation, conducted for three or four consecutive years in three locations in Thailand, showed that the best method of land preparation differed among the three locations, but that overall the use of a subsoiler followed by a chisel plow, or the standard practice of using a 3-disk plow followed by a 7-disk harrow and ridger, produced the highest yield **(Table 6)**. In Khaw Hin Sorn, plowing with a 3-disk plow and a 7-disk harrow, either alone or preceded by a subsoiler, produced the highest yield, which was significantly higher than that obtained using zero-tillage or using only a subsoiler. In Rayong, subsoiling followed by a 3-disk plow, and in TTDI subsoiling followed by a chisel plow, produced the highest yield (Watananonta et al., 2006; Aye, 2012).

Another experiment to determine the effect of land preparation methods, conducted at Sri Racha Experiment Station in Thailand, indicated that the various tillage practices had no significant effect on cassava yield except when the soil was prepared by the standard 3-disk plow and 7-disk harrow followed by artificially compacting the soil by driving over the prepared plots five times with a tractor **(Table 7)**. The compaction resulted in poor internal drainage, leading to clear Mn toxicity symptoms in the lower leaves, poor growth, and markedly reduced root yield and dry matter content. This clearly shows the need to prevent soil compaction as this will result in an excessively high bulk density and low soil porosity and water infiltration rate as indicated by a very low hydraulic conductivity (K_{sat}).

Table 8 shows that planting on top of ridges had no significant effect on root yield or starch content when planting occurred during either the rainy or dry season. However, in the dry-season planting, germination was significantly better without ridges as ridging caused more rapid drying of the soil. On gentle slopes, contour ridging is an effective way to reduce runoff and erosion. However, when too much water accumulates above the ridge, this may cause waterlogging and lower yield, or the ridges may break, causing serious gully erosion.

Table 6. Summary of land preparation experiments conducted for three or four years in each of three locations in Thailand from 2001 to 2006.

Tillage treatment	Fresh cassava root yield (t/ha)[1] Rayong	TTDI	Khaw Hin Sorn	Average
1. No tillage; weeds killed with glyphosate	19.26	20.37	22.31	**20.65**
2. Chisel plow; glyphosate	19.93	17.94	23.13	**20.33**
3. Subsoiler; glyphosate	20.18	16.91	21.44	**19.51**
4. Subsoiler + chisel; glyphosate	21.96	21.59	26.00	**23.18**
5. Cassava harvester; glyphosate	21.28	18.04	28.84	**22.72**
6. 3-disk plow	20.08	-	-	**-**
7. Subsoiler + 3-disk plow	24.60	-	-	**-**
8. 3-disk plow + 7-disk harrow	19.65	16.79	30.75	**22.40**
9. 3-disk plow +7-disk harrow + contour ridging	22.47	17.81	28.53	**22.94**
10. 3-disk plow + 7-disk harrow + up-down ridging	22.92	-	-	-
11. Subsoiler + 3-disk plow; glyphosate	-	-	28.14	-
12. Subsoiler + 7-disk harrow; glyphosate	-	-	-	-
13. Subsoiler + 7-disk harrow	-	-	23.31	-
14. Subsoiler + 3-disk plow + 7-disk harrow	-	-	30.09	-
Average	21.23	18.49	26.25	

1) Average root yields of four cassava varieties planted for 3 or 4 consecutive years.
Source: *Aye, 2012.*

Table 7. Effect of several methods of land preparation on the yield and dry matter content of fresh cassava roots and on the physical characteristics of the soil in Sri Racha, Thailand, in 1991/92.

Land preparation method	Root yield (t/ha)	DM content (%)	Bulk density (g/cm^3)	Penetrometer resistance (kg/cm^2)	Soil porosity (%)	Infiltration rate (cm/h)	K_{sat} (m/day)
No tillage	30.39 a	28.2 a	1.60 b	3.8 c	40 a	12	1.61 a
3-disk plow	27.38 a	25.1 ab	1.62 b	8.0 bc	39 a	30	1.18 ab
3-disk plow + 7-disk harrow	25.93 a	26.0 ab	1.63 b	10.3 b	38 a	20	1.62 a
3- + 7-disk, soil compaction	10.30 b	22.8 b	1.82 a	36.7 a	31 b	0	0.20 b
3- + 7-disk, ridging	30.36 a	28.9 a	1.50 b	3.8 c	38 a	15	1.25 ab
Subsoiling	31.46 a	28.2 a	1.64 b	6.8 bc	38 a	20	1.28 ab

Note: Data in each column followed by the same letter are not significantly different
Source: *Silpamaneephan, 1994.*

Table 8. Effect of stake position, stake length, and planting depth on cassava yield, with cassava planted in both the rainy and dry season at Rayong Field Crops Research Center, Thailand. Data are the average of 3 years, planted in 1987, 1988, and 1989.

Treatments	Rainy season (May -August) Plants survived (000/ha)	Root yield (t/ha)	Starch content (%)	Early dry season (November) Plants survived (000/ha)	Root yield (t/ha)	Starch content (%)
Method of planting						
-Ridge	14.57 a	14.98 a	16.64 a	10.69 b	14.69 a	18.63 a
-No ridge	14.43 a	13.47 a	16.66 a	12.09 a	14.96 a	18.65 a
F-test	NS[3]	NS	NS	**	NS	NS
Stake position						
-Vertical	14.87 a	16.04 a	17.03 a	13.04 a	17.74 a	19.04 a
-Inclined	14.89 a	15.46 a	17.14 a	11.99 b	16.40 b	18.68 a
-Horizontal	13.74 b	11.08 b	15.85 b	9.31 c	10.32 c	18.17 b
F-test	**[1]	**	**	**	**	**
Stake length (cm)						
-20	14.55 a	14.52 a	16.67 a	10.58 b	14.53 a	18.51 a
-25	14.41 a	13.54 b	16.69 a	13.02 a	15.41 a	18.87 a
F-test	NS	*[2]	NS	**	NS	NS
Planting depth (cm)						
-5–10	14.43 a	13.90 a	16.61 a	9.74 b	13.14 b	18.21 b
-15	14.56 a	14.43 a	16.73 a	12.71 a	16.17 a	18.97 a
F-test	NS	NS	NS	**	**	**

No interaction between methods and treatments in all characters.
1) and 2): Mean within a column separated by DMRT at 0.01% and 0.05%, respectively.
3) NS = not significantly different.
Source: *Tongglum et al., 1992.*

4. Selection and Preparation of Planting Material

Cassava is normally planted using stem cuttings, also called "stakes". The stems are normally cut when the mother plants are 8−15 months old.

Since cassava is vegetatively propagated using stem cuttings, there is always the danger of disseminating to the next generation diseases and pests that were present in the mother plants. For that reason, it is prohibited to take stems or stakes from one country to another, and it is unwise to move planting material over long distances even within the same country because of the possibility of spreading diseases and pests from one region to another. Even within the same region, precautions must be taken to cut stems to be used as planting material only from vigorous and healthy-looking plants. A further precaution is to immerse the stakes in a solution containing insecticides and fungicides, as indicated in **Table 9**, just before planting. The stakes can be put in a gunny bag or nylon netting bag and the bag submerged for 10 minutes in the solution. The bag is then lifted up to let the excess solution drain back into the tank before the stakes are spread out on the ground to dry before planting.

Table 9. Solutions used to treat cassava stakes for the control of pests and diseases.

Problem	Commercial product or method	Dosis
Soil pathogens	Derosal + Orthocide	6 cc + 6 g/L water
Root rots (*Phytophthora* spp.)	Ridomil + Orthocide	3 g/L + 3 g/L water
CBB (*Xanthomonas campestris*)	Coccide	3 g/L water
Dry rot (*Diploidia manihotis*)	Benlate + Orthocide	3 g/L + 3 g/L water
Superelongation (*Sphaceloma manihoticola*)	Difolatan	6 g/L water
Insects and spider mites	Thiamethoxam	0.5 g/L water
CBB Root rot Insects and spider mites	Thermotherapy: soak stakes in 49°C water for 49 min	
Pathogens of the vascular system (*Fusarium, Diploidia manihotis, Phythopthora* spp.)	Soak stakes in a suspension of *Trichoderma* (1 kg/80 L) for 10 min	

Source: *López, 2002.*

To ensure high yield, the stems should be cut only from vigorously growing mother plants that had been well supplied with all essential nutrients. The nutrients, sugar, and starch stored in the stakes are the reserves that allow the sprouting of the buds. Without adequate reserves, the stakes may not sprout, or sprouting and early growth are delayed, resulting in lower yield. If the mother plants had not been adequately fertilized, they will not only produce less planting material for the next planting, but the plants produced from those stakes will also have significantly lower yield than those produced from well-fertilized mother plants. **Table 10** shows that cassava plants grown in a soil with low N, P, and K produced stakes that were also low in these nutrients, as well as starch, reducing sugars, and total sugars. Plants grown from stakes with a lower nutrient content had a lower rate of sprouting and also produced fewer stems and had lower root yield **(Table 11)**. A lack of either N or P application to mother plants did not significantly affect the rate of sprouting, whereas a lack of K application reduced it significantly (López and El-Sharkawy, 1995; López, 2002).

Table 10. Effect of N, P, and K fertilization of mother plants on the dry weight of stakes and their contents of N, P, and K, as well as starch, reducing sugars, and total sugars.

Fertilization of mother plants (kg/ha)[1]			DW of stake	Nutrient content (mg/stake)			Starch/sugar content (mg/stake)		
N	P	K	(g)	N	P	K	Starch	Reducing sugars	Total sugars
0	0	0	11.0	70	10	19	2.62	0.33	0.39
0	100	100	12.5	76	21	54	3.38	0.20	0.38
100	0	100	15.5	146	14	87	4.68	0.55	0.58
100	100	0	14.0	117	21	28	3.17	0.54	0.61
100	100	100	16.5	139	25	72	4.29	0.50	0.68

[1] Rates are in kg/ha of N, P, and K, not N, P_2O_5, and K_2O.

Source: *López and El-Sharkawy, 1995.*

Table 11. Effect of N, P, and K fertilization of mother plants of cassava used for producing planting material on the root and stem yield of the subsequent crop.

Fertilization of mother plants (kg/ha)[1]			Sprouting	Fresh root and stem yield (t/ha)			
				Unfertilized		Fertilized[2]	
N	P	K	(%)	Roots	Stems	Roots	Stems
0	0	0	85 b	13.5	2.02	19.1	4.49
0	100	100	97 a	17.5	2.63	24.7	3.64
100	0	100	98 a	14.9	2.98	23.5	4.38
100	100	0	77 b	15.8	2.25	24.7	4.53
100	100	100	97 a	24.2	3.10	30.2	6.22

[1] Rates are in kg/ha of N, P, and K, not N, P_2O_5, and K_2O.

[2] Application at planting of 50 kg N, 43 kg P, and 83 kg K/ha.

Note: Data in each column followed by the same letter are not significantly different

Source: *López and El-Sharkawy, 1995.*

Even within a uniformly fertilized field, some plants grow better and produce more roots than others. Farmers can increase their next cassava yield by pulling up the mother plants first, and selecting only those plants with high root yield for cutting stems to be used as planting material. This simple practice will markedly increase yield, especially for traditional varieties that may be susceptible to many pests and diseases **(Table 12)**.

Table 12. Effect of the root yield of mother plants used as planting material on the root yield of the subsequent crop.

Variety	Year	Root yield of subsequent crop (t/ha) Root yield of mother plants Above average	Below average	% increase
CMC 40[1]	1985	9.6 a[2]	5.8 b	66
	1986	16.6 a	9.2 b	80
MPan 19	1985	9.0 a	7.5 a	21
	1986	20.3 a	16.1 b	26
MVen 77	1985	13.5 a	12.2 a	11
	1986	25.1 a	22.1 b	14

[1] Traditional variety susceptible to local production constraints.

[2] Data within each row followed by the same letter are statistically not significantly different.

Source: *CIAT, 1988b.*

Stakes derived from the lower and middle part of the stem had significantly higher germination rates than those derived from the upper part of the stem (George et al., 2001), and 15−20 cm stakes had higher germination than shorter stakes of 5−10 cm length (Chankam, 1994). Stake germination is also affected by the method and length of stem storage after cutting. **Table 13** shows that germination and the survival of young plants decreased with increasing length of storage, but decreased faster if stems were stored in the sun in the open field, or were covered only with leaves. Varieties differ markedly in the storability of their stems, but, for most varieties, stems should be stored upright in the shade, and for no longer than 1½−2 months to obtain at least 80% germination; other varieties lose their germination capacity already after 3−4 weeks of storage.

Table 13. Plant survival rate (%) from stakes cut from stems stored under different conditions and for various lengths of time at Rayong Field Crops Research Center, Thailand. Data are the average of stems stored in 1976, 1977, and 1978.

Storage time (days)	Storage method		
	Under shade	In the sun	Covered with leaves
0	95.6	95.3	96.5
15	93.5	93.4	91.6
30	83.4	84.3	87.9
45	80.0	55.9	58.4
60	57.5	48.9	50.0
75	49.2	31.9	43.1
90	44.9	28.9	35.9
105	43.2	21.0	22.1

***Source:** Sinthuprama and Tiraporn, 1986.*

5. Planting Method

If the soil is loose and friable, stakes can be planted vertically or slanted by pushing the lower part of the stake 5−10 cm into the soil. Stakes can also be planted horizontally at 5−7 cm depth by digging individual holes or by making a long shallow furrow, laying the stakes down and covering with soil. The latter method is common in heavy clay soils or with zero- or minimum-tillage methods of land preparation. When the soil is well prepared and friable, planting vertically or inclined is faster than planting horizontally, but care should be taken that the eyes or buds on the stakes face upward; with horizontal planting, this is of no concern.

In sandy clay-loam soils in Rayong, Thailand, planting vertically or inclined produced significantly higher root yield than planting horizontally **(Table 8)**; this was especially the case when stakes were planted in the early dry season (November), when horizontal planting resulted in a slower and significantly lower rate of germination (Tongglum et al., 2001). Research conducted in two locations in China indicates that vertical planting resulted in the highest germination percentage, but that inclined planting produced the highest yield **(Table 14)** (Zhang Weite et al., 1998). Similar results were also obtained in Cambodia, where inclined planting produced the highest average root yield in 12 trials conducted in four different provinces **(Table 15)** (Sopheap et al., 2010).

Table 14. Effect of stake planting position and ridging on cassava yield and germination at one month after planting at GSCRI, Nanning, Guangxi, and at CATAS, Danzhou, Hainan, China. Data are the average for SC201 and SC205 at GSCRI and for SC205 and SC124 at CATAS.

		GSCRI (1990−1992)		CATAS (1994)
Planting Position	Ridging	Germination [1] (%)	Root yield [2] (t/ha)	Root yield (t/ha)
Horizontal	-Ridging	61.5	11.7	20.0
	-No ridging	67.4	10.9	18.6
Inclined	-Ridging	66.4	13.0	25.3
	-No ridging	78.1	11.5	16.9
Vertical	-Ridging	82.8	11.1	19.4
	-No ridging	85.8	11.2	18.5

1) Average of 1991 and 1992 (no data obtained in 1990).

2) Average of 1990 and 1992 (no harvest in 1991 due to drought).

***Source:** Zhang Weite et al., 1998.*

Table 15. Average results of 12 on-farm trials on stake planting position of cassava cv. KU 50 conducted in four provinces of Cambodia from 2005/06 to 2007/08.

Stake planting position	Kamp. Speu (2 sites)	Kamp. Cham (5 sites)	Battambang (4 sites)	Preah Vihear (1 site)	Average
Vertical	40.85	29.25	28.64	23.75	**30.52**
Horizontal	39.0	26.92	28.86	19.58	**28.97**
Inclined + one stake per hill	43.4	30.18	31.46	32.50	**33.01**
Inclined + two stakes per hill	36.6	23.80	25.10	12.08	**25.38**

***Source:** Adapted from Sopheap et al., 2010.*

6. Plant Population and Spacing

For maximum root production, cassava is usually planted at a population of 10,000 plants/ha in fertile soil and at about 16,000 plants/ha in infertile soil where plant growth is less vigorous. At 10,000 plants/ha, stakes are generally planted at 1.0×1.0 m for monoculture cassava or at wider row spacing (up to 2 m between rows) and closer in-the-row spacing (down to 0.5 m) for intercropping. The wider row spacing allows one to three rows of the intercrop to be planted between cassava rows. At a higher plant population of 16,000 plants/ha, cassava is generally planted in a square pattern of 0.8×0.8 m, but this can also vary to 1.2×0.52 m to allow for easy access by machinery or for intercropping. In general, the planting pattern can be varied somewhat without affecting yield as long as the plant population is maintained near the optimum, depending on soil fertility and the branching habit of the variety (**Figure 3)**

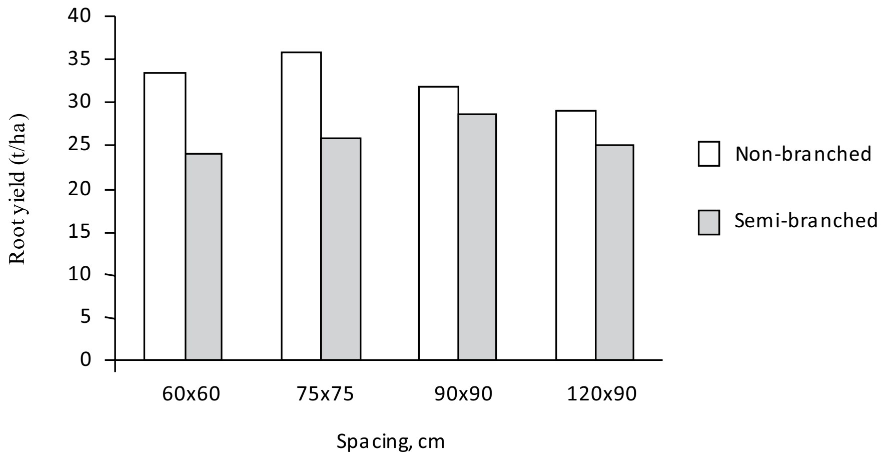

Figure 3. *Effect of plant spacing on the root yield of nonbranching and semibranched cassava varieties at CTCRI, Thirivananthapuram, Kerala, India, in 1973.*

Source: *Mandal et al., 1973; George et al., 2001.*

If some stakes do not germinate, the plant stand is reduced. As long as the plant stand is above 70−80% of maximum, yield may not be significantly affected as plants surrounding the open space will grow more vigorously and have higher yield, thus compensating for the lower plant stand. If possible, missing plants should be replaced by new stakes or transplants within 2−3 weeks from the original date of planting.

7. Weeding

Cassava is a poor competitor and may suffer serious yield losses if the crop is not adequately weeded during the early stages of plant growth. In general, the crop should be weeded two to three times during the first three months or until canopy closure **(Table 16)**.

Table 16. Effect of hand weeding at different times and frequencies on the fresh root yield of cassava cv. CMC 39 at 280 days after planting at CIAT, Cali, Colombia.

No. of hand weedings	Frequency of hand weedings (days)	Fresh cassava root yield (t/ha)	% of maximum yield[1]
4 +[2]	15, 30, 60, 120, UH[3]	18.0	86
3 +	30, 60, 120, UH	16.0	76
2+	60, 120, UH	11.0	52
1+	120, UH	7.0	33
4	15, 30, 60, 120	19.5	92
3	15, 30, 60	12.9	61
2	15, 30	13.3	63
1	15	5.8	28
2	30, 60	16.3	77
2	15, 45	15.4	73
0	Chemical weed control[4]	21.1	100
0	Weedy check	1.4	7

[1] Percentage of the yield of cassava weeded with herbicides.
[2] The "+" indicates additional weedings.
[3] UH = until harvest, as needed.
[4] Alachlor + fluometuron were applied in preemergence and directed applications with a shielded nozzle were made with paraquat as needed in postemergence.

Source: *Doll and Piedrahita, 1978.*

Weeding is most often done by hoe, by animal-drawn cultivator, or by hand tractor, but can also be done by a tractor-mounted cultivator or with herbicides. Weed competition can also be reduced by adequate and early application of fertilizer to speed up canopy closure, by intercropping, and by planting in the early dry season when weed growth is less vigorous. When herbicides are used, it is recommended (**Tables 17**and **18**) to apply metolachlor at 1.5 kg a.i./ha immediately after planting, followed by one to two hand weedings or spot application of glyphosate, using a shield over the applicator to prevent damage to the cassava plants (Tongglum et al., 2001). Alternatively, Nguyen Huu Hy et al., (2001) showed that application of 2.4 L/ha of Dual as a preemergence herbicide in Vietnam increased cassava yield and net income compared with hand weeding.

Table 17. Herbicides used for the control of weeds in cassava under monocropping.

Technical name	Commercial name[1)]	Selectivity for cassava	Time of application [2)]	Dosage of CP/ha [3)]	Type of weeds controlled
Diuron	Karmex	Intermediate	Pre	2.0–3.0 kg	Broadleaved
Alachlor	Lazo	High	Pre	3.0–4.0 L	Grasses
Fluometuron	Cotoran	Intermediate	Pre	4.0–5.0 L	Broadleaved
Oxifluorfen	Goal	Intermediate	Pre	2.0–4.0 L	Broadleaved/grasses
Metribuzin	Sencor	Intermediate	Pre	1.0–1.5 L	Grasses
Linuron	Afalon	Intermediate	Pre	2.0–3.0 kg	Broadleaved/grasses
Trifluralina	Treflan	High	Ibp	2.5–3.5 L	Broadleaved/grasses
Metolachlor	Dual	High	Pre	3.0–4.0 L	Grasses
	Karmex + Lazo	Intermediate	Pre	1.0–1.5 + 1.5–2.0	Broadleaved/grasses
	Cotoran + Lazo	Intermediate	Pre	1.0–2.5 + 1.5–2.0	Broadleaved/grasses
	Goal + Lazo	Intermediate	Pre	1.0–2.0 + 1.5–2.0	Broadleaved/grasses
	Afalon + Lazo	Intermediate	Pre	1.0–1.5 + 1.5–2.0	Broadleaved/grasses
	Karmex + Dual	Intermediate	Pre	1.0–1.5 + 1.5–2.0	Broadleaved/grasses
	Cotoran + Dual	Intermediate	Pre	1.0–2.5 + 1.5–2.0	Broadleaved/grasses
	Goal + Dual	Intermediate	Pre	1.0–2.0 + 1.5–2.0	Broadleaved/grasses
	Afalon + Dual	Intermediate	Pre	1.0–1.5 + 1.5–2.0	Broadleaved/grasses
Glyphosate	Roundup	Not selective	Post	2.0–3.0 L	Broadleaved/grasses
Glufosinate	Basta	Not selective	Post	1.0–3.0 L	Broadleaved/grasses
Paraquat	Gramoxone	Not selective	Post	2.0–3.0 L	Broadleaved/grasses
Fluazifop	Fusilade	High	Post	1.0–3.0 L	Grasses
Sethxydim	Poast	High	Post	0.20–0.25 L	Grasses

1) Commercial names may vary between continents or countries.
2) Ibp = incorporated before planting; Pre = preemergence; Post = postemergence.
3) CP = commercial product; lower dosage for use in light-textured soils and higher dosage in heavy-textured soils.
Source: *Calle, 2002.*

Table 18. Preemergence herbicides used for crops grown in association with cassava.

Product or mixture	Dosage (kg a.i./ha)[1)]	Time of application	Selective for crops grown in association with cassava
Linuron + fluorodifen	0.25–0.50 + 1.50–2.10	Postplanting	Common bean, cowpea, and mungbean
Linuron + metolachlor	0.25–0.50 + 1.00–1.50	Postplanting	Common bean, cowpea, mungbean, peanut, and maize
Oxadiazon + alachlor	0.25–0.50 + 1.44	1–2 weeks before or after planting	Cowpea, mungbean, peanut
Oxadiazon + metolachlor	0.50–1.0 + 1.0	Postplanting	Common bean, cowpea, mungbean, peanut, and maize
Oxifluorfen	0.25–0.50	1–2 weeks before or after planting	Peanut

1) The doses indicated are used as follows: low doses on light-textured soils and high doses on heavy-textured soils. Quantities individually indicated for each product are combined to obtain the tank mix; a.i. = active ingredient.
Source: *Adapted from López and Leihner, 1980.*

8. Application of Plastic Mulch

In the northern part of Guangxi Province of China, the winters are quite cold, with temperatures sometimes below zero °C. Cassava is generally planted in late February or early March when the soil has warmed up enough for stake germination. Recently, farmers have started to plant cassava along the sides of about 1-m-wide plastic film covering the soil, alternated with 1-m-wide strips without film. Stakes are inserted at an angle along the two sides of the plastic film with the bottom of the stake just under the plastic. The plastic mulch serves to warm the soil during the early spring, so cassava can be planted 2−3 weeks earlier than without the plastic. This will increase cassava yield enough to pay for the extra cost of the plastic and the work of mulch application. In 2000, the cost of the plastic film was about 450 yuan/ha (about US$60). In addition, the plastic mulch helps to reduce weed competition, and, when placed across the slope, the film will also reduce erosion. Moreover, other crops such as watermelon and maize can be intercropped with cassava,thus producing higher yield and extra income (**Table 19**).

Table 19. Effect of using plastic film to cover the soil before planting cassava intercropped with maize on the yield of maize and cassava in Wuming County, Guangxi Province, China, in 1999.

Treatment	Yield (t/ha)	
	Cassava	Maize
Cassava intercropped with maize and with plastic film covering the soil	54.3	5.3
Cassava monoculture without plastic film	46.5	

Source: *Science and Technology Bureau of Wuming County, Guangxi, China.*

9. Harvest

Cassava can be harvested any time, but the roots are usually harvested between 6 and 18 months. Some early-maturing varieties can be harvested at 6 MAP for direct human consumption, but most industrial varieties are harvested between 8 and 12 MAP. **Table 20** indicates that root yield nearly tripled between 8 and 18 months and that starch content increased substantially between 8 and 10 months. Harvesting cassava at 18 months provides an income only every 1½ years, but at a considerable savings in production costs. Harvesting early, at 6−8 MAP, however, allows for double cropping cassava with a subsequent short-duration crop of rice, sweet corn, or mungbean.

Cassava is usually harvested by cutting off the tops at 20−30 cm above the ground and using the remaining stump to pull up the roots. If the soil is not too hard, the roots can be lifted out of the ground with a pointed metal bar inserted into the soil below the root clump; or by using a special harvesting tool consisting of a metal plate with a large V cut out on one edge of the plate. The metal plate is welded onto a 2 inch diameter piece of pipe into which a 2 inch wooden dowel of about 1.2 to 1.5 m length can be inserted. The roughly edged metal V is pulled around the lower stem to grab the stump just above the ground after which the wooden stick is used as a lever to pull the whole root clump up and out of the ground. Roots can also be dug out with a pick, hoe, or shovel. In areas where labor is expensive or the soil is too hard during the dry season, farmers in Thailand now use a tractor-mounted cassava-harvesting tool that loosens the soil and lifts up the roots for easy gathering by hand. In Malaysia, a more sophisticated cassava-harvesting machine will dig up the roots and deposit them in an attached wagon.

After pulling up the root clumps, the individual roots are cut off from the stumps and packed in baskets or sacks for transport to the house, drying floor, or starch factory. To prevent spoiling, fresh roots should be processed within 2−3 days after the harvest.

Table 20. Average fresh root yield of variety Rayong 1 as affected by age at harvest when planted at Rayong Field Crops Research Center, Thailand. Data are the average of experiments conducted in 1975/77, 1976/78 and 1977/79.

Age at harvest (months)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Starch yield (t/ha)	Starch content (%)
8	16.19 f[1)]	6.44 f	2.31 f	14.3
10	23.06 e	8.31 e	4.81 e	20.9
12	31.31 d	10.69 d	5.94 d	19.0
14	37.56 c	13.06 c	7.38 c	19.6
16	41.50 b	15.00 b	8.69 b	20.9
18	45.25 a	16.44 a	9.19 a	20.3

1) Mean separation within each column: DMRT, 0.01.
Source: *Tongglum et al., 2001.*

Conclusions

Cassava is an easy crop to grow, and in Southeast Asia it did not suffer from any serious pest or disease problems until very recently. It can grow in poor soils and in drought-prone areas with little risk of complete crop failure. However, to obtain high and sustainable yield, the crop should be well managed and it should be planted at an optimum time of the year, weeded two to three times during the first 3−4 months, and fertilized with chemical fertilizer and/or manure to supply adequate amounts of all nutrients required by the crop, particularly K and N. Cassava will remain a highly competitive industrial crop only if farmers obtain high yield at low production costs by using high-yielding varieties and good production practices.

CHAPTER 13

WHAT TO DO TO PREVENT SERIOUS PEST AND DISEASE PROBLEMS

Until very recently, pests and diseases were not a serious problem in Asia, except in India, where cassava is often affected by Indian cassava mosaic disease, which is transmitted by the whitefly, *Bemisia tabaci.* More recently, another related virus disease, Sri Lankan cassava mosaic disease, has also been found in India, and it can cause even more damage to susceptible varieties. Fortunately, these two virus diseases have not been reported in Southeast and East Asia. There have been occasional reports of the presence of *B. tabaci* on cassava in the region, but these have yet to be confirmed. Other diseases and pests present in Southeast and East Asia were usually not a serious threat, and farmers paid little attention to these problems (Bellotti et al., 2012).

However, this changed in 2008, when an exotic mealybug species appeared in Thailand. This species was called the "pink mealybug" and was later identified as *Phenacoccus manihoti*. This new pest rapidly spread throughout Thailand and into Lao PDR, Cambodia, and Vietnam, where it devastated cassava production. Around the same time in Vietnam, there was a serious outbreak of a previously unknown disease, which caused excessive proliferation of buds and shoots as well as short internodes. This new disease, called "witches' broom disease," is thought to be caused by phytoplasmas and can be transmitted mainly through the use of infected planting material. Also, some pests that previously did little damage, such as the spiraling whitefly (*Aleurodicus dispersus*) and red spider mites, seem to have become more serious, probably because of more widespread and intensive cassava cultivation in the region. The presence in many areas of recently planted cassava throughout the year provides these pests with a continuous food supply, which has increased their populations. Thus, it seems that pests and diseases are becoming a serious problem in cassava fields in Asia, as they already are in Latin America and Africa, and farmers should learn what to do—and what not to do—to prevent pests and diseases from seriously affecting their cassava yield.

Since cassava has its origin in Latin America, most pests and diseases have co-evolved with the crop on that continent. Until recently, none of the major pests of Latin America had become established in Asia. However, currently, pest species originally from Latin America are causing the greatest crop losses. These pests were accidentally introduced into Asia, most likely through the introduction of infected vegetative planting material from either Latin America or Africa (some of these pests had already found their way into Africa, probably also through the illegal movement of planting material). The accidental introduction of the latest pest, the mealybug *Phenacoccus manihoti,* has caused multimillion-dollar losses to the cassava industry in Asia. It is therefore extremely dangerous, and absolutely forbidden, to move vegetative planting material between continents, and even between countries, without the necessary legal documents, including a phytosanitary certificate from the country of origin and an import permit from the receiving country.

The following pests and diseases now commonly affect cassava in Asia:

PESTS

1. Whiteflies

These are one of the world's most damaging agricultural pests, both as direct sap feeders and as vectors of many virus diseases. They are probably also one of the worst pests for cassava. Many species of whiteflies attack cassava, but the most common one in Southeast Asia is the spiraling whitefly, *Aleurodicus dispersus*, while in India both *A. dispersus* and *Bemisia tabaci* are found. There is mounting concern that *A. dispersus* is associated with cassava brown streak virus, a very serious virus disease in Africa. On the other hand, *B. tabaci* is the vector for Indian and Sri Lankan cassava mosaic virus. Both whitefly species have a wide host range, including many vegetables, ornamental and fruit crops, as well as cassava. The immature and adult stages bring about direct feeding damage that can cause premature leaf fall. The feeding damage is accompanied by a heavy production of honeydew and (in the case of *A. dispersus*) a white, waxy material produced by the insect that is deposited in concentric circles on the plant. Sooty mold develops on the honeydew and decreases photosynthesis; it also attracts ants. The high populations of spiraling whiteflies observed on cassava in Thailand may be causing root yield losses.

Control measures

Several cassava varieties in Colombia were found to have moderate to high resistance to the whitefly species dominant in that country, *Aleurotrachelus socialis,* but these have not yet been tested for resistance to the spiraling whitefly. Work from Nigeria in the early 2000s showed certain cassava varieties with lower susceptibility to *Bemisia tabaci*, but true resistance to this pest remains to be found.

Little is known about the effectiveness of biological control of the spiraling whitefly, either by resident natural enemies in Southeast Asia or in its region of origin, that is, in the Caribbean and Central America. Several species of parasitoids are reported to parasitize *A. dispersus* in Benin, Africa, and some of these, in particular *Euderomphale haitiensis* and *E. guadeloupae*, were also reported to be present in Malaysia and the Philippines, but much remains to be investigated on their effectiveness in controlling the spiraling whitefly. Predatory ladybeetles, such as *Nephaspis bicolor* or *N. amnicola,* can also play a role in biological control of this pest.

A cultural control measure that is effective in the control of *A. socialis* is to intercrop cassava with cowpea. This markedly decreased the yield losses due to this whitefly species in Colombia. Another control measure is to establish a "cassava-free period" in which no cassava is grown in an area for some time. This is to break the whitefly development cycle so that a rapid population buildup cannot occur. Please note that this measure needs to be adopted over a large enough area, and in concert with other growers, to be effective. Also, the presence of large expanses of other whitefly host plants in the area should be avoided.

A chemical alternative that is commonly adopted by local cassava producers is to immerse stakes for 7−10 minutes in a solution of thiamethoxam (Actara©) at 1 g/L water before planting. You can also spray a high dose of 2 L/ha of thiamethoxam or 1.5 L/ha of imidacloprid as a drench on young plants in hot spots, applying the pesticides to the undersurface of leaves. The crop should be closely monitored every five days after the first leaves appear and the whitefly population evaluated. Pesticide applications should be made only when the whitefly populations are starting to build up, as high whitefly populations are very difficult to control. No more than two pesticide applications should be made during the cassava crop cycle and no applications should be made in cassava crops of more than six months of age. Cost-benefit analysis indicates that chemical pesticide application for control of whiteflies in cassava is generally uneconomical. Also, the broad-scale use of neonicotinoid insecticides, such as imidacloprid and thiamethoxam, is increasingly criticized in Europe and North America, given their important effects on beneficial insects such as honeybees and natural enemies. In conclusion, insecticides should clearly constitute a last resort for the management of cassava whiteflies.

These control measures can be summarized as follows:

- Plant whitefly-resistant or -tolerant varieties whenever available
- Intercrop cassava with cowpea
- Establish a "cassava-free period," in which no cassava is present in the area, in order to break the whitefly development cycle
- Treat stakes in a solution of 1 g/L of thiamethoxam for 10 minutes before planting. This measure should be adopted with caution as thiamethoxam can have unknown (negative) side effects on myriad beneficial insects in the cassava crop. Hence, its use is recommended only in areas that have recurrent outbreaks of whitefly
- When whitefly populations are starting to build up, treat infestation "hot spots" with a drench of 2 L/ha of thiamethoxam or 1.5 L/ha of imidacloprid to the undersurface of leaves. Do not mix these two insecticides and do not spray more than twice during the cassava growth cycle.

2. Cassava Mealybugs

About 15 species of mealybugs are reported to feed on cassava, but only two species are of economic importance in the Americas: *Phenacoccus herreni* and *P. manihotis*. Several other species have been found on cassava in Asia, the most common one being the striped mealybug, *Ferrisia virgata*. Although *F. virgata* populations have historically been low, recent observations indicate that its populations have increased dramatically and that this species may now be causing yield losses. Other species recently collected from Southeast Asian cassava crops include *Pseudococcus jackbeardsleyi, Pseudococcus elisae (possibly* synonymous with *P. jackbeardsleyi*), *Paracoccus marginatus, Phenacoccus madeirensis, Phenacoccus solenopsis,* and *Phenacoccus manihoti.* All of these species are exotic to Southeast Asia, and only the following species have been reported as pests in cassava: *P. marginatus, P. madeirensis,* and *P. manihoti.* As of now, *P. manihoti,* in Thailand known as the pink mealybug, was found in very high populations and doing the greatest damage to cassava, with yield losses estimated as high as 25%. This species is also causing considerable damage in Lao PDR, southern Vietnam, and Cambodia, and has recently made its arrival in Indonesia. Another species, *Maconellicoccus hirsutus*, is reported to be feeding on cassava in the Philippines. In 2010, *P. herreni* was suspected to be present in India, but these claims remain to be verified and confirmed.

Both *P. herreni* and *P. manihoti* cause similar damage: adult and nymphal feeding causes leaf yellowing, curling, and cabbage-like malformation of the apical growing point. High populations lead to leaf necrosis, defoliation, stem distortion, and shoot death. Yield losses in northeast Brazil due to *P. herreni* surpassed 80% and maximum losses in parts of Africa due to *P. manihoti* reached 82%. These yield losses are due to two types of injury: direct effects caused by their sucking habits and indirect effects produced by the buildup of sooty mold on sugar-rich mealybug excrements. Formation of this fungus considerably interferes with leaf photosynthesis.

Ferrisia virgata, the striped mealybug, normally feeds on the undersurface of leaves and in clusters along the stems and branches. At high populations, considerable sooty mold can be observed. When high populations occur on young plants, growth is slowed and plants remain stunted. Stems will have shortened internodes and shoots and leaves are deformed, and wilting eventually leads to leaf fall and shoot desiccation. Populations of this species, as well as most other mealybugs, are particularly high during the dry season.

Mealybugs are oval, flattened, soft-bodied insects, distinctly segmented but without a clear definition between the head, thorax, and abdomen. They are covered with a white powdery or mealy wax, and feed by inserting their slender mouth parts into plant tissues and sucking cell contents. Mealybugs of the species *P. manihoti* reproduce without the presence of males, while other species possess two morphologically distinct sexes. The females deposit ovisacs containing hundreds of eggs on the underside of leaves and around apical and lateral buds. Immature mealybugs can be found around the lateral buds on cassava stems and subsequently on stem cuttings used as planting material. If infested stems or stem cuttings are transported from one region to another, this can cause the spread of the mealybug to regions where it was not found before.

Control measures

Mealybugs are most effectively controlled by the use of (exotic) natural enemies, especially minute parasitic wasps. Chemical control is very difficult and expensive. To effectively prevent mealybug populations from reaching economic damage levels, most control measures need to be taken when pest populations are still low. This requires constant monitoring of pest populations in the field. The presence of effective natural enemies, especially parasitoids, can prevent or slow down the buildup of mealybug populations. The most effective natural enemy of *P. manihoti* was found to be a parasitoid, *Anagyrus lopezi,* a tiny wasp, which was originally collected in Paraguay (Latin America). This species was introduced into Africa in the 1970s, and recently into Asia, to control outbreaks of *P. manihoti* on both continents. After the introduction of the *A. lopezi* wasp into Thailand in 2009, it was found to be very effective in controlling the mealybug while not causing any harm to farmers or other organisms in the broader farming environment. The wasp was mass-reared and millions were then released in all the cassava-producing areas of the country. This markedly decreased the population of *P. manihoti* (**Figure 1**), and helped restore local cassava production and yield.

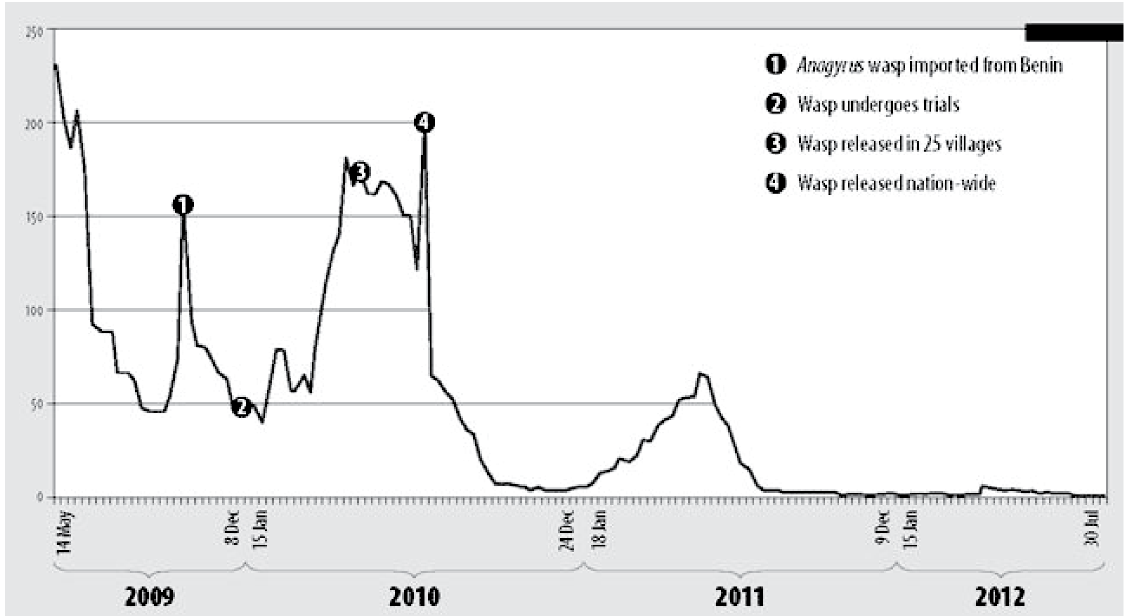

Figure 1. *Area infested by the pink mealybug, Phenacoccus manihoti, in Thailand from 2009 to 2012 (000 ha).*
Source: *Rojanaridpiched et al., 2012.*

The most effective control measures can be summarized as follows:

- Constant monitoring of plantations at least every 2−4 weeks, especially during the dry season when mealybugs tend to reach high population levels
- Detect focal points of infestation (so-called "hot spots")
- In the focal points, remove the infested parts of the plants (apical buds) and burn these
- Apply a systemic pesticide in the area of infestation and in surrounding areas
- Through diversification of the farming environment (e.g. conservation of flower-rich field borders), create suitable conditions for mealybug natural enemies, mainly the *Anagyrus lopezi* wasp
- Avoid movement of planting material from one region to another
- Avoid the spraying of chemical insecticides in order to conserve the natural enemy population
- Pay proper attention to crop sanitation by removing (and burning) residues of the previous cassava crop in and near new fields
- For establishment of a new crop, carefully select cassava stems free of mealybugs as planting material
- Treat the stem cuttings in a solution of thiamethoxam (Actara©) for 7−10 minutes before planting. This measure should be adopted with caution as thiamethoxam can have unknown (negative) side effects on myriad beneficial insects, including *Anagyrus lopezi*, in the cassava crop. Hence, its use is recommended only in areas that have recurrent outbreaks of this pest

- In Brazil and Madagascar, liquid extract from cassava roots upon processing (so-called cassava wastewater or "manipueira") is used as an effective and low-cost alternative to treat cassava stakes prior to planting. Stake dips of 60 minutes are recommend, as they do not interfere with the viability of the planting material.

3. Cassava Mites

Although more than 40 species of mites are reported to feed on cassava, the most important ones in Asia are the red spider mites: *Tetranychus urticae, Tetranychys kanzawai* (Philippines) and *Tetranychus sp*. (Indonesia), as well as *Eutetranychus orientalis, Tetranychus neocalidonicus*, and *Olygonychus biharensis* (India). Overall, all these mites are dry-season pests. Mites of the genus *Tetranychus* first attack mature leaves at the lower part of the plant and then move to the upper leaves. The first symptoms generally occur at the base of the leaf and along the midrib. Red spider mites feed on the underside of leaves, often causing considerable webbing. Initial spotting becomes reddish or rust-colored as the infestation increases; defoliation occurs from bottom to top leaves, and, if the dry season is prolonged, may cause plant death. In China, the exotic *Mononychellus mcgregori* has recently been reported. This same species was also reported in Cambodia and Vietnam in 2009 (Bellotti et al., 2012).

Control measures

For most cassava farmers, pesticide applications are not a feasible or economic option for controlling mites on a long-cycle crop such as cassava. Moreover, even low doses of pesticides can severely disrupt the resident natural enemy community, and thereby considerably worsen mite problems. Mites can be most effectively controlled through the use of resistant or tolerant cassava varieties or by (natural) biological control.

Most studies on mite resistance of cassava varieties have been carried out with the cassava green mite, *Mononychellus tanajoa*, which is the dominant mite species in Latin America. For this pest, however, high host-plant resistance does not appear to be available. Nevertheless, in the presence of effective biological control, much can be accomplished by using low to moderate resistance. Similar studies remain to be conducted in Asia with the red mite. Limited studies on *Tetranychus urticae* conducted in Colombia show that cassava varieties MBra 12 and MCol 1351 show some promise. Also, some wild *Manihot* species could be useful sources of resistance to these mites.

Biological control constitutes a cheap, environmentally sound, and practical solution, as long as no chemical pesticides are being used. Many potentially useful predators have been collected in Latin America. It was found that the phytoseiid predators (i.e., mites that actively feed upon mites) are particularly effective when the mite population is relatively low. However, these phytoseiid predators are very sensitive to even low doses of acaricide applications, making these applications actually counterproductive. Research in Colombia has shown that the presence of an abundant and diverse population of phytoseiid predators could markedly decrease the population of the green mite and prevent cassava yield losses. Cassava in Africa is also seriously affected by attacks of the green mite, *M. tanajoa*. After ten species of phytoseiid predators from Colombia and Brazil were introduced into Africa (following intensive quarantine testing), on-farm trials indicate that the predator *Typhlodromalus aripo* reduced green mite populations by 30−90% and increased root yield by 30−37%. The widespread distribution of these predators in various African countries has virtually resolved mite problems in many of those locales.

The most effective control measures can be summarized as follows:

- Treat stakes with thiamethoxam for 10 minutes before planting in endemic areas
- Plant at the beginning of the rainy season to obtain good plant establishment
- Apply chemical fertilizers and maintain proper amounts of soil organic matter to obtain good plant vigor
- Use resistant or tolerant varieties when these are available
- Use overhead irrigation with water at high pressure to wash off many mites and reduce populations
- Use only selective insecticides (i.e., acaricides) to protect the natural enemies of mites, as phytoseiid predators are very sensitive to pesticides, even at low-dose applications
- Increase quarantine measures to prevent the accidental introduction of severe mite pests such as *M. tanajoa.*

Many other pests in Asia may attack cassava and do serious damage, but these tend to be more localized problems. They include scale insects, white grubs, termites, thrips, and stemborers as well as several pests that attack dried cassava chips (Bellotti et al., 2012).

DISEASES

Among the various diseases of cassava that limit production, cassava bacterial blight (CBB), cassava mosaic disease (CMD), cassava root rot (CRR), cassava mosaic virus (CMV), cassava brown streak disease (CBSD), and cassava frogskin disease (CFSD) are the most important. Fortunately, among these, only cassava bacterial blight and cassava root rots are serious in Southeast Asia, while Indian and Sri Lankan cassava mosaic disease are major problems only in India. The latter disease is widespread in India and may cause yield losses of up to 80% in susceptible varieties. Another important disease is root rot caused by *Phytophthora palmivora*, which is becoming a major problem in several areas of Tamil Nadu State of India and Bangladesh, but is also observed in many wet areas throughout Asia. Planting cassava on heavy clay soils, excessive irrigation, poor drainage, and the development of a hardpan in the subsoil favor this disease. Another serious disease, recently observed in Asia, is "witches' broom disease," which results in excessive proliferation of small leaves and short internodes. To prevent the accidental introduction of other diseases currently not present in Asia, plant quarantine measures need to be strictly implemented (Álvarez et al., 2012).

1. Indian and Sri Lankan Cassava Mosaic Disease (ICMD and SLCMD)

These two virus diseases are present only in India and Sri Lanka, with overall incidence estimated at 23% in Kerala and 30% in Tamil Nadu States, and much lower incidences in Andhra Pradesh and Karnataka States. The symptoms of these two diseases include chlorotic mottling of green leaves with leaf deformation, which may lead to leaf fall and severe stunting of plants. Leaves can also be reduced in size, twisted, and deformed. Symptoms appear mainly during the wet season, making the identification of diseased plants very difficult during the hot dry season. The disease is spread mainly through the use of infected planting material as well as by the whitefly, *Bemisia tabaci.* It can also be transmitted through grafting.

Cassava mosaic disease is caused by a begomovirus, but there are several recombinant strains. The Indian mosaic virus is distinct but similar to the East African mosaic virus and the South African mosaic virus. Recently, Indian cassava mosaic virus was found to belong to the geminivirus group. The rate of virus spread and crop losses depend on the time of infection, the susceptibility of the variety, climatic factors, and vector populations.

Control measures

- Plant field-tolerant cassava varieties such as H-97, H-165, Sree Vijaya and Sree Padmanabha
- Select disease-free meristem-derived planting materials, followed by clonal multiplication with periodic screening and roguing of newly infected plants
- Select disease-free planting material before the beginning of the hot dry season
- Multiply disease-free planting material on a large scale at higher altitudes, where whitefly populations are very low or nonexistent
- Raise plants in a nursery at close spacing before transplanting only plants without disease symptoms to the field to prevent the spread of the disease
- Follow strict phytosanitary practices such as timely harvesting, prompt destruction of crop residues, and pulling out of self-sown plants and weeds that may harbor both the disease and its vector
- Cultural practices such as intercropping or change of planting dates should be further investigated to determine their effectiveness.

2. Cassava Bacterial Blight (CBB)

Cassava bacterial blight is caused by a bacterium, called *Xanthomonas axonopodis* pv. *manihotis (Xam).* It is the most common cassava disease, present in practically all cassava-growing countries and continents, and it can cause total crop loss in affected areas. During the 1960s and '70s, this disease caused major damage to the cassava crop, but the application of integrated management programs, the introduction of quarantine measures in some countries, and the use of resistant varieties have markedly decreased crop losses. In Asia, CBB has been observed in Thailand and most other countries during the rainy season, but it is seldom very severe. Typical symptoms are small, angular, aqueous-looking leaf spots found on the underside of leaf blades. Leaves can also be blighted or show brown leaf-burn wilt, there may be die back of stem apices, and, under severe conditions, there may be a gummy exudation in infected young stems, petioles, and spots on leaves. The vascular bundles of infected petioles and stems are also necrotic, appearing as bands of black or brown color. Symptoms occur 11−13 days after infection. Under favorable climatic and soil conditions for the disease, plants of susceptible varieties may die. This is mainly the case in areas with high temperatures and heavy rainfall, and when plants are weak due to inadequate nutrition, especially of K.

The bacteria can penetrate the host plant through stomas and wounds in the plant's epidermis. The infection can move through the xylem in stems and petioles, and possibly also through the phloem.

Different strains of the disease can be present in different geographic areas, and can move between different regions, probably because of the movement of infected planting materials. It was found that Colombia has three distinct pathotypes specific to three different ecozones.

Control measures

To control the disease, integrated management is the key, involving varietal resistance, cultural practices, and biological control. Of these, the use of resistant varieties is the most efficient and economic method for farmers. But, the identification of resistant germplasm is a laborious and time-consuming task. In greenhouse studies, many different cassava varieties were inoculated with 39 different isolates from different regions in Colombia, Venezuela, and Brazil. Eventually, 15 genotypes were identified as having high to intermediate resistance. Also, 6,400 cassava genotypes from the CIAT germplasm collection were evaluated in the Eastern Plains of Colombia, which is an area with particularly high CBB incidence. Of these, 117 genotypes were identified as having partial resistance. New biotechnological tools and a molecular genetic map of cassava are helping to better understand the genetic and biochemical basis for resistance, which will speed up the future identification of sources of resistance.

Among cultural practices, the following management practices are recommended:

- Plant resistant or tolerant varieties, when available
- Use only healthy planting material obtained from disease-free fields, plants derived from meristem culture, or by rooting buds and/or shoots
- Treat stakes by immersion for 10 minutes in a solution of cupric fungicides such as copper oxychloride or Orthocide© (Captan) at 3−6 g/L
- Immerse stakes in an extract of citrus fruit seeds (Lonlife©)
- Treat stakes using hot water at 49 °C for 49 minutes; this does not affect germination.

Other recommended practices are the following:

- Planting at the end of the rainy season
- Crop rotation with grass species
- Planting barriers of maize to prevent dissemination by wind
- Improving soil drainage
- Good weed control
- Fertilizer application, especially K
- Eradication of diseased plants
- Preventing the movement of people, machines, and animals from infected fields to healthy fields
- Eliminating infected materials after harvest by burning branches and stems
- Incorporating harvest residues into the soil

3. Root Rots *(Phytophthora spp.)*

Root rots are a very common problem in many cassava-growing areas, causing yield losses as high as 80% of total production in seriously affected areas. The disease is usually caused by a pseudo-fungus, *Phytophthora* spp., and is found in practically all cassava-growing countries, but mainly in areas with clay soils, the presence of a hardpan in the subsoil resulting in poor internal drainage, and during periods of heavy rainfall. In Asia, the disease has been causing serious crop losses in Buriram and Nakorn Ratchasima provinces of Thailand, in certain areas of Vietnam, and in irrigated areas of Tamil Nadu, India.

The pathogens *Phytophthora drechsleri* and *P. palmivora* cause maceration of root parenchyma, which produces a strong odor and changes the root color to cream. The pathogen *P. tropicalis* causes crown and root rot, irreversible wilting of plant tops, and defoliation. In contrast, *P. nicotianae* var. *nicotianae* produces only a mild odor with brown discoloration of roots as well as leaf blight. Under severe conditions, plants may die.

Twelve species of *Phytophthora* have been reported as causing root rot, and these are the most common pathogens causing root rots. But, other pathogens may also be involved, such as *Sclerotium rolfsii, Botryodiploidia theobromae, Fomes lignosus, Rosellinia necatrix*, *Rhizoctonia solani,* and *Fusarium* spp.

Control measures

The integrated management of root rots includes the use of varietal resistance and appropriate cultural practices.

Root rot incidence varies markedly between different varieties, and varieties with good resistance to specific causal agents of root rots have been identified. It was also found that harvesting at 14 months after planting increased yield but also caused a greater incidence of root rots, indicating that the damage of root rot-causing pathogens varies with the variety as well as the plants' age at harvest.

The best cultural practices to reduce or prevent root rots are summarized as follows:

- Select a well-drained and moderately deep soil
- If the soil is flat and clayey, plant cassava on top of ridges
- Apply chemical fertilizers high in K, either to the soil or as foliar sprays
- If root rot incidence surpasses 3%, rotate cassava with cereals or grasses for at least one year
- Eradicate diseased plants, remove infected roots from the field, and burn them.
- Select healthy plants to obtain clean planting material
- If planting material comes from areas infested with root rots, treat stakes with metalaxyl at 0.3 g a.i. per liter
- Treat stakes in hot water at 49 °C for 49 minutes as an alternative to chemical treatment
- Immerse stakes in a suspension of *Trichoderma harzianum* and *T. viride* at 2.5×10^8 spores/L, and later apply the same suspension in drench form.

The latter biological control of root rots using *Trichoderma harzianum* and *T. viride* is promising, as field trials conducted in Colombia have shown that soils inoculated with these two species also increased cassava yield.

Other practices that showed promise when applied with indigenous communities in the Colombian Amazon region are the following:

- Incorporate into the soil ash or dry leaves, or a 1:1 mixture of both materials, at about 200 g/plant
- Intercrop with cowpea *(Vigna unguiculata)*
- Select stakes from the middle part of the stems of healthy mother plants.

4. Cassava Anthracnose *(Glomerella manihotis)*

Although cassava anthracnose has been known for a long time, it has been considered of minor importance. It is characterized by the presence of sunken leaf spots (about 10 mm in diameter) that are similar to those caused by *Cercospora henningsii.* The pathogen also causes young stems to wilt and induces cankers on mature stems. New leaves produced at the beginning of the rainy season are the most susceptible. The disease disappears at the beginning of the dry season. The fungus will stop invading plant tissue when the relative humidity drops below 70%. The insect *Pseudotheraptus devastans* is associated with the disease, contributing to the pathogen's dissemination and increasing the severity of symptoms.

In Asia, stem anthracnose caused by a *Colletotrichum* sp. has been observed in Thailand. In green immature portions of the stem, shallow oval depressions appear that are pale brown, but with a point of normal green tissue in the center. In the lignified portion of the stems, lesions are round, swollen, and in bands, forming deep cankers on the epidermis and cortex, and sometimes deforming the stem.

5. Brown Leaf Spot and White Leaf Spot

These two diseases are frequently seen on cassava in Asia. Brown leaf spot is caused by *Cercospora henningsii* and white leaf spot by *Phaeoramularia manihotis.* These fungal diseases appear mainly on older leaves and on older plants.

Brown leaf spot is a serious disease mainly in India, where it causes severe defoliation. It is found mainly in hot cassava-growing areas. The disease is characterized by spots on both sides of the leaves. On the leaves' upper surface, uniform brown spots appear, with defined and dark margins. On the leaves' undersurface, the lesions have less-defined margins, and, toward the center, the brown spots have a gray-olive background caused by the presence of the fungus' conidiophores and conidia. As these circular lesions grow, from 3 to 12 mm in diameter, they take on an irregular angular form, their expansion being limited by the leaves' major veins. The disease is best controlled by the planting of resistant or tolerant varieties.

White leaf spot is prevalent in cold humid cassava-growing regions, where it can cause considerable defoliation of susceptible varieties. The disease is characterized by leaf spots that are smaller and of a different color than those caused by brown leaf spot. They vary from circular to angular, with diameters of usually 1 to 7 mm. They are normally white but sometimes yellowish brown. Lesions are sunken on both sides to half the thickness of a healthy leaf blade. The fungus penetrates the host through stomatal cavities and then invades the host's tissues through intercellular spaces. The pathogen produces conidiophores with conidia, which are dispersed by wind and rain splash. The disease is best controlled by the planting of tolerant varieties, but specifically resistant varieties have not yet been identified.

6. Witches' Broom Disease

Symptoms of a new disease have been observed on a few isolated cassava plants in Thailand and Vietnam for 10−15 years. Plants showed excessive sprouting of small leaves having short petioles, and plants remained small. However, in 2008, these same symptoms appeared on many plants in southern Vietnam and later in Thailand and Lao PDR, as well as in Cambodia and the Philippines. Many different varieties were affected, but some more than others. In general, plants are dwarfed and show an exaggerated proliferation of buds, as well as shoots and/or rachitic branches growing from a single stake. Sprouts have short internodes and small leaves, but do not show deformation or chlorosis. The roots of affected plants are thinner and smaller with rough-textured skins, and have drastically reduced starch content.

The disease is mainly transmitted by the use of stakes cut from infected plants. Leaf samples collected in southern Vietnam and Thailand were found to contain phytoplasmas. These same phytoplasmas were detected in roots, small leaves, and leaf veins showing typical symptoms of the disease. However, the phytoplasmas detected in Asia were not the same as those found in Latin America in plants showing similar witches'-broom symptoms. Recently, a similar phytoplasma was found in a cassava field in Paraguay (Álvarez, 2014).

Control measures

To prevent the disease from spreading, it is recommended to use only healthy planting material cut from symptomless plants, and to eliminate any diseased plants from the field. Also, restrict the movement of planting material from areas where the disease is prevalent to other areas where the disease does not exist. Also, restrict the movement of planting material of related species such as *Jatropha*, which have a disease complex similar to that of cassava. Varietal resistance does exist, but it needs to be more intensively investigated.

CHAPTER 14

FARMERS DECIDE!

Although this book makes many recommendations about **good agricultural practices** with respect to cassava, especially to make cassava production more environmentally friendly and sustainable, these recommendations are of little value unless they are actually adopted by farmers. And, before they can be adopted, farmers need to be convinced that these are better than what they are using already, and, very importantly, that they have significant economic benefits. Not all recommended practices are equally useful nor are they universally applicable. Farmers are interested only in those practices that are most suitable for their own conditions, and fit well into their traditional practices. For that reason, it is not so useful to "promote" certain practices that were found to be effective under experiment station conditions as these may not be the best under the farmers' local conditions. A good example is the promotion of vetiver grass as a contour hedgerow to reduce erosion on sloping land. In hundreds of erosion control trials, both on experiment stations and in farmers' fields, the planting of vetiver grass hedgerows was usually found to be the most effective practice to reduce erosion (see **Chapter 11**). As such, this practice is strongly promoted by the Thai government, which provides free planting material of the grass in plastic bags to farmers. During a 10-year project on farmer participatory research (FPR), 89 erosion control trials were conducted by cassava farmers in Thailand, and most farmers selected vetiver grass contour hedgerows as the best way to control erosion. At the end of the project, more than 1,000 farmers had planted a total of 145 km of vetiver grass hedgerows (Vongkasem et al., 2008).

Similarly, as part of the same project in Vietnam, 187 FPR erosion control trials were conducted, and again most farmers selected vetiver grass as the best method to control erosion. In Thailand, 72% of the participating farmers finally adopted the planting of vetiver grass hedgerows; in Vietnam, this was only 17%, while 48% had adopted hedgerows of *Tephrosia candida* and 17% had adopted hedgerows of *Paspalum atratum.* This difference is because vetiver grass can be propagated only vegetatively, requiring the planting of tillers in small plastic bags of soil and transplanting the plantlets later in the field. This requires considerable labor. Although this is no problem for conducting small experiments, it becomes a major problem to do this in larger production fields, especially when these are located in the mountains and far from main roads. So, since the Vietnamese government did not provide free planting material of vetiver grass, most farmers adopted the use of the leguminous shrub *Tephrosia candida* or the grass *Paspalum atratum,* as both can be planted from seed, also serve to improve soil fertility, and provide cut-and-carry feed for cattle, respectively. Thus, due to the political and socioeconomic conditions in Thailand, farmers adopted vetiver grass, while in Vietnam they preferred the other two species.

Thus, it is clear that farmers do not necessarily adopt the same improved technologies, but only adopt those that are best under their own conditions and that fit best in their own cropping systems. Since most technologies have certain advantages and disadvantages, trade-offs need to be made and this can best be done by the farmers themselves, rather than by researchers or extensionists.

To get farmers' feedback, it is important to involve farmers directly in the development of new technologies. This can be done with the guidance of researchers and extension workers. The difference between this approach and the more traditional "transfer of technology" approach is that the extension workers do not "promote" or "recommend" any particular technology but only provide a menu of options of alternative technologies from which farmers can choose those they are most interested in, and then test those selected technologies in simple FPR trials in their own fields with help from research or extension staff.

Members of a farmers' group, or farmers in a particular village or district, first diagnose their main problems and, with help from project staff, consider some possible solutions. From this, they decide the specific topics of their trials, such as testing new varieties, fertilizers, green manures, erosion control practices, weed control options, etc. Ideally, the farmers visit some trials on these topics at an experiment station or in other villages where similar trials are being conducted, or they visit a village where farmers have already adopted certain selected practices. From these visits, they select four to six treatments that they want to test in simple unreplicated FPR trials in their own fields, with one treatment being their own traditional practice. If in the village all farmers conducting one type of trial use the same treatments, each trial can be considered a replication, and results can be averaged over those replications. This will improve the confidence in the results obtained. The next step is for the farmers to set out and establish the trials, initially with help from project staff. The farmers manage the trials while staff may visit occasionally to help solve problems. Finally, at the time of harvest, all farmers in the village, or from neighboring villages, are invited to a field day when they will visit the trials and discuss the results obtained. After visiting and evaluating the trials in the field, the project staff present not only the average yields obtained in the various treatments in each type of trial but also the gross income, production costs, and net income obtained with each treatment. Based on this information, farmers can select those treatments that they consider most suitable for their own conditions. Once they have seen the effect of each treatment in their own fields and have selected the most suitable technologies, they are more likely to adopt these technologies and improve their production practices, leading to higher yield.

Examples of various types of FPR trials conducted in Thailand and Vietnam are shown in **Tables 1** to **5**. It is clear that farmers generally prefer those treatments that produce the highest net income.

Table 1. Results of a FPR variety trial conducted by farmers in Kut Dook Village, Baan Kaw subdistrict of Daan Khun Thot District, Nakhon Ratchasima Province, Thailand, in 2001/02.

Variety	Cassava yield (t/ha)	Starch content (%)	Gross income[1)]	Production costs[2)] (US$/ha)	Net income
Kasetsart 50	29.6	26.5	705.60	433.80	271.80
Rayong 5	28.3	26.5	674.20	426.40	247.80
Rayong 90	32.7	26.0	779.00	451.50	327.50
Rayong 72	28.4	23.2	676.60	427.00	249.60

1) Prices: cassava US$23.84/ton fresh roots.
2) Productions costs are based on data from the Office of Agricultural Economics in 2000.
Source: *Watananonta et al., 2008.*

Table 2. Average results of three FPR intercropping trials conducted by farmers in Suoi Rao and Son Binh villages, Chau Duc District, Ba Ria-Vung Tau, Vietnam, in 2001/02.

Treatment	Cassava yield (t/ha)	Starch content (%)	Intercrop yield (t/ha)	Gross income[1)]	Production costs[1)] (000 dong/ha)	Net income	Farmers' preference (%)
C + peanut intercrop	30.74a	27.66	1.483	25,805	10,071	15,734	48
C + mungbean intercrop	29.81a	26.66	0.570	20,383	8,640	11,743	42
C + soybean intercrop	34.54a	27.50	0	18,997	8,620	10,377	6
C + maize intercrop	21.00b	24.30	3.643	15,557	8,588	6,900	35
Cassava monoculture	31.88a	27.93	-	17,534	7,116	10,418	29
CV (%)	2.16						
LSD 0.05	6.872						

1) Prices: cassava dong 550/kg fresh roots
peanut 6,000/kg dry pods
mungbean 7,000/kg dry grain
maize 900/kg dry grain

Note: Data in a column followed by the same letter are not significantly different.
Source: *Nguyen Huu Hy et al., 2008.*

Table 3. Average results of two FPR soil erosion control trials conducted by farmers in Minh Duc commune of Pho Yen District in Thai Nguyen Province of Vietnam in 1999 and 2000.

Treatment[1)]	Dry soil loss (t/ha)			Yield (t/ha) Cassava		Yield (t/ha) Peanut		Farmers' preference (%)[2)]	
	1999	2000	Av.	1999	2000	1999	2000	1999	2000
1. Farmers' practice	32.55	21.30	26.92	15.75	13.12	-	-	0	0
2. C+P; no hedgerows	22.84	18.51	20.67	24.88	18.68	0.21	0.31	5	50
3. C+P; vetiver grass hedgerows	11.62	10.35	10.98	27.00	20.00	0.18	0.28	90	73
4. C+P; *Tephrosia candida* hedgerows	15.32	11.22	13.27	26.25	19.87	0.16	0.27	90	67
5. C+P; *Tephrosia*+ vetiver hedgerows	12.01	9.87	10.94	28.88	21.81	0.15	0.27	100	97

1) Farmers' practice: 12 t/ha of FYM + 45 kg N + 30 kg P_2O_5/ha
Treatments 2–5: 10 t/ha of FYM + 80 kg N + 40 kg P_2O_5 + 80 kg K_2O/ha; C=cassava, P=peanut
2) Farmers may indicate more than one preference.
Source: *Nguyen The Dang, 2007.*

Table 4. Average results of four FPR fertilizer trials conducted by farmers in Khook Anu Village, Naayang Klak Subdistrict, Thep Sathit District of Chayaphuum Province, Thailand, in 2001/02.

Fertilizer treatment	Cassava yield (t/ha)	Gross income[1]	Production costs (US$/ha)	Net income	Farmers' preference (%)
1. No fertilizer or manure	20.48	585.20	272.30	312.90	0
2. 156 kg/ha of 15-15-15	27.08	773.80	302.10	471.70	52
3. 312 kg/ha of 15-15-15	29.44	841.10	331.90	509.20	19
4. 1.56 t/ha of chicken manure (CM)	28.12	803.30	302.80	500.50	19[2]
5. 1.56 t/ha CM+156 kg/ha 15-15-15	28.32	809.00	332.60	476.40	10[2]

[1] Prices: cassava US$ 28.57/ton fresh roots at 30% starch
chicken manure 0.019/kg
15-15-15 fertilizers 0.190/kg

[2] Chicken manure is difficult to find in the area.

Source: *Watananonta et al., 2007.*

Table 5. Average results of six FPR green manure trials conducted by farmers in Khook Anu Village, Naayang Klak Subdistrict, Thep Sathit District of Chayaphuum Province, Thailand, in 2001/02.

Green manure[1]	Cassava yield (t/ha)	Starch content (%)	Gross income[2]	Production costs (US$/ha)	Net income	Farmers' preference (%)
1. No green manure	26.14	26.3	703.30	272.30	431.00	0
2. *Crotalaria juncea*	29.87	29.4	839.20	328.00	511.20	0
3. Mungbean	29.60	27.9	817.60	331.90	485.70	0
4. *Canavalia ensiformis*	30.24	30.0	864.00	302.10	561.90	100

[1] No fertilizer was applied; green manures were intercropped and planted at the same time as cassava and were weeded out by hoe at 2 MAP; farmers suggest planting green manures either before cassava and incorporating them before cassava planting, or planting GM as an intercrop at 1–1½ MAP and weed out the green manure at 2 MAP.

[2] Prices: cassava US$28.57/ton fresh roots at 30% starch.

Source: *Watananonta et al., 2007.*

At the end of the second 5-year phase, the project had worked in 99 villages in Thailand, Vietnam, and China and farmers had conducted a total of 1,154 FPR trials, mostly on varieties, fertilization, erosion control, plant spacing, green manures, and even pig feeding with cassava leaves and roots.

After having conducted the trials and participated in field days or training courses, many farmers adopted some or all of the improved technologies tested in their village. In many cases, this increased their cassava yield substantially. A good example is Tien Phong commune in Thai Nguyen Province in North Vietnam, where FPR trials were conducted for several years after the start of the project in 1994. **Table 6** shows how the cassava yield in the village gradually increased from 8.5 t/ha in 1994 to 36 t/ha in 2003 as more farmers started to plant the new higher yielding varieties and used improved agronomic practices, including fertilizer application.

Table 6. Impact of the adoption of new cassava varieties and improved production practices on the livelihoods of farmers in Tien Phong commune, Pho Yen District of Thai Nguyen Province, Vietnam.

Year	Variety or practice[1]	No. of farmers	Cassava area (ha)	Cassava yield (t/ha)	Peanut yield (t/ha)	Gross income[2]	Production costs (mil. dong/ha)	Net income	Total net income (mil.dong)
1994[3]	Vinh Phu	115	50	8.5	-	3.40	2.93	0.47	23.50
	New varieties	0	-	-	-	-	-	-	-
			50						**23.50**
2000	Vinh Phu	NA[4]	NA	21.5	-	NA	NA	NA	NA
	New varieties	25	1.31	30.9	-	15.45	4.36	11.10	14.54
	Intercropping	37	2.59	29.3	0.81	18.70	6.16	12.54	32.48
	Erosion control	4	0.20	24.7	-	12.35	4.66	7.69	1.54
			>4.10						**>48.56**
2001	Vinh Phu	61	2.17	22.7	-	11.35	4.36	6.99	15.17
	New varieties	122	4.70	29.0	-	14.50	4.36	10.14	47.66
	Intercropping	40	3.38	26.2	0.77	16.94	6.16	10.78	36.44
	Erosion control	4	0.20	NA	-	NA	NA	NA	NA
			10.45						**>99.27**
2002	Vinh Phu	18	0.64	25.4	-	12.70	4.33	8.37	5.36
	New varieties	100	5.16	33.7	-	16.85	4.33	12.52	64.60
	Intercropping	118	3.69	32.3	1.73	24.80	6.13	18.67	68.89
	Balanced fertilizer	48	2.95	33.4	-	16.70	4.83	11.87	35.02
	Erosion control	5	0.18	25.4	-	12.70	4.63	8.07	1.45
			12.62						**175.32**
2003	Vinh Phu	NA	NA	NA	-	NA	NA	NA	NA
	New varieties	225	17.00	36.8	-	18.40	4.33	14.07	239.19
	Intercropping	120	11.00	36.0	0.67	21.35	6.13	15.22	167.42
	Balanced fertilizer	54	3.40	33.6	-	16.80	4.83	11.97	40.70
	Erosion control	5	0.60	27.0	-	13.5	4.63	8.87	5.32
			>32.00						**>452.63**

[1] In Tien Phong, farmers traditionally grow mainly variety Vinh Phu but have now largely changed to KM 95-3 and KM 98-7; the new practices include intercropping with peanut, balanced fertilization of 10 t/ha of pig manure plus 80 kg N + 40 kg P_2O_5 + 80 kg K_2O/ha, and erosion control by contour hedgerows of *Tephosia candida.*

[2] Price of cassava in 1994: 400 VND/kg fresh roots.
Price of cassava in 2000–2003: 500 VND/kg fresh roots.
Price of peanut in 2000–2003: 5,000 VND/kg dry pods.

[3] Data from RRA at the start of project;

[4] NA = data not available.

Source: *Howeler, 2008.*

An impact assessment conducted by an outside consultant in 2003 found that 100% of the farmers who had directly participated in the project in Thailand and 82% of those in Vietnam had adopted the planting of improved varieties, while 98% of the farmers in Thailand and 80% in Vietnam had adopted the use of chemical fertilizer (Howeler, 2008). The adoption of new cassava technologies by many farmers in Asia resulted in marked increases in yield and an estimated increase of US$325.4 million in their annual gross income as a result of their higher yield in 2004 compared with 1994. The annual increase in gross income for all of Asia due to higher yield in 2009 compared with 1994 was estimated at US$1.75 billion **(Table 7)**.

Table 7. Estimated increase in gross income of cassava farmers in China, Thailand, Vietnam, and all of Asia as a result of increased cassava yield in 2009 compared with 1994.

Country or continent	Total cassava area (ha)[1]	Cassava yield (t/ha)[1]		Yield increase (t/ha)	Cassava price (US$/ton)	Increased gross income due to higher yield (mil. US$)[2]
		1994	2009			
China	275,500	15.23	16.36	1.13	65	20.23
Thailand	1,326,740	13.81	22.67	8.86	55	646.52
Vietnam	508,800	8.44	16.82	8.38	60	255.82
Asia total	**4,056,819**	**12.93**	**20.12**	**7.19**	**60**	**1,750.11**

1) Data from FAOSTAT, 2011.

2) In addition, farmers benefited from higher prices due to higher starch content.

Thus, there is no doubt that improved production practices, combined with a farmer participatory approach to extension, as well as favorable market conditions, had markedly improved cassava yield and farm income, and had lifted many cassava farmers out of poverty in Asia. During the past two decades, cassava has changed from a poor man's crop to a highly profitable crop that can be grown even on poor soils, in areas with unpredictable rainfall, and with relatively little labor and few purchased inputs. But, because the crop has become more profitable, many farmers would like to expand their cassava-growing areas to ever steeper slopes or into previously forested areas. Governments must ensure that increased cassava production is achieved by the use of production practices that do not damage the environment, but that are ecologically sustainable, economically profitable, and socially acceptable.

APPENDIX
CONDUCTING FIELD EXPERIMENTS WITH CASSAVA

Many cassava field experiments have been conducted over the past 40 years and a wealth of information has been obtained. Still, many questions remain to be answered as results have not always been conclusive, while some results also need to be confirmed or adapted to particular local conditions. Thus, additional experiments will need to be conducted, either on-station or on-farm, that are both designed and managed by researchers, or in farmer participatory research (FPR) trials that are designed and managed by farmers with help from researchers. This chapter provides some guidance about how to conduct these experiments and how to calculate the yield of cassava as well as that of intercrops or other associated crops that are planted in the experiment.

1 Plot size and shape and the need for border rows in cassava experiments

Cassava is a vegetatively propagated crop and most experiments are planted with about 20 cm long stem cuttings, also called "stakes." Mature plants are quite large and each plant will therefore require considerable space, enough to minimize plant-to-plant competition but to maximize yield. In many cases, planting material is limited and should be used as efficiently as possible. Also, the length and thickness of each stake will differ, as well as the maturity of the stem from which it was cut, resulting in large variability between individual plants in the experiment. To reduce the coefficient of variation, experimental plots will need to be relatively large, the plant stand will need to be as complete as possible, and plant growth should be as uniform as possible. Unlike rice or maize, for which each plot may have hundreds of plants, in cassava experiments, the plot size may be larger but the number of plants per plot will probably be much smaller. Thus, every plant counts and each plant makes a considerable contribution to the total yield determination.

Research to determine the minimum number of harvested plants per plot was conducted at CIAT in the early 1970s (CIAT, 1974). Although the results varied between different varieties, the preliminary recommendation was to use a minimum of 25 harvested plants per plot, and to use square plots with two border rows (not harvested for yield determination) and six replications when using a randomized complete block design. In practice, however, smaller plots with a minimum of 12−16 harvested plants in the so-called "effective plot" and with only one border row on all sides and 3−4 replications are often used to reduce costs, to save planting material, and to keep the trial within a reasonable size, say, 0.25 ha, with as uniform soil conditions as possible. As with any other crop, the experiment should be laid out in such a way that any existing variation in slope or soil occurs between replications, while the variation within each replication is held to a minimum.

Most cassava fibrous roots are present in the top 20 cm of soil, but some roots can go down to as much as 1 meter depth while others may grow 1−2 meters sideways. Thus, interplant competition occurs not only above-ground by shading but also underground by roots for the uptake of water and soil nutrients. In the center of a field (or plot), each plant is surrounded by eight neighbors, which all compete with each other for light, water, and nutrients. Plants growing in a border row are surrounded by only five neighboring plants and those growing in the plot's corner by only three neighboring plants; these plants are thus subjected to less competition and have a higher yield than those plants in the center of the plot. To calculate the "true" yield of a certain treatment, we should harvest only plants fully surrounded by other plants inside the "effective plot" and exclude any plants growing in border rows, as the latter have had less competition. Border-row plants are generally taller and have higher yield than those inside the plot because they receive more light, and can extend their roots into alleyways or neighboring plots to absorb additional nutrients or water not corresponding to the treatment of their own plot.

It is recommended to use square plots because these have a greater number of plants inside the "effective plot" in relation to the total number of plants in the plot with borders. For instance, using a planting distance of 1.0 × 1.0 m and a square plot of 6 × 6 m or 36 m², there will be 4 × 4 = 16 plants in the "effective plot," which is surrounded on all four sides by one border row. The yield will be calculated from the yield of these 16 plants. If we use a long narrow plot of 9 × 4 m or the same 36 m², there will be only 7 × 2 = 14 plants in the effective plot. With the square plot, we can use 16/36 = 44% of the plants to calculate the yield, while with the rectangular long and narrow plot we can use only 14/36 = 39% of the plants to calculate the yield. For that reason, square or squarish plots give you a better yield estimate than long narrow plots with the same number of plants.

Figure 1 indicates that, as the plant population increased from 3,000 (spacing 1.8 × 1.8 m) to 40,000 (spacing 0.5 × 0.5 m) plants/ha, root yield per plant decreased due to increasing interplant competition. Furthermore, border plants in the first row had significantly higher yield, while those in the second border row had slightly higher yield, and those in the third border row had the same yield as the plants in the plot's center, which had at least three border rows. Thus, to obtain a true estimate of treatment effects on yield, at least one and preferably two border rows should not be included in the effective plot that is harvested for yield determination.

It is not necessary to have the same plot or effective plot size throughout the experiment, especially in plant-spacing trials. It is important, however, to harvest at least a minimum of 16−25 plants per plot (in the effective plot) to reduce the coefficient of variation. This means that those treatments having closer plant spacing (higher plant density) can be planted in smaller plots, while treatments having a wider spacing may need bigger plots.

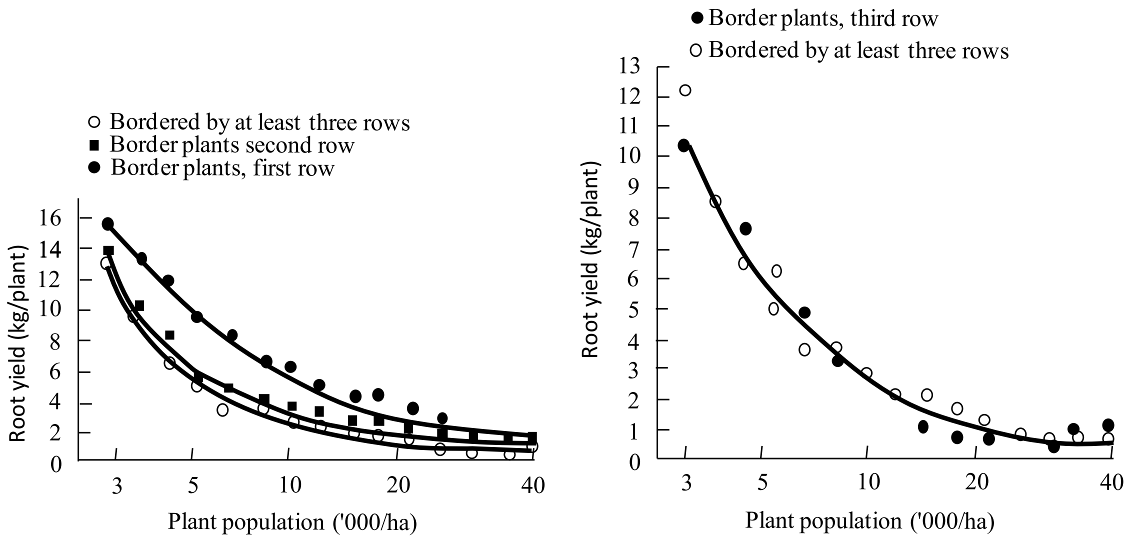

Figure 1. *Yield of border plants of cassava cv. Llanera at different plant populations.*

Source: *CIAT, 1974.*

2 Laying out an experiment with 90-degree corners

Before laying out an experiment, the available area should be carefully observed to see whether there is any consistent variation in slope or soil conditions. If so, the replications should be laid out in such a way that the existing variation occurs between replications and not within each replication. Thus, replications should be laid out perpendicular to the slope or to the soil fertility gradient. Furthermore, plots should be at least 5−10 meters away from trees because trees not only affect plant growth in nearby plots through shading, but tree roots can extend far beyond the shade line and absorb water and nutrients within a 5−10 m radius surrounding the tree, depending on the height and type of tree.

Once the general shape of the experiment is determined, you stake out a baseline, using stakes and string, corresponding to the longest side of the experiment. At one end, set out a line perpendicular to the baseline by measuring exactly 8 meters along the baseline, 6 meters along the perpendicular line, and exactly 10 meters along the diagonal line, as shown in **Figure 2.** Any multiple of a 3:4:5 ratio will make a 90-degree angle.

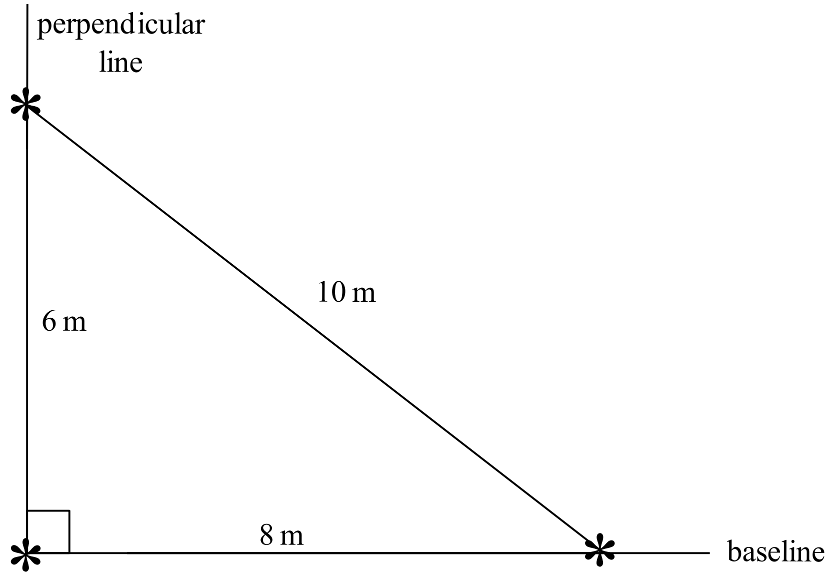

Figure 2. *A simple way of setting out a 90-degree corner in field experiments.*

The plots are staked out according to the experimental plan along the baseline and the perpendicular line. The other two sides of the experiment are staked out in a similar fashion by setting out another 90-degree angle and making sure that the two long sides and the two short sides of the experiment are indeed of the same length, respectively. The plots and replications are staked out along all four external border lines and the stakes are then connected with string to lay out all plots.

3 Plant spacing and layout

In any experiment, cassava should be planted at a uniform plant spacing, either throughout the whole experiment or in each treatment in case of a plant-spacing trial. To simplify the laying out of experiments, a planting distance of 1.0 × 1.0 m is often used; this also corresponds to the near optimum spacing for most cassava varieties planted in fertile soils. In infertile soils or when cool climates result in slow growth, a closer spacing of 0.8 × 0.8 m or 0.8 × 0.9 m is more appropriate.

The first row of cassava should never be planted on the plot border line as it would be impossible to say to which plot the plants in this row belong. Instead, the first row is generally planted at half the planting distance from the border line and the last row is also planted at half the planting distance from the opposite plot border line; similarly, the first and last plants in each row are planted at half the planting distance from the perpendicular plot border line, as shown in **Figure 3**.

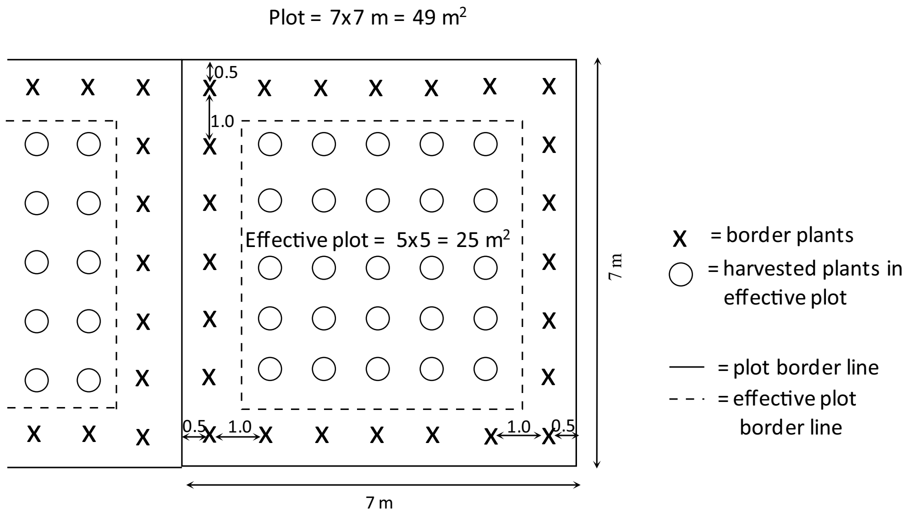

Figure 3. *Layout of cassava experimental plot with cassava planted at 1.0 × 1.0-m spacing and plot size of 7.0 × 7.0 m.*

Since it is important to have as complete a plant stand as possible, especially within the effective plot, it is advisable to plant a few extra stakes in the space between the first row and the plot border line in each plot. These can be used for transplanting to replace those plants that have not germinated at 2–3 weeks after planting (WAP). Alternatively, new stakes of the same variety are used to replant in the empty spaces where the original stakes had not germinated. This "gap filling" should be done as soon as most stakes have germinated, usually at 2–3 WAP, so as to obtain as uniform a plant growth within the plot as possible. If gap filling is done too late, the new plants will not be able to compete with their taller neighbors and will never catch up and produce normal yield (**Table 1**).

Table 1. Yield of cassava cv. Golden Yellow under different periods of replanting missing hills in ViSCA, Leyte, Philippines.

Replanting time of missing hills	Total[1] root yield (t/ha)	Root yield[2] of sample plants (kg/plant)
1. Control, 0 missing hills (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 (treatments 3, 4, 5, 7, and 8) or those adjacent to a missing hill (treatments 2 and 6) or those with complete borders (treatment 1).

Source: *Villamayor, 1988.*

4 Common experimental designs used in cassava field experiments

Many experimental designs can be used, the most common being the randomized complete block (RCB), the split plot, the split-split plot, and the complete or incomplete factorial designs. For varietal evaluations, the most common is an RCB design, but in fertilizer trials a split plot, split-split plot, or incomplete factorial design is often used. In that case, the main plots often have two or more varieties and the subplots have different fertilizer treatments. In long-term fertilizer trials, there is always the danger that previously applied fertilizers are moved across plot borders during land preparation or weeding, especially when using tractors, thus contaminating the neighboring plots. To avoid this problem, the fertilizer treatments should be in the largest plots, that is, the main plots, while the different varieties are planted in subplots within the main plots. Similarly, in experiments on land preparation methods using various tractor-mounted implements, these treatments require rather long plots to enable the tractor to move at a constant speed. In that case, the land preparation treatments are usually in the main plots, while different varieties can be planted in subplots.

5 Application of fertilizers, manures, and lime

Fertilizers and soil amendments (such as lime or manures) can be divided into two general classes: those that are readily soluble in water and those that need time and good contact with the soil to dissolve or decompose. Most chemical fertilizers, such as urea, single superphosphate (SSP), triple superphosphate (TSP), potassium chloride (KCl), potassium sulfate (K_2SO_4), magnesium sulfate ($MgSO_4$), zinc sulfate ($ZnSO_4$), and various compound NPK fertilizers dissolve rather rapidly in water. They can be spot- or band-placed at 5−10 cm from the planted stake. These fertilizers will dissolve in the soil solution and the roots will tend to grow toward the fertilizer band. A single hole or short band at 10 cm on one side of the stake or plant is made with a pointed stick or hoe and the fertilizer (or mixture of several fertilizers) is placed in the hole and then covered with soil. Fertilizers should never be left on top of the soil as nutrients may be lost by volatilization or by runoff or erosion, nor should they be in direct contact with the planted stake as this may affect germination. The advantage of spot or band placement is that the fertilizer is concentrated near the cassava plants that will benefit from it, while most weeds will not be able to access the fertilizer.

Lime, gypsum, rock phosphates, basic slag, and manures need good contact with the soil to dissolve or decompose in order that the nutrients become available to the plants. For that reason, they are normally applied broadcast uniformly over the entire plot or experiment and then incorporated into the soil during land preparation and before planting. The disadvantage of this method of application is that weeds also benefit from the fertilizers or amendments applied.

For cassava, most water-soluble chemical fertilizers should be applied either at the time of planting or at about 1 month after planting (MAP). In the case of horizontally planted stakes, the fertilizers are generally applied after the young plants have emerged from the soil. Plants need phosphorus (P) mainly at the early stages of growth, so most P sources are applied at or shortly (1 month) after planting. Nitrogen (N) and potassium (K) can also all be applied at or shortly after planting, or the applications can be split with half applied at or shortly after planting and the other half at 2−3 MAP. Applying fertilizers at a later stage is generally less effective.

Micronutrients such as zinc (Zn) and iron (Fe) can be applied (if necessary) to the soil as sulfates or chelates at the time of planting, but, in high-pH or calcareous soils, these fertilizers should be applied to the leaves as a spray at 2, 3, and 4 MAP. These nutrients can also be applied by soaking the stakes for 15 minutes in a solution of 2−4% $ZnSO_4.7H_2O$ or $FeSO_4.7H_2O$ before planting.

When fertilizers, lime, or manure need to be applied in an experiment, these are usually weighed out in separate plastic bags for each plot before going to the field. In the field, these bags are laid out in each plot, either uniformly for all plots or according to specific treatments. Before application, it is important to check that every plot has the correct number and types of fertilizer. After this check, the lime or manure could be mixed and applied broadcast over the entire plot and then incorporated into the soil with a hoe or hand tractor. The bags of chemical fertilizer are emptied into a pail and thoroughly mixed, after which a small amount of the mixture is applied in short bands or holes previously made alongside each planted stake or young plant, making sure that each plant receives more or less the same amount of fertilizer. If, after all plants in the plot have received fertilizer there is still some left in the pail, this remaining fertilizer should be distributed again evenly over all plants in the plot until all the fertilizer has been applied. Once this is finished, the fertilizer in the holes or bands should be covered with soil. Applying fertilizers evenly over all the plants in the plot requires considerable experience by field workers.

6 Weeding

Cassava is a poor competitor. It suffers greatly from competition from weeds or other crops growing nearby, especially during the early stages of growth. This early growth is also quite slow as compared to many other crops such as maize, rice, and beans. For that reason, weeds should be eliminated during the first 3−4 MAP and intercrops should be planted at least 30 cm away from the young cassava plants. Once the cassava canopy closes, most weeds will be shaded out, and in general no more weeding is necessary after 3−4 months. If leaf drop during the later growth stages is severe and weeds reappear, these might be cut off using a machete to prevent weeds from flowering and reseeding. Weeding at this late stage is unlikely to increase root yield and may damage the swollen roots if weeding is done with a hoe. Thus, hand weeding with a hoe should start at 3−4 WAP and be followed by another one to two weedings at 2 and 3 MAP.

Band application of fertilizers can markedly speed up cassava canopy formation and thus reduce the need for additional weeding. On the other hand, the application of cow or goat manure can increase weed problems as many weed seeds will pass through the animal's gut and will germinate when the manure is broadcast and incorporated.

When labor is scarce or expensive, weeds can also be controlled by spraying of preemergence herbicides such as diuron, alachlor, oxifluorfen, and metolachlor right after planting (even over vertically planted stakes); this can be followed by hand weeding or by the application of postemergence herbicides such as paraquat and glyphosate when weeds reappear at 2 to 3 MAP; the latter herbicides should be applied using a plastic or metal shield over the nozzle to prevent hitting the cassava leaves or stems. If windy weather makes spraying difficult without damaging the cassava, these herbicides can also be wiped on with a "wick-it weeder" or "pipewick wiper".

7 Determination of yield in cassava monoculture and when intercropped

Determining the effective plot when cassava is planted in monoculture and at the same plant spacing is quite simple (**Figure 4**). Usually, one border row along all four sides of the plot is excluded, and only the plants within the remaining center part of the plot, that is, the "effective plot", are harvested and the root (and top) weight determined. The root yield of the plot in t/ha is calculated as the root weight (in kg) in the effective plot x 10 divided by the area of the effective plot (in m²).

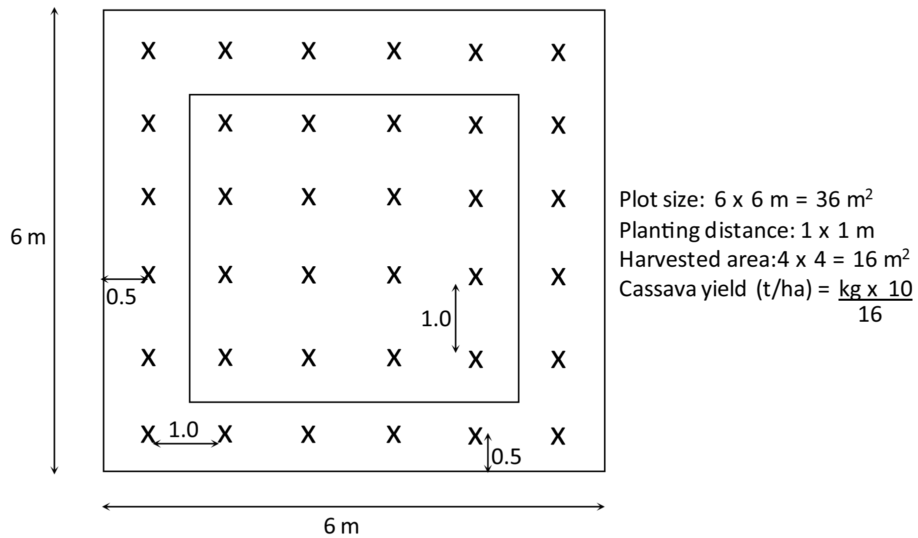

Figure 4. *Plot layout when cassava is grown in monoculture.*

When cassava is intercropped, the space between rows is often widened, while the space between plants in the rows is shortened to maintain a cassava population of 10,000 plants per ha, while accommodating one, two, or three rows of intercrops between the cassava rows (**Figures 5** and **6**). To determine the yield of both cassava and the intercrops, it is important to determine the correct area of the effective plot to be harvested. The effective plot should always exclude at least one border row, and include the same ratio of cassava to intercrop rows as you would find in the larger field. Thus, **Figure 5** shows that, if one row of cassava is alternated with three rows of upland rice, the effective plot may include two rows of cassava and six rows of upland rice, and the harvested area for both crops would be 4 × 5 = 20 m².

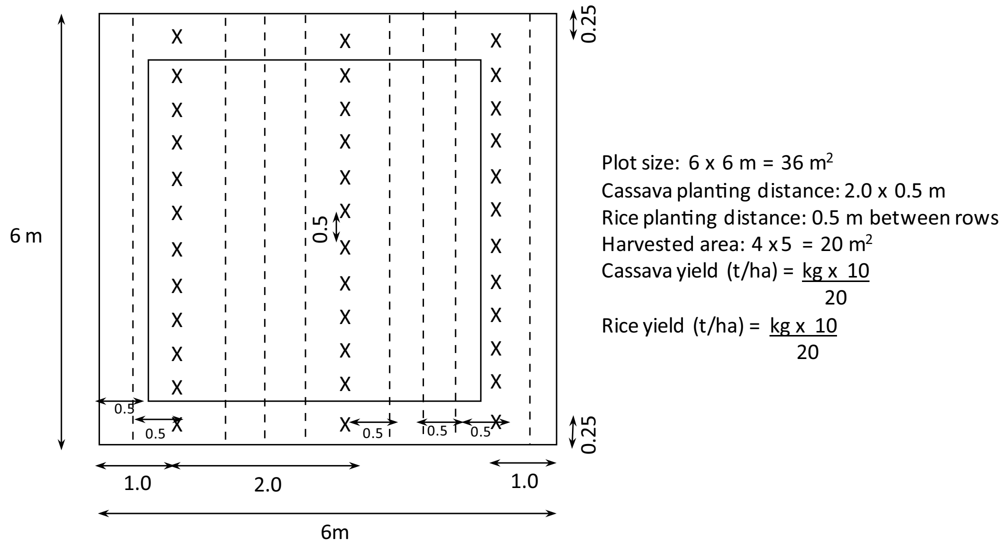

Figure 5. *Plot layout when cassava is intercropped with three rows of upland rice*

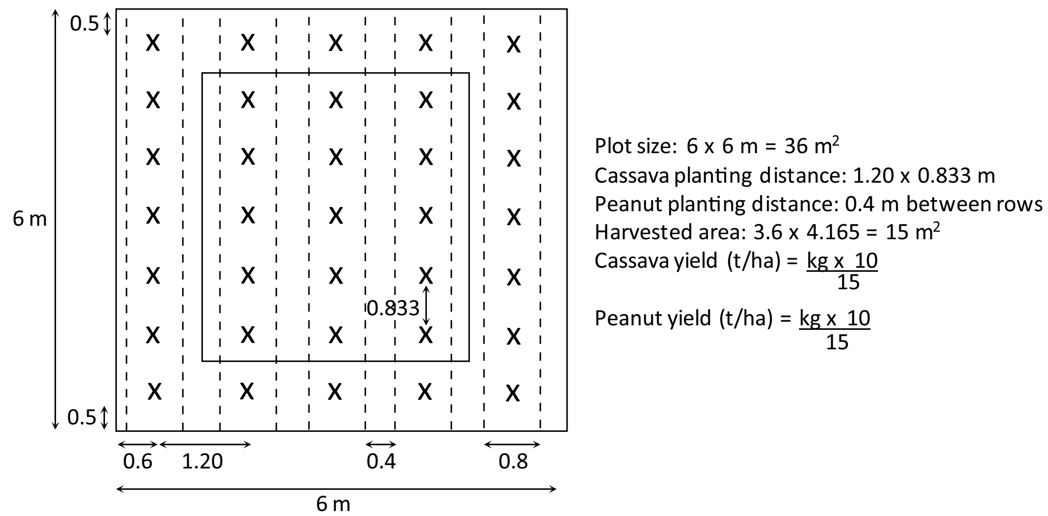

Figure 6. *Plot layout when cassava is intercropped with two rows of peanut.*

In **Figure 6**, if cassava is intercropped with two rows of peanut, the effective plot could include three rows of cassava and six rows of peanut, and the harvested area would be 3.6 × 4.165 = 15 m².

Figure 7 is an example of an alley-cropping trial in which one out of every five rows of cassava is replaced by one hedgerow of *Leucaena leucocephala.* To maintain a constant cassava population of 10,000 plants per ha, the plant spacing within the row is reduced to 0.75 m. In this case, the effective plot should include one hedgerow of *Leucaena* and four rows of cassava, and the harvested area would be 4.5 × 5.0 = 22.5 m². To accommodate two hedgerows and six cassava rows, the plot size had to be increased to 6 × 8 m.

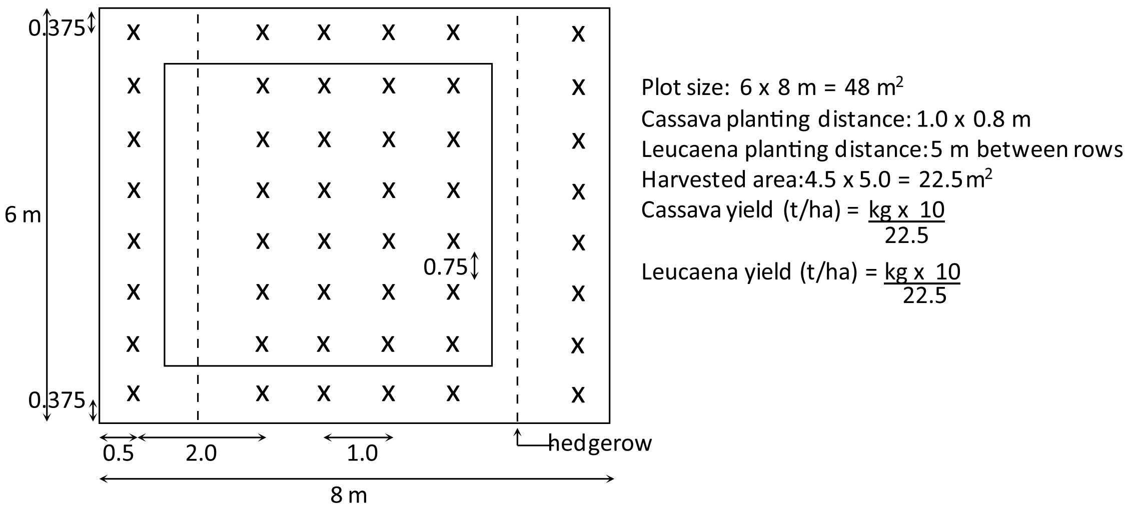

Figure 7. *Plot layout when four rows of cassava are grown in alleys between hedgerows of Leucaena leucocephala.*

8 Determination of yield when some plants are missing

Since cassava experiments generally have relatively few plants in each plot, it is very important to try to have a complete plant stand, especially inside the effective plot that is used to measure yield. However, sometimes, one or more plants may be missing because they did not germinate, they were attacked by termites, or they were rogued out because of CMD. If we try to correct for missing plants by multiplying the weight of the roots of the remaining plants in the effective plot by the number of plants that should have been harvested divided by the number of plants actually harvested, we tend to grossly overestimate the actual yield. This is because cassava plants surrounding the missing hill have less competition and will thus have higher yield than those that are completely surrounded by eight other plants. Similarly, statistical methods of estimating the yield of missing plants tend to overestimate that yield as cassava plants adjacent to missing hills generally have higher yield because they have more space in which to grow.

Research conducted in the Philippines indicates that plants adjacent to missing hills (treatments 2 and 6 in **Table 1**) had substantially higher yield than those in plots without missing hills (treatment 1 in **Table 1**), and that cassava yield in plots with up to 30% missing hills was not significantly different from that of plots without missing hills, because the higher yield of plants adjacent to the missing hills compensated for the missing plants (**Table 2**). These results were independent of the variety, the plant population, or the fertilizer used. Thus, when up to 30% of the plants in the effective plot are missing, the root weight (in kg) of the remaining plants x 10 divided by the area (in m^2) of the effective plot will give the best estimate of actual yield (in t/ha). If more than 30% of the plants are missing, the yield data obtained should probably not be used; alternatively, some border row plants could be harvested and weighed to be included with the harvested plants in order to complete up to 70% of a complete plant stand in the effective plot. If more than 50% of the plants in the effective plot are missing, then the yield data of those plots should not be used. In any case, it is always useful to count and record the actual number of harvested plants in the effective plot as this may explain some of the observed yield differences.

Table 2. Summary of results of experiments on the effect of missing hills on yield as influenced by variety, population, and fertilization, in ViSCA, Leyte, Philippines.

Treatment	Yield[1] (t/ha)	Treatment	Yield[1] (t/ha)	Treatment	Yield[1] (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 hills (NS)		*Missing hills (NS)*		*Missing hills (*)*	
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)	

[1] Mean separation (LSD, 0.05).
***Source:** Villamayor, 1988.*

In some cases, plants are missing because they were stolen shortly before the experiment was harvested or plants were uprooted and the roots damaged by wild pigs. In that case, the plants surrounding the missing hills would not have benefited from reduced competition during the growth cycle and thus would not have increased yield. To determine the yield of the plot, the root weight of the remaining plants in the plot could therefore be corrected for those missing hills that were stolen or damaged shortly before the harvest.

9 On-station, on-farm, and farmer participatory research trials

In **on-station experiments,** researchers design and manage the trial with their own trained personnel and thus maintain full control over every aspect of the experiment. The experiment should have enough replications to obtain reliable results and to be able to analyze the data statistically. But, if soil or climatic conditions in the cassava-growing areas differ from those at the experiment station (at many stations, soil fertility is much higher than in farmers' fields due to repeated use of fertilizers or manures), then it may be better to conduct **on-farm experiments** in farmers' fields that are more representative of the agroecological conditions in which much of the cassava is grown. These experiments are still designed and mostly managed by researchers although the farmer may be paid for the land and for maintaining the trial free of weeds. The results are used by the researchers and the planting material produced is often taken away while the farmers receive the roots for their own consumption or for sale. These experiments also have replications and the data can usually be analyzed statistically.

In contrast, **farmer participatory research (FPR) trials** are designed and managed by volunteer farmers, who are also the owners of the trials and the owners of the results, the roots, and the planting material produced. Usually, researchers or extension workers first discuss with the farmers of a village (or pilot site) about cassava, how it is grown, what it is used for, and what might be the main problems for increasing yield. After this, farmers may want to visit some experiments at an experiment station or in another farmer's field to see and discuss possible solutions to their problems. They could be encouraged to test some of those solutions as treatments in simple FPR trials in their own fields in order to select the best varieties or practices. Researchers or extension workers should discuss and help farmers design these trials. Most of these trials have only five to eight treatments with one being the farmers' traditional variety or practice. In each trial, only one factor should vary among treatments while all other factors remain constant. Thus, in an FPR variety trial, the treatments consist of different varieties, while fertilization, weeding, etc., remain the same for all treatments. Similarly, in an FPR fertilizer trial, the treatments consist of different rates of NPK fertilizer or may have different combinations of N, P, or K fertilizer, but the variety and other practices are the same throughout the trial. These trials generally have small plots (see **Figure 4** for monoculture or **Figure 5** or **6** for intercropping) and no replications. If several farmers in the village conduct the same type of trial and all agree to use the same treatments, then each of these trials can be considered a replication. By calculating the average yield of each treatment across these trials, the results obtained become more reliable and more convincing.

At the time of harvest, researchers or extension workers harvest the trials together with the participating farmers. The roots of plants harvested in the effective plots are weighed and the weights recorded, while border rows remain standing. The harvested roots are left in a pile in the center of the plot with a sign indicating the root yield (and sometimes starch content).

The following day, a farmers' field day can be organized with the participation of other farmers from the village or from surrounding villages. Farmers are briefed about the objective of the field day and the type of trials that have been conducted. They then receive sheets with the layout of the various types of trials; they are asked to write down on those sheets their evaluation of each treatment (1 = very bad, 2 = OK, and 3 = very good) when they visit the trials. These evaluations can be based on the root yield shown with each pile of harvested roots; on root size, shape, and color; on the taste of raw roots; on the plant type of the plants still standing in the border rows; or on any other criteria farmers use. After visiting all the trials conducted in the village, the treatments and their average yield are shown on a large sheet of paper and the results discussed. For every treatment, farmers are asked to raise their hands if they had scored the treatment as "very good" (3). The number of hands raised is quickly counted and written down on the chart with the results. The treatments with the highest scores are obviously the most preferred. Reasons for farmers' preferences should be discussed. Besides data on yield (and starch content?), it is often useful to show the gross income from yield obtained, the estimated total production costs, and the resulting net income of each treatment. Farmers who sell their harvested roots generally prefer those treatments with the highest net income.

Thus, in FPR trials, farmers design and conduct the trials, and they make the final selection of the most suitable varieties and production practices. Researchers and extension workers help farmers in identifying and prioritizing their own problems, suggesting possible solutions, discussing designs, setting out the trials, solving any unexpected problems, and finally harvesting the trials and discussing the results. Researchers and extensionists do not promote or recommend any particular treatments, but let farmers make their own decisions and their own selections. Farmers are more likely to adopt those varieties or practices that they themselves have tested and selected as the most suitable for their own conditions.

10 Simple erosion control trials at experiment stations or in farmers' fields

To determine the effect of particular treatments on soil losses from erosion, researchers have generally done erosion control trials using "runoff plots" on a uniform slope at an experiment station. These experiments are expensive in terms of equipment used and are labor-intensive because soil losses and water runoff need to be determined after each rainfall event. To determine how certain agronomic practices affect soil losses from erosion, a much simpler method can be used that determines only the amount of eroded soil in each treatment by weighing the amount of wet eroded soil that is trapped in a plastic covered trench dug along the entire bottom edge of each plot. The amount of runoff water is not determined as the runoff is allowed to seep away through small holes made in the plastic. The eroded wet soil collects on top of the plastic and can be dug out and weighed every month or two to three times during the crop's growth cycle, mainly during the rainy season. After weighing the wet eroded soil, a sample of 1−2 kg is taken to be dried to determine the percent dry soil in the original sample. The amount of dry soil loss (t/ha) can be estimated from the weight of the wet soil collected and the dry matter (DM) content of the wet sample as follows: dry soil loss (t/ha) = wet soil (in kg/plot) × % DM/100, times 10, divided by the plot size (in m^2). One can plot the accumulative dry soil loss against time, from planting to the final harvest, in order to see when most soil loss from erosion occurred.

To get rather accurate data, one must take certain precautions:

a. The trial must be laid out on as uniform a slope as possible and plots are laid out side by side perpendicular to the slope, that is, on the contour. If there are many plots, these can also be laid out in two to three rows perpendicular to the slope as long as each plot has more or less the same slope. An example of such a trial is shown in **Figure 8**.

b. It is very important that the soil-collecting ditches be laid out exactly on the contour so that all runoff water will flow naturally into the ditches and not enter or leave the plot through side borders. If the contour line is not straight but curved, the ditches also need to curve to follow the contour. If the slope is not uniform and uni-directional, the plots may end up with curved borders and be trapezoidal rather than square or rectangular. This does not matter as long as we can more or less accurately determine the size of each plot.

c. Erosion must be caused only by the rainfall falling on the plot and not by runoff coming into the plot from the area upslope from the plot. To achieve this, a diversion ditch is dug along the upper side of the experiment, so that runoff water from above-slope is diverted away and does not enter the experimental plots. To prevent runoff water from entering or leaving through the side borders (which happens when the plots are not exactly on the contour), you can build a soil ridge or dig in a metal sheet along each side border.

d. The plastic-covered channel should be able to accommodate all the eroded soil and runoff water resulting from a heavy rainstorm. Usually, a 40 × 40 cm channel along the entire lower side of the plot is sufficient. The ditch is covered with a plastic sheet of 1.5−2.0 m width. The side edges are dug into the soil as shown in **Figure 8**. PVC plastic (used for shower curtains) generally lasts longer than polyethylene plastic. Exposed to the sun, the plastic may deteriorate after a while. A few holes or tears are not a problem as runoff water is allowed to seep out anyway, but, if the plastic deteriorates too much, it may need to be replaced. If runoff water does not seep out within a few days after a heavy rainstorm, it may be necessary to make additional holes in the bottom of the plastic sheet with a nail or pointed stick. If the channel is 40–50% full with eroded soil, this soil should be dug out and weighed so as to accommodate additional soil and runoff water during the next rainstorm without danger the channel will overflow. If the channel is not on the contour, soil and water will accumulate at one end with the possibility that soil and water will overflow at that end.

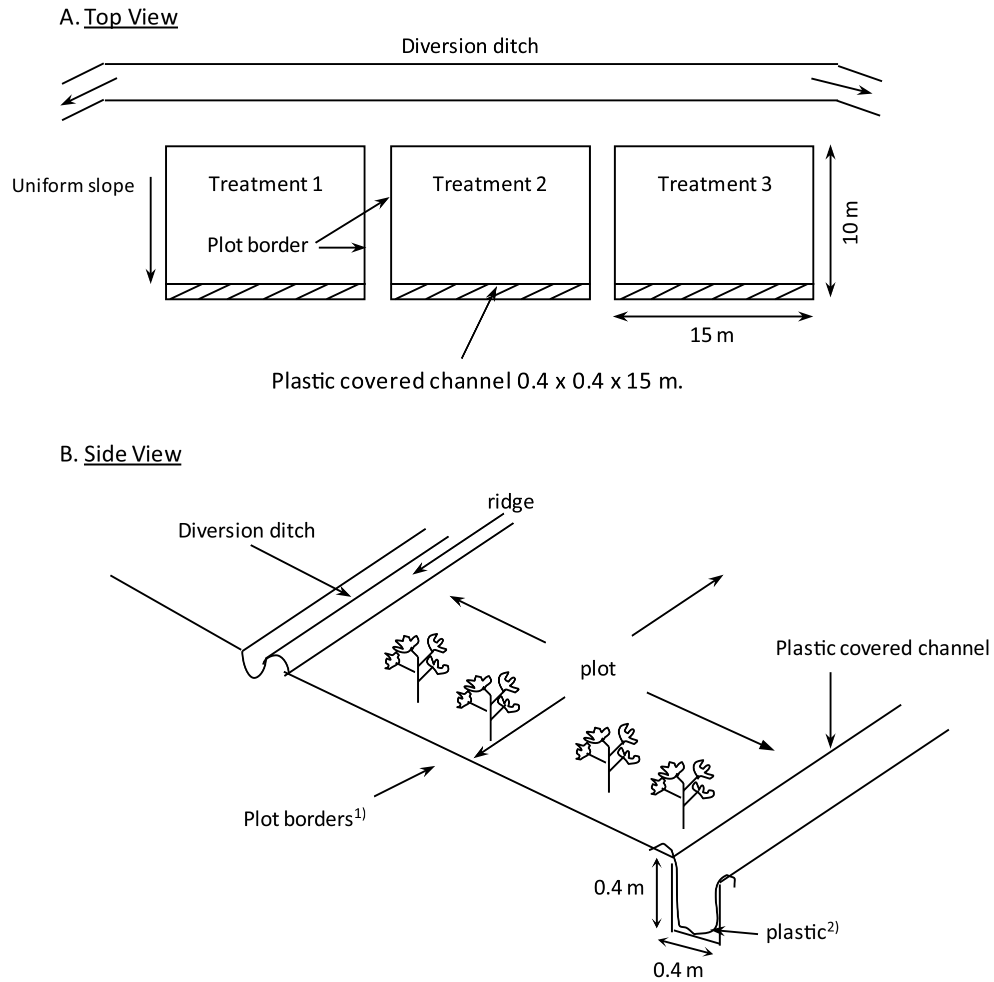

Figure 8. *Experimental layout of simple trials to determine the effect of soil/crop management practices on soil erosion.*

1) Plot borders of sheet metal, wood or soil ridge to prevent water, entering or leaving plots.
2) polyethylene or PVC plastic sheet with small holes in bottom to catch eroded soil sediments but allow run-off water to seep away. Sediments are collected and weighed once a month.

e. At the time of harvest, cassava plants in the effective plot (excluding one border row) are harvested and yield is determined according to the size of the effective plot. If contour hedgerows are planted as an erosion control treatment, these hedgerows as well as the adjacent cassava row(s) should be included as part of the effective plot, since they occupy space in the farmer's field; moreover, the hedgerows sometimes compete with the adjacent cassava rows and reduce their yield.

f. In case of FPR erosion control trials, the number of treatments (plots) should be limited to five or six, one of which is the farmer's traditional practice. The advantage of conducting these trials in farmers' fields is that farmers can see clearly which practices (treatments) are most effective in reducing soil losses from erosion by looking at the amount of eroded soil in each plastic-covered channel. Once they see how much soil (including water and fertilizer) they are losing each year, they will want to adopt those practices that are effective in reducing erosion while requiring little additional money or labor. For that reason, the gross income, total production costs, and net income, as well as soil loss, should be calculated and shown to farmers for each treatment, so farmers can make an informed choice about which erosion control practices to adopt.

11 Measuring the % slope of a piece of land

Figure 9 shows an easy way of measuring slope using a "line level"; this is basically a small carpenter level that has two hooks for hanging on a horizontal string. The string is exactly horizontal when the air bubble is between the lines indicated on the leveling device. One person holds one end of a 2-meter string on the soil surface, while a second person holds the other end of the string against a vertical pole (can be the handle of a hoe) and moves that end up or down until the carpenter's level indicates that the string is exactly horizontal. The distance (in cm) from the string on the pole to the foot of the pole (a in **Figure 9**) divided by b (= 200 cm) times 100 is equal to the % slope of the land.

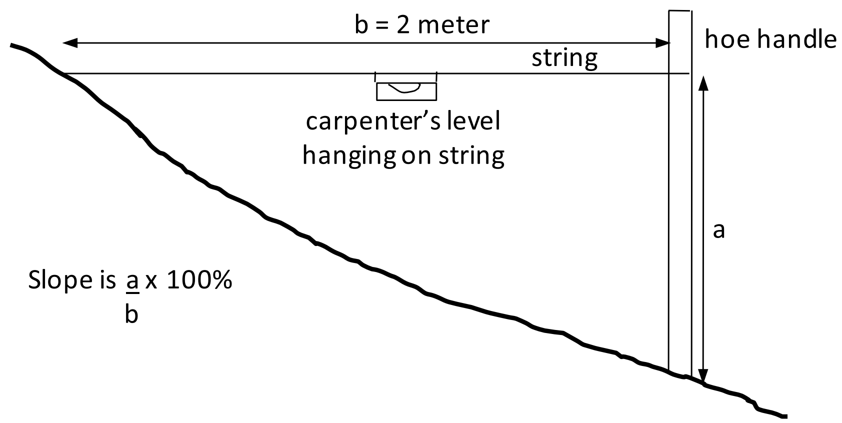

Figure 9. *Simple method to determine slope using a line level.*

12 Setting out contour lines

Most people are familiar with the A-frame (**Figure 10)** to set out contour lines. One leg of the A-frame is placed next to a stake placed to mark the beginning of the contour line, while the other leg is moved sideways until the string touches the mark on the horizontal bar of the A-frame. At that point, the two legs are level; a second stake is placed to mark the position of the second leg. This leg stays next to the second stake while the first leg is swayed around to find the third point of the contour line. The process is repeated over and over again until the whole contour line has been marked. The advantage of the A-frame is that it can be built from commonly used materials, such as wooden posts, string, and a stone used as weight. However, this method is time consuming and will not work well if the soil surface is rough or the path of the contour line is obstructed by weeds, bushes, or trees.

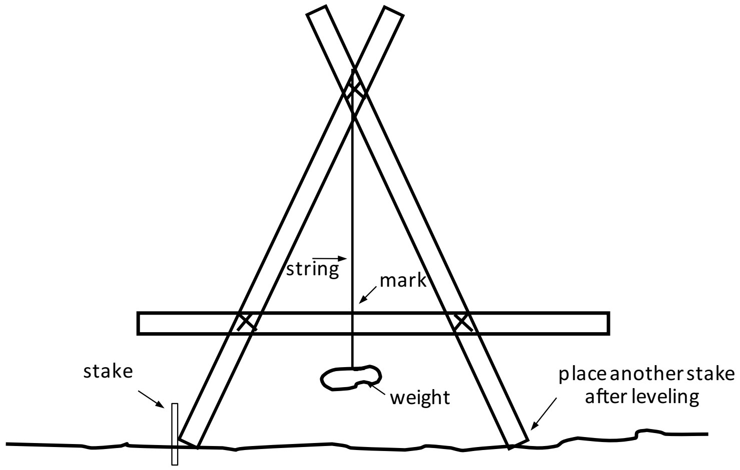

Figure 10. *A-frame to set out contour lines.*

Figure 11 shows an easier way again using a line level hung on a 10–20 m long string. Two poles (or hoe handles) are both marked at the same height, say, 1 meter. One pole is placed next to a stake placed to indicate the beginning of the contour line and a person holds one end of the string on the 1-meter mark. A second person moves 10–20 m away holding the other end of the string on the 1-meter mark on his/her pole. With the string tightened, a third person watches the line level hanging on the string between the two poles, signaling to the second person to move the second pole up- or down-slope until the line level indicates that the string is exactly horizontal. A second stake is placed at the foot of the second pole to indicate that the first two stakes are on the same level. The first person now moves his/her pole to the second stake and the process is repeated until the whole contour line has been marked. This method is much faster as the length of the string can be varied depending on the roughness of the terrain, and the string can go around obstacles in the path of the contour line.

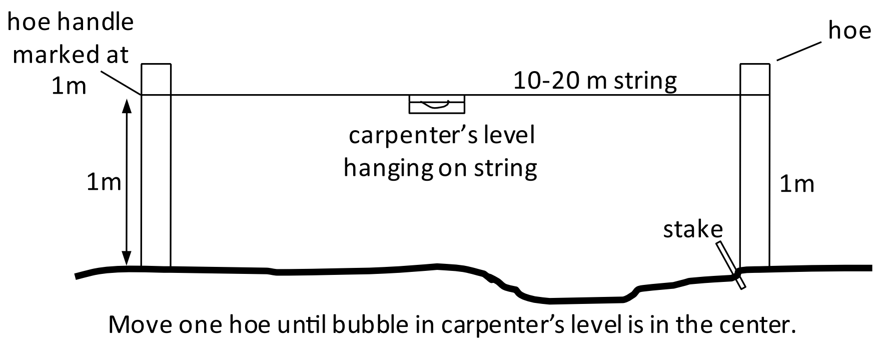

Figure 11. *Simple method to set out contour lines using a line level.*

Figure 12 shows a third method (called "buffalo horn") using a clear plastic tube that is half filled with water. The tube is tied to a vertical pole marked at eye level, say, at 1.6 m, so that the water level is at the height of the mark. A second pole is marked at the same level as the first. A second person moves the second pole 10–20 m away. The first person signals to the second person to move the pole up- or down-slope until he/she can see the mark on the second pole exactly across the two water levels in the plastic tube. In that case, the position of the two poles is on the same level in the landscape. This can be marked by placing stakes; the process is repeated until the whole contour line has been marked.

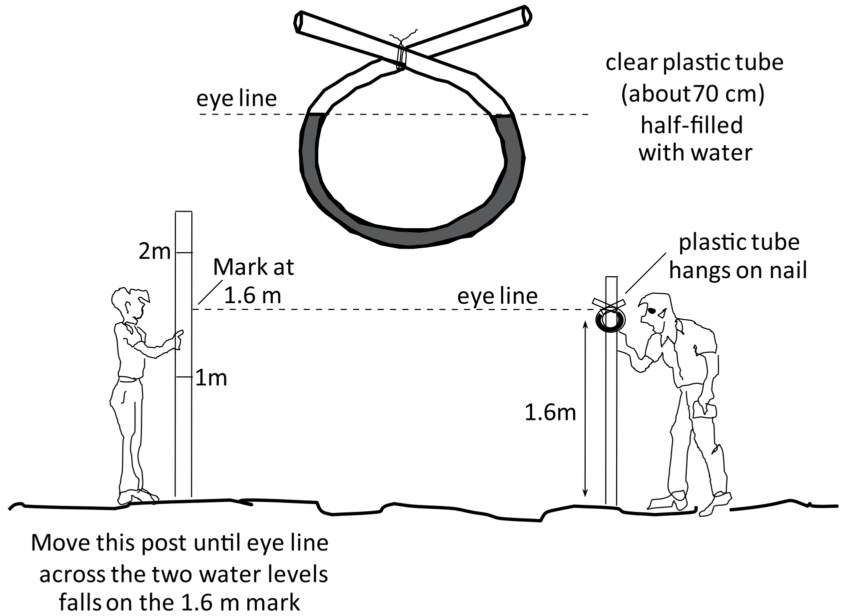

Figure 12. Simple method to set out contour lines using a plastic tube with water: the "buffalo horn".

13 Determination of the starch content of cassava roots

The percent starch or dry matter (DM) in cassava roots can be determined or calculated rather quickly from the specific gravity of the roots. The higher the specific gravity (kg/liter), the higher the starch and DM content of the fresh roots. The specific gravity can be determined by weighing a certain amount of fresh roots in air and then weighing the same roots completely submerged under water. Many starch factories use a special starch balance, with which they first weigh exactly 5 kg of fresh roots in a basket hanging in air, and then transfer these roots into a second basket hanging in water. A second scale of the same balance indicates both the weight of the root sample under water and the starch content. Farmers get paid a certain price according to the starch content of the roots.

While a specially made starch balance is convenient, it is not essential. The same methodology can be applied using two different balances, one of 10 kg capacity, to weigh in the air about 5 kg of fresh roots (cut in smaller chunks) placed in a nylon screen bag. After recording the exact weight of the roots (anywhere between 4 and 6 kg), the bag with roots is hung on a hanging scale of 1,000 g capacity while being completely submerged under water, without touching the bottom or sides of the container, such as a plastic garbage can filled with water. The second balance indicates the weight of the cassava roots under water; this tends to be 10–15% of their weight in air. Thus, a 5-kg sample of fresh cassava roots may weigh anywhere between 500 and 650 g when completely submerged under water. The starch or DM content can be calculated as follows:

$$\text{Specific gravity } X = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$$

$$\text{Starch content} = 210.8\,X - 213.4$$

$$\text{DM content} = 158.3\,X - 142.0$$

and

$$\text{Starch content} = 1.33165 \times (\%\ \text{DM}) - 24.306$$

As an example: fresh roots of a certain variety are cut into smaller chunks and put in a nylon screen bag and the bag is weighed on a normal kitchen balance. The weight is 4.53 kg or 4,530 g. When the same bag of roots is completely submerged under water and weighed again with the hanging scale, its weight is now only 550 g. In that case, the specific gravity of the roots is

$$X = \frac{4{,}530}{4{,}530 - 550} = \frac{4{,}530}{3{,}980} = 1.1382 \text{ kg/liter}$$

Starch content of the roots = (210.8 × 1.1382) – 213.4 = 26.53%
and DM content = (158.3 × 1.1382) – 142.0 = 38.18%

With this simple method, we can rapidly determine the starch and DM content of the roots; the higher the starch or DM content is, the more valuable the roots are for the starch, animal feed, or ethanol industries, and thus the higher the price that they are willing to pay for the roots. For that reason, cassava breeders will normally select those varieties having both high yield and high starch or DM content. To obtain accurate data, it is important to tare the balances with the empty baskets or nylon bag in the air or in water.

CHAPTER 1:
WHAT IS CASSAVA, WHERE IS IT GROWN, AND WHAT IS IT USED FOR?

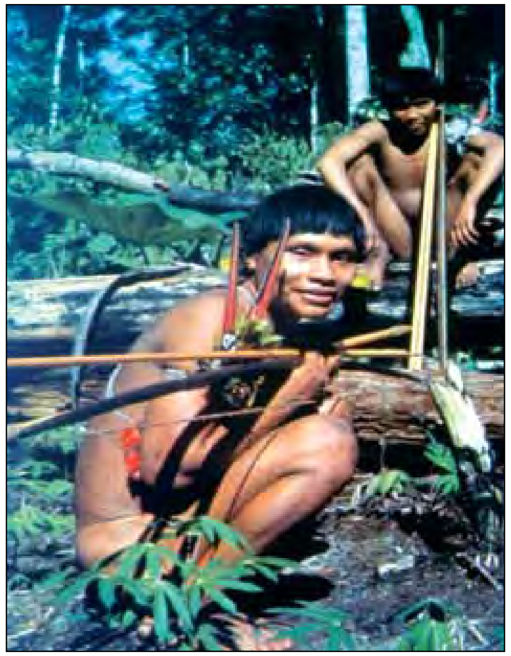

Photo 1. *Cassava originated in the Amazon region of Brazil*

Photo 2. *Cassava Rayong 9. A beautiful plant type*

Photo 3. *Roots evenly distributed around the stem*

Photo 4. *A typical landscape of intercropped cassava in North Vietnam*

Photo 5. *A large cassava field in Battambang, Cambodia*

Photo 6. *A bountiful harvest in Thailand*

Photo 7. *Cassava is an important food for minority people living in Nam Dong, Vietnam*

Photo 9. *Boiled cassava is a preferred snack for kids in Phou Lath, Lao PDR*

Photo 11. *In Thailand most cassava is chipped and sun-dried*

Photo 8. *In Luang Prabang, Lao PDR, cassava leaves are boiled for lunch*

Photo 10. Ensiled cassava leaves are fed to pigs in Hong Ha, Hue, Vietnam

Photo 12. *In China, most fresh roots are processed into starch*

CHAPTER 2:
HOW IS CASSAVA GROWN?

Photo 1. *In Kanchanaburi, Thailand, cassava grows quite well*

Photo 2. *In Vietnam, cassava is often grown in the uplands, above the rice paddies*

Photo 3. *In Pati, Indonesia, cassava grows luxuriously*

Photo 4. *In Yen Bay province of Vietnam, some cassava is grown up and down the mountains*

Photo 5. *In Kerala, India, much cassava is now grown in the lowlands after rice*

Photo 6. *In China, cassava is often planted along strips of plastic mulch to warm the soil and enhance germination*

CHAPTER 3:
WHAT ARE THE MAJOR CONSTRAINTS TO HIGH YIELDS?

Photo 1. *Cassava is often grown on very poor soils*

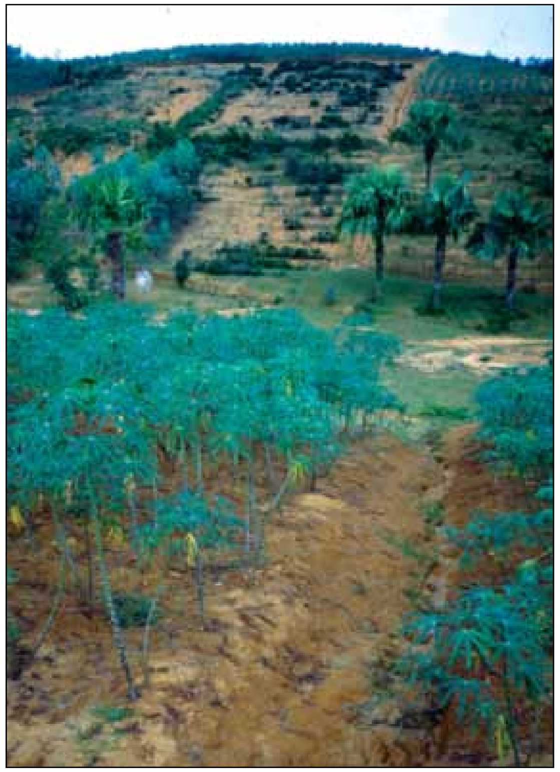

Photo 2. *When poorly managed, cassava can seriously degrade the soil*

Photo 3. *On very light textured soils, cassava can cause serious erosion*

Photo 5. *In many cassava fields, weeds are a serious problem*

Photo 4. *When heavy machinery is used, the soil can become very compacted, leading to water logging*

Photo 6. *The spiraling whitefly is a major pest in East Timor*

Photo 7. *The arrival of the pink mealybug has greatly affected cassava production, especially in Thailand*

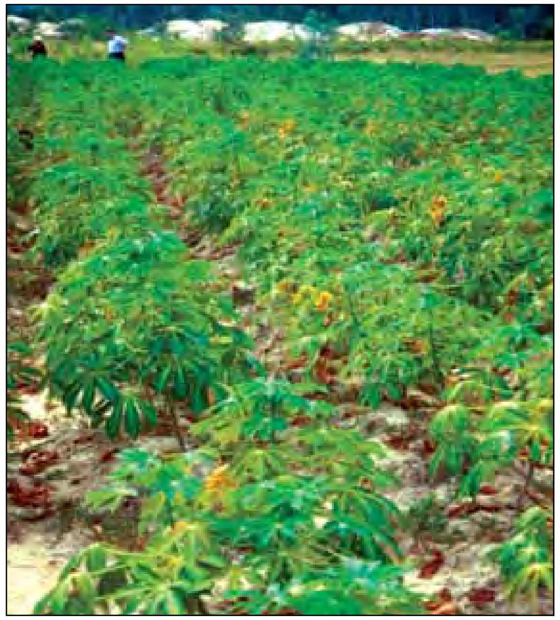

Photo 8. *During the dry season, the red spider mite can cause serious defoliation*

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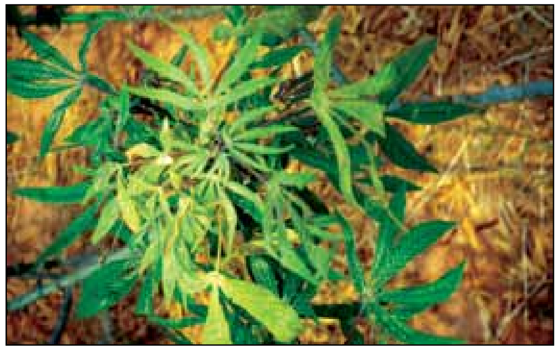

Photo 15. *Zn deficiency in lime stone-derived soil in Huay Bong, Thailand*

Photo 16. *Zn deficiency in alkaline soil at CIAT, Colombia*

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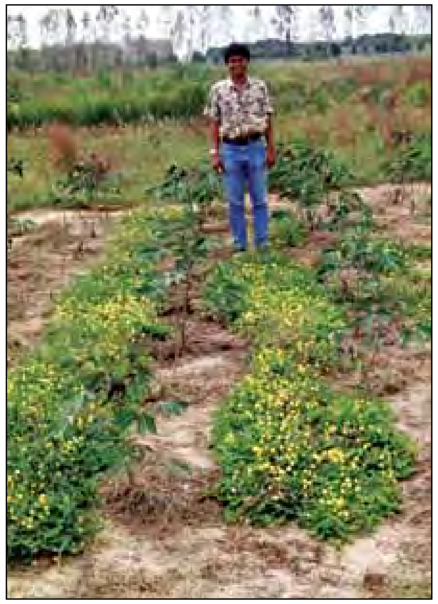

Photo 7. *Poor growth of cassava due to strong competition from Arachis pintoi cover crop*

Photo 8. *Evaluating green manure species at Rayong FCRC in Thailand*

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Photo 2. *Serious gully erosion at TTDI, Thailand*

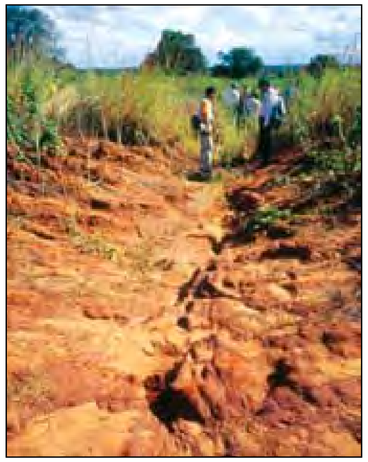

Photo 3. *Top soil is completely washed out in a natural drainage way*

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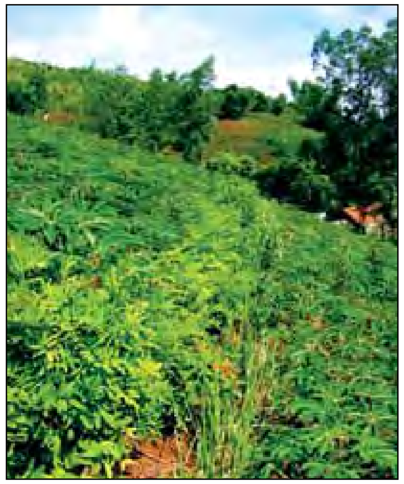

Photo 14. *Adoption of contour hedgerows of Tephrosia candida and vetiver grass in Vietnam*

Photo 15 *Adoption of contour hedgerows of vetiver grass in cassava fields in Thailand*

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Photo 3. *Soil erosion control experiment using brick channels*

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Photo 6. *After two years an 80 cm high terrace riser had formed behind the sand bag and vetiver grass barrier*

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