BIBLIOGRAPHIC DATA SHEET	1. CONTROL NUMBER PN-AAJ-140	2. SUBJECT CLASSIFICATION (695) AF00-1540-0000

3. TITLE AND SUBTITLE (240)

Intercropping with cassava; proceedings of an international workshop held at Trivandrum, India, 27 Nov.-1 Dec, 1978

4. PERSONAL AUTHORS (100)

5. CORPORATE AUTHORS (101)

Int. Development Research Ctr.; Central Tuber Crops Research Inst., Trivandrum, India

6. DOCUMENT DATE (110)	7. NUMBER OF PAGES (120)	8. ARC NUMBER (170)
1979	142p.	633.68.C397

9. REFERENCE ORGANIZATION (130)

IDRC

10. SUPPLEMENTARY NOTES (500)

(In IDRC- .42e)
(Cosponsored by the Central Tuber Crops Research Inst. and the Int. Development Research Ctr.)

11. ABSTRACT (950)

12. DESCRIPTORS (920)

Intercropping
Agricultural research
Cropping patterns
Cassava
Soil fertility
Multiple cropping

13. PROJECT NUMBER (150)

931078600

14. CONTRACT NO.(140)

AID/ta-G-1406

15. CONTRACT TYPE (1[illegible])

16. TYPE OF DOCUMENT (160)

21

AID 590-7 (10-79)

633.68
C397

Intercropping with Cassava

Proceedings of an international workshop held at Trivandrum, India, 27 Nov–1 Dec 1978

Editors: Edward Weber, Barry Nestel, and Marilyn Campbell

CANADA

IDRC-142e

PN- AAJ-140

IDRC-142e

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Editors: Edward Weber,[1] Barry Nestel,[2] and Marilyn Campbell[3]

Cosponsored by the

Central Tuber Crops Research Institute (Indian Council for Agricultural Research)

and the

International Development Research Centre

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Erratum

Cassava Harvesting and Processing: Proceedings of a Workshop held at CIAT, Cali, Colombia, 24–28 April 1978. IDRC-114e. *Editors:* Edward J. Weber, James H. Cock, and Amy Chouinard. Ottawa, IDRC, 1978. 84p.

The trials reported by Dietrich Leihner in his paper *Follow-up Evaluation of Two Harvesting Machines* (p. 58–59) did not equate the performance of the CIAT and Richter machines demonstrated at the cassava workshop. Therefore, the last statement in the abstract, which was included without the author's corroboration, may be misleading. For the same reason, the caption under the accompanying photograph (p. 59) is also misleading. The Richter machine is a full-scale harvester with an elevator that delivers the roots to a truck or other means of transport; the CIAT implement is a harvesting aid that only digs the roots to be picked up by labourers.

IDRC regrets this editorial change that may have suggested the Richter Engineering Pty Ltd. machine was inferior to the CIAT equipment.

4

Foreword

This publication represents the 15th volume published by IDRC in its cassava monograph series. Most have been the result of small workshops organized by IDRC in collaboration with research institutions working on cassava. These workshops usually involve small numbers of experienced researchers and policymakers from around the world who are brought together to present papers, discuss a defined topic or problem in a structured way, and suggest further research and program priorities.

For some time it has been a concern that a great deal of the improvement work on cassava has been monocrop oriented even though as much as 50% or more of total cassava production in some regions is grown by small farmers in multiple cropping systems. Since 1972, IDRC has been involved in supporting and encouraging major research efforts in both cassava and multiple cropping systems and, therefore, it seemed logical and timely to bring the experience of these two networks together and focus on the problems and benefits of intercropping cassava with other crops.

IDRC cassava research support has been strongly oriented to the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia, and its outreach network in Latin America and Asia. Cropping systems research support has been concentrated on the International Rice Research Institute (IRRI), Los Baños, Philippines, and collaborating national research programs in more than half a dozen southeast Asian rice-producing countries. Considerable research on both cassava and small farm production systems has also been carried out in Nigeria at the International Institute of Tropical Agriculture (IITA) and in Turrialba, Costa Rica, at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). Specific papers were invited from each of these institutions as well as from national research programs in Brazil, India, Indonesia, Malaysia, the Philippines, and Thailand. The objectives of the meeting were: to review past and ongoing research on multiple cropping systems that include cassava; to examine the methodologies used in this research in the context of cassava improvement programs; and, to establish guidelines for future research on cassava intercropping problems.

The workshop was jointly sponsored with IDRC by the Indian Council for Agricultural Research (ICAR) and its dependent Central Tuber Crops Research Institute (CTCRI) located in Trivandrum, Kerala, India. CTCRI is carrying out a major cassava development program strongly related to small farmers' needs and intercropping practices and thus provided an excellent environment in which to discuss and study cassava intercropping.

The first two days of the workshop program were devoted to field visits. This enabled the participants to visit CTCRI's central research station and a number of its field trials on farmers' farms. It also presented the opportunity to see examples of cassava processing in Kerala. The third day of the meeting was devoted to a series of papers describing current practices relating to intercropping with cassava in dif-

ferent countries and current research being undertaken in this field. The fourth and final day of the meeting reviewed the methodologies used in this research and attempted to establish guidelines for future research activities involving intercropping with cassava.

The meeting benefited considerably from the strong support given to it by the Kerala State Government whose Chief Minister Shri P.K. Vasuderan Nair and Minister of Agriculture Shri A.L. Jacob addressed the opening session, which also had the pleasure of listening to the Archbishop of Trivandrum, His Grace Benedict Mar Gregorius, whose specialized knowledge of root crop agriculture made him a welcome addition to the meeting participants.

Many thanks are due Dr N. Hrishi, CTCRI Director, and his staff for their excellent administrative and organizational as well as technical input to the meeting, which ensured its success. Mention must also be made of the valuable contribution of the three rapporteurs, Douglas Wholey, Jerry McIntosh, and Gordon Banta, who ably commented on the methodological papers and summarized the content of ensuing discussions. The logistical and organizational support of Robin Hallam and Esther Chan of the IDRC regional office in Singapore is also gratefully acknowledged.

It is hoped that the papers and discussion summary included in this publication will prove useful and stimulating to cassava and farming systems researchers as well as agricultural development policymakers, and serve to inspire new advances in research, ideas, and production programs oriented toward improving small farmer production systems including cassava as an intercrop.

Edward Weber
and
Barry Nestel

Multiple Cropping Cassava and Field Beans: Status of Present Work at the International Centre of Tropical Agriculture (CIAT)

M. Thung and J. H. Cock

International Centre of Tropical Agriculture, Cali, Colombia

The cassava program at the International Centre of Tropical Agriculture (CIAT) has basically been developing monoculture systems for cassava production. However, an agroeconomic survey in Colombia showed that about 40% of cassava is grown in mixed culture (Diaz and Andersen 1977). The authors furthermore estimated that in Latin America the figure of 40% is probably fairly representative. Okigbo (1976) estimated that in Africa about half the cassava is grown in mixed cropping systems. In general, the mixed cropping systems are used by the smaller farmers from the lower income groups. In the last 2 years, the CIAT Cassava Program has started serious investigations on cassava intercropping systems.

The cassava crop is among the most efficient calorie producers (250 kilocalories ha^{-1} day^{-1}) of the major crops (Coursey and Haynes 1970). The protein content of cassava is, however, very low and hence in CIAT we decided to concentrate on cassava grain legume mixes, so as to give a combination that might more nearly satisfy dietary requirements.

The emphasis of the research has been on cassava and *Phaseolus vulgaris* as CIAT has expertise on both these crops. We have not tried to develop multiple cropping systems as such, but rather have attempted to define what parameters are important in determining the yield of the two crops when grown together and later use this knowledge to design more efficient systems of production.

The cassava crop is generally slow to cover the ground, with complete cover occurring some 3 months after planting. Changing the spatial arrangement from rectangular to square can further delay the time to full ground cover without apparently reducing cassava yield (Cock et al. 1978). The cassava crop is, however, highly sensitive to early competition (Doll and Piedrahita 1974). The bean crop develops very rapidly and often completes its growth cycle in 90 days or less. This led us to the hypothesis that it should be possible to grow a bean crop under the cassava crop, in such a manner that it did not compete for light but utilized the light not intercepted by the cassava.

Not only has multiple cropping been suggested as a means for maximizing capture of solar energy, but also as a probable control method for diseases and pests. This pest control could be of tremendous importance for the small farmer with limited resources who cannot use purchased inputs to control disease and pests. Hence we have started to investigate the advantages of mixed cropping in this context.

Whilst planning the trials to investigate multiple cropping systems we became aware that experimental design was often necessarily extremely complex. Many of the trials done previously on multiple cropping systems have used a number of different treatments and cropping systems; however, the results have been difficult to interpret because of the enormous number of interactions. In our trials we have tried to study the effects of varying only one parameter and have observed this factor in detail. The authors feel that this approach may not necessarily lead to immediate optimum solutions to multiple cropping systems but that it will eventually give the insight necessary to design successful multiple cropping systems.

Experimental Site

All experiments were carried out at CIAT headquarters, which is located 3° north of the equator, at 1050 m above mean sea level, on a heavy fertile alluvial soil. Mean annual temperature is 24 °C with little seasonal change; the rainfall is bimodal with two wet and two dry seasons with a total of approximately 1100 mm per year. Beans were irrigated as necessary during the dry periods. The characteristics of the different cassava clones and grain legumes are shown in Table 1.

Table 1. Characteristics of cassava and dry bean varieties used in the experiments.

Cassava: *Manihot esculenta* (Crantz)	
M Mex 11	A germ-plasm collection variety; has a medium early growth vigour, single erect stemmed and late branched; a good and stable yield performance.
M Mex 59	A germ-plasm collection variety; has a moderate early growth vigour but early branched type; heavy foliage stand 3 months after germination; also a good and stable root producer.
M Col 113	A germ-plasm collection variety; has a poor early growth vigour, early branched type; heavy foliage stand 3 months after germination.
Bean: *Phaseolus vulgaris* L.	
P 302	A black bush bean with a growth habit II, indeterminate erect type; growth cycle 80 days at CIAT conditions; a good yielder.
P 566	A bush black bean with growth habit II, indeterminate erect type, growth cycle less than 80 days at CIAT conditions.
P 498	A black bean with growth habit IV, indeterminate prostrate type, growth cycle more than 90 days at CIAT conditions.

Planting Date

When the relative date of planting of beans and cassava (P 302 and M Mex 11 respectively) was altered, the relative yield of the two crops changed markedly (Fig. 1). The yield of beans was greatest when the beans were planted before the cassava and lowest when planted after. The yields of cassava were completely in the opposite direction. The maximum reduction of cassava yield was 25% when the beans were planted 2–4 weeks before the cassava. Planting cassava and beans at the same time gave the highest Land Equivalent Ratio (LER) (1.7). The LER was corrected for total time of land use, which was greater when beans were planted before the cassava (Fig. 2). The yield of fresh cassava was 35 t/ha and of beans (14% moisture) 2.9 t/ha when planted at the same time; these high yields suggest great potential for cassava-bean mixed cropping systems.

Soybeans (var. ICA-Tunia) were planted 1 month before, at the same time, and 1 month after cassava. The medium vigour late branching M Mex 11 and the vigorous early branching M Mex 59 cassava clones were used. When soybeans were planted 1 month after cassava, yield was essentially zero and when planted 1 month before the cassava, soybean yields were the same in mono or mixed culture. When planted at the same time as the cassava, yields of soybeans were slightly reduced (Fig. 3). Yield of cassava roots was very variable due to a high percent of root rot caused by very heavy rain just before harvest. The total harvested biomass of cassava was, however, very greatly reduced by planting soybeans before cassava. It appears once again that the optimum planting date is both crops at the same time (Fig. 4).

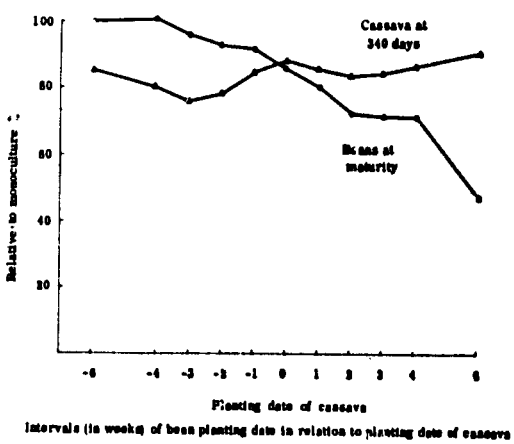

Fig. 1. Yield of cassava (root dry matter) and beans (14% moisture content) at different relative planting dates.

Plant Population

To study different plant populations using a traditional randomized block design it was necessary either to use a restricted number of plant populations or a very large experiment so as to eliminate border effects. To avoid these problems the cassava plant population was varied by systematically changing the distance between plants in the row. Hence each population is bordered on one side by a slightly lower plant population and on the other side by a slightly higher plant population.

In a monoculture system, the yield of the two bean varieties P 302 and P 498 were not significantly different and were not insignificantly increased by increasing the plant population up to 40 plants/m². The yield of P 498 in association was not affected by

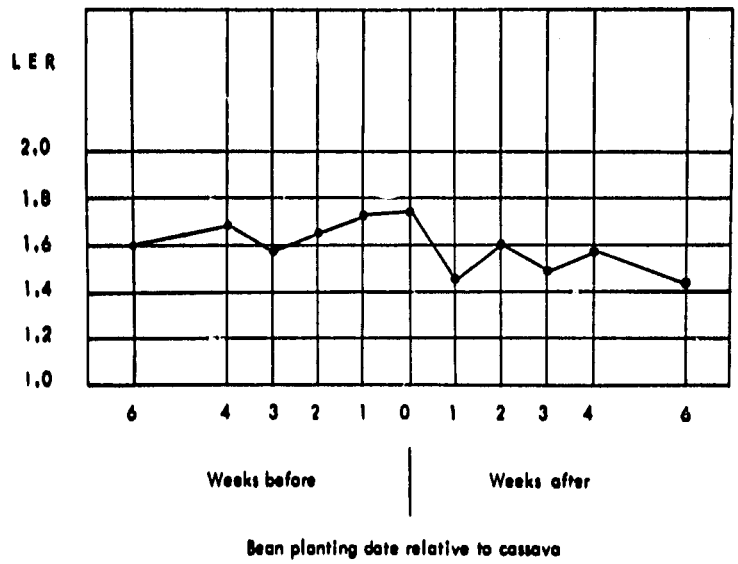

Fig. 2. Land equivalent ratio (LER) of cassava-bean associations at different relative planting dates (cassava, M Mex 11; bean, cv P 302).

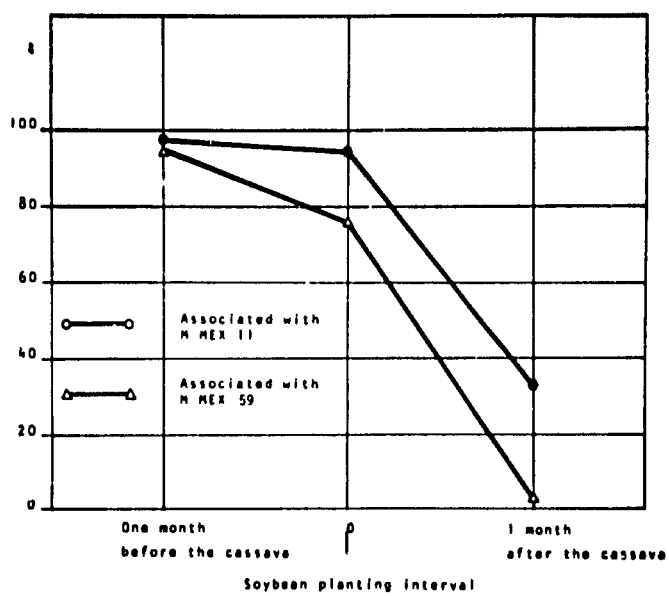

Fig. 3. Dry soybean yield at maturity when soybean was planted before, at the same time, or after cassava (monoculture yields, 3.4 t/ha).

changes in plant population, but P 302 showed a tendency for yield to increase with increasing plant population. The bean yields in association with M Col 113 were always higher than with M Mex 11 (Fig. 5). M Col 113 is less vigorous than M Mex 11 in the early stages. Bean yields decreased as the cassava density increased (Fig. 6). The maximum yield of cassava in monoculture was 39.4 metric tonnes (t) per hectare with M Mex 11, and 26.0 t per hectare with M Col 113. The cassava yield of M Mex 11 increased as cassava population increased either in monoculture (Fig. 7) or in association (Fig. 8),

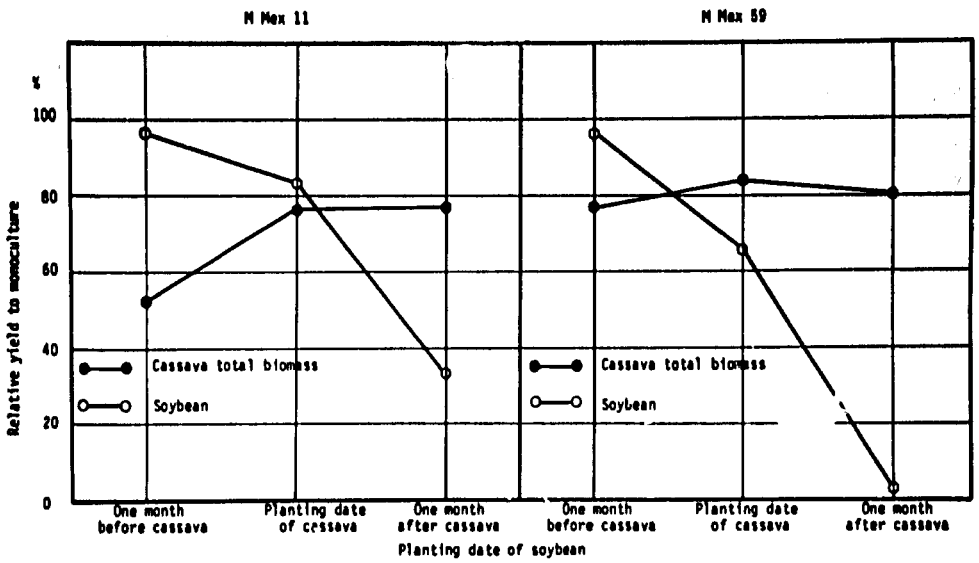

Fig. 4. Relative yield of cassava and soybean as affected by different planting date of soybean.

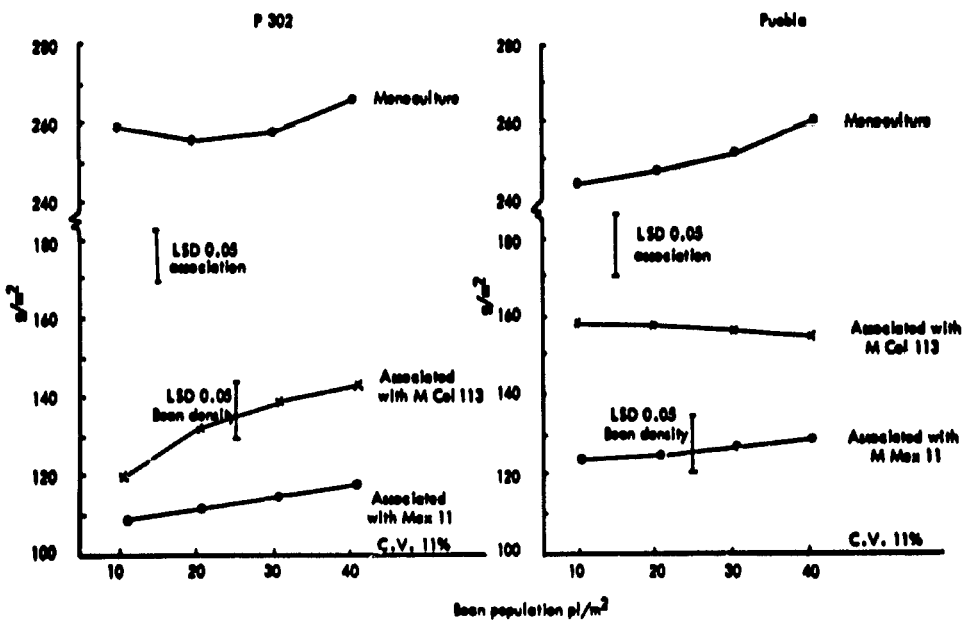

Fig. 5. Dry bean yield as affected by plant density of beans, alone and in association with cassava.

whereas the yield of M Col 113 tended to decline when the plant population increased. The yields of M Col 113 when intercropped with P 302 were sometimes higher than in monoculture of M Col 113 itself. This apparent anomaly is probably due to a reduction of early growth, which reduces leaf area index (LAI) to the optimum level and consequently improves yield (CIAT 78). Intercropping M Col 113 with the more vigorous P 498 did not give the same result, probably because the competition of the P 498 with the cassava reduced LAI below the optimum and hence reduced yield. Cassava yields were not affected by bean population.

The cassava yields in association with P 498 were

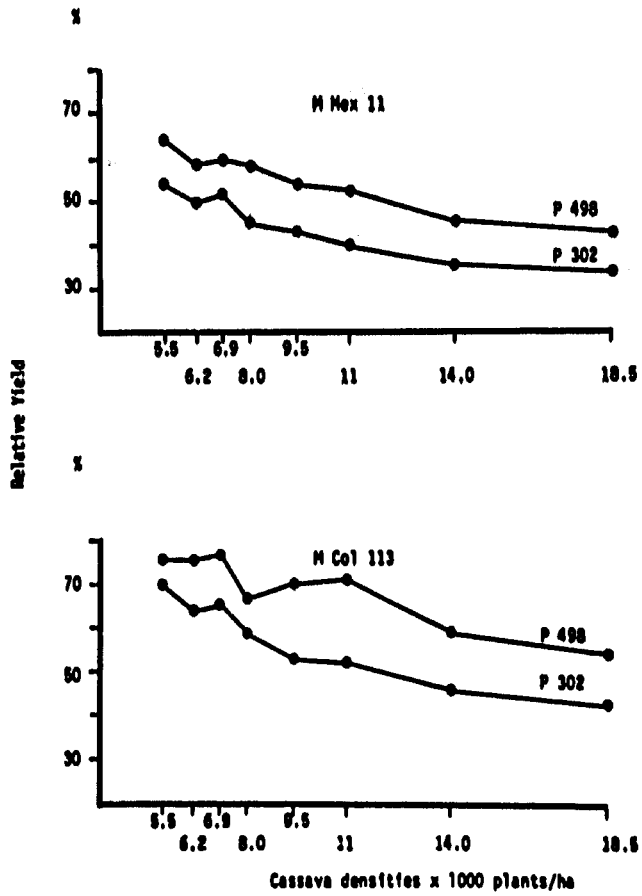

Fig. 6. Dry bean yield as affected by cassava densities.

less than those with P 302; however, P 498 gave higher yields in association than P 302. Hence it may be difficult to select bean varieties that yield well in association but do not greatly depress the cassava yield. The highest LERs were in fact obtained by the combination of P 302 and M Mex 11 (Fig. 9). It should be noted that the growth cycle of P 302 is 80 days and P 498 is more than 90 days. These LERs were obtained at normal monoculture densities for cassava (10 000 plants/ha) and beans (250 000 plants/ha).

Genotypic Variation

Twenty different cassava clones were planted 2 weeks before the black bean P 566. The bean yield was negatively correlated with the top growth of cassava 3 months after planting (Fig. 10) but there was no correlation between final cassava yield and bean yield. This suggests that cassava types can be selected that cause minimum reduction in bean yield but also yield well. Cock et al. (1978) have shown that late branching is a desirable character for high yields in monoculture; late branching varieties presumably will give less shade to the grain legume in the early stages.

When 20 cassava clones were planted with a 125-day soybean (var. ICA-Tunia) there was a negative correlation between cassava root yield and soybean yield (Fig. 11). This suggests that with a short season (less than 90 days), grain legume, cassava types can be selected that are both high yielding and also allow enough light to pass to enable the grain legume to yield well; however, in the case of longer season grain legumes this cannot be achieved as the low light interception of cassava for a period of 4 months is detrimental to its final yield.

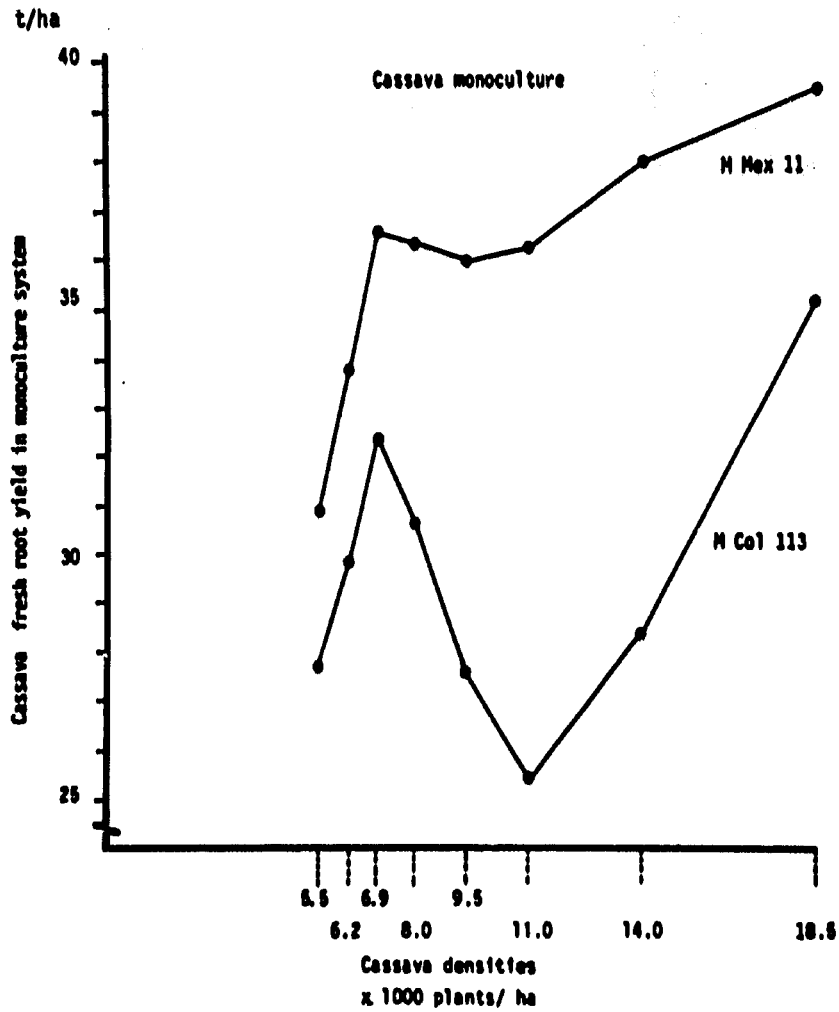

Fig. 7. Cassava yield as affected by plant densities.

Pest Control

The monoculture system has been criticized because the genetic and stand uniformity results in continuous pest susceptibility (Pimentel 1961; Southwood and Way 1970; Nickel 1973). Multiple cropping systems on the other hand are praised because the diversity of vegetation within the crop area can be used to give integrated pest management (DeLoach 1970; Dempster and Coaker 1974; Altieri et al. 1978).

To study the plant protection potential of the intercropping system, a field experiment was set up and the insect population was measured in a cassava bean intercropping system both with and without insect control systems.

The populations of lace bug and whiteflies were less in the intercropping system than in the cassava monoculture with or without plant protection. Hornworm populations were lower in the intercropping system than in the cassava monoculture without insecticide (Table 2).

Similar results were obtained in the beans: Diabrótica and Ceratoma and thrips populations were lower in the intercropping system compared to the monoculture system and the lowest insect population was found in the intercropping system when insecticides were applied (Table 3).

The yield of cassava was reduced little by mixed cropping with beans in the no insecticide treatment and the bean yield was essentially the same in the mixed and monocropping system (Fig. 12). Hence,

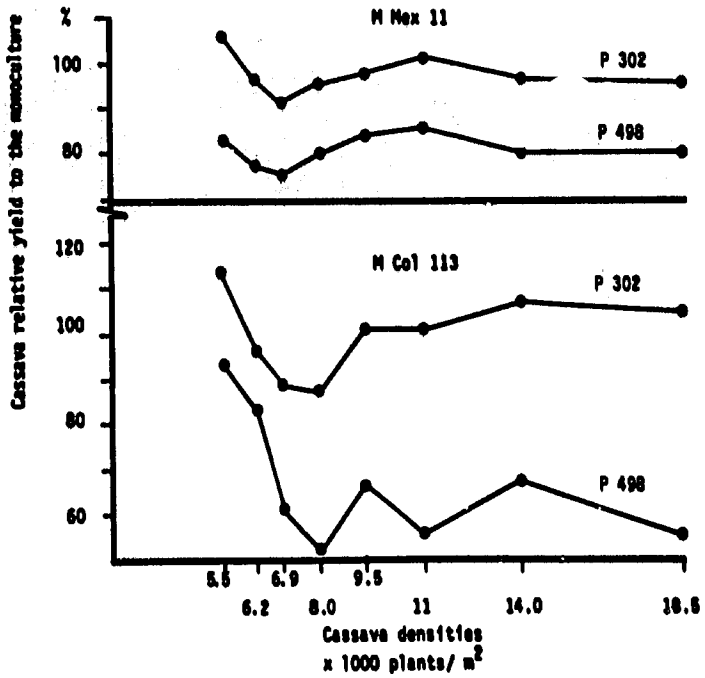

Fig. 8. Cassava yield when intercropped with P 302 and P 498 as affected by different cassava densities.

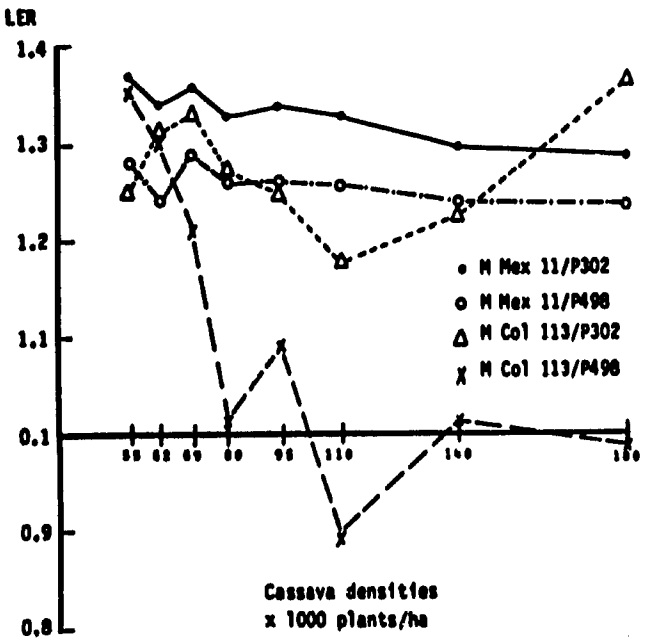

Fig. 9. Land equivalent ratio of different combinations as compared to best monoculture yield of cassava and bean.

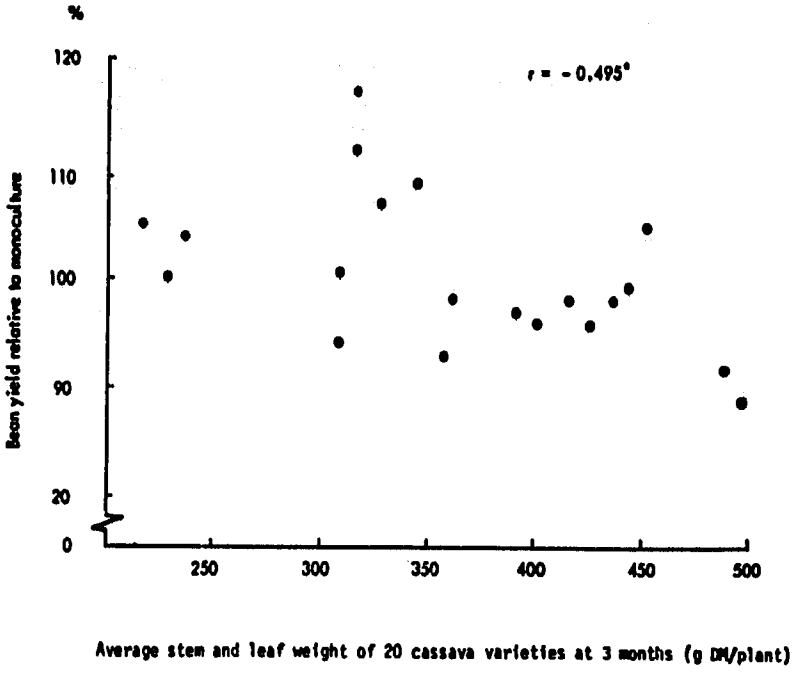

Fig. 10. Bean yields relative to monoculture as affected by different cassava genotypes.

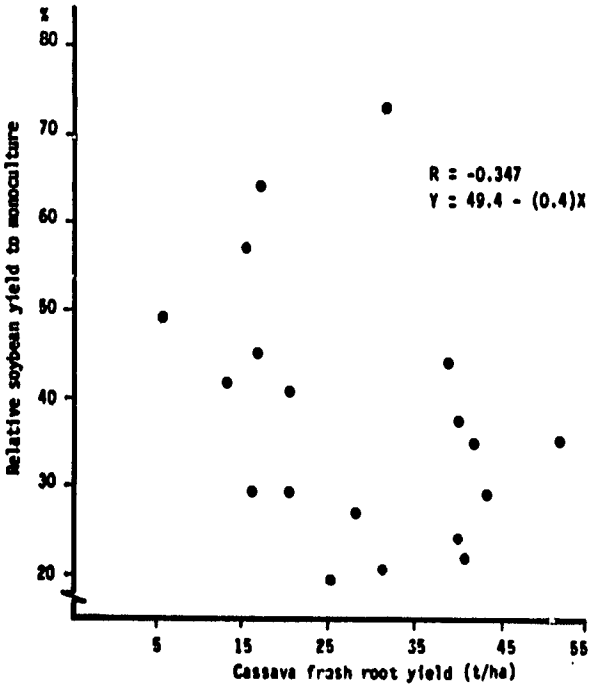

Fig. 11. Soybean yields relative to monoculture as affected by different cassava genotypes.

Table 2. Insect population in cassava monoculture vs. intercropping system cassava-bean, with and without insecticide treatment.

Insect	Cassava monoculture[a]		Cassava intercropped[b]		% in population reduction by different system
	With insecticide[c]	Without insecticide	With insecticide[c]	Without insecticide	
Lace bug, 3 leaves/plant	4.5	5.6	2.7	3.8	32.1
White fly 3 leaves/plant	7.2	6.5	3.3	4.5	30.0
Shoot fly/plot	2.1	2.0	1.5	2.2	
Hornworms/plot	0.5	0.8	0.5	0.6	30.0
Hornworm eggs/ parasitized plot	50.7	52.4	51.2	45.5	

[a]Cassava variety M Mex 11.
[b]Bean variety P 566 with M Mex 11.
[c]Endosulfan.

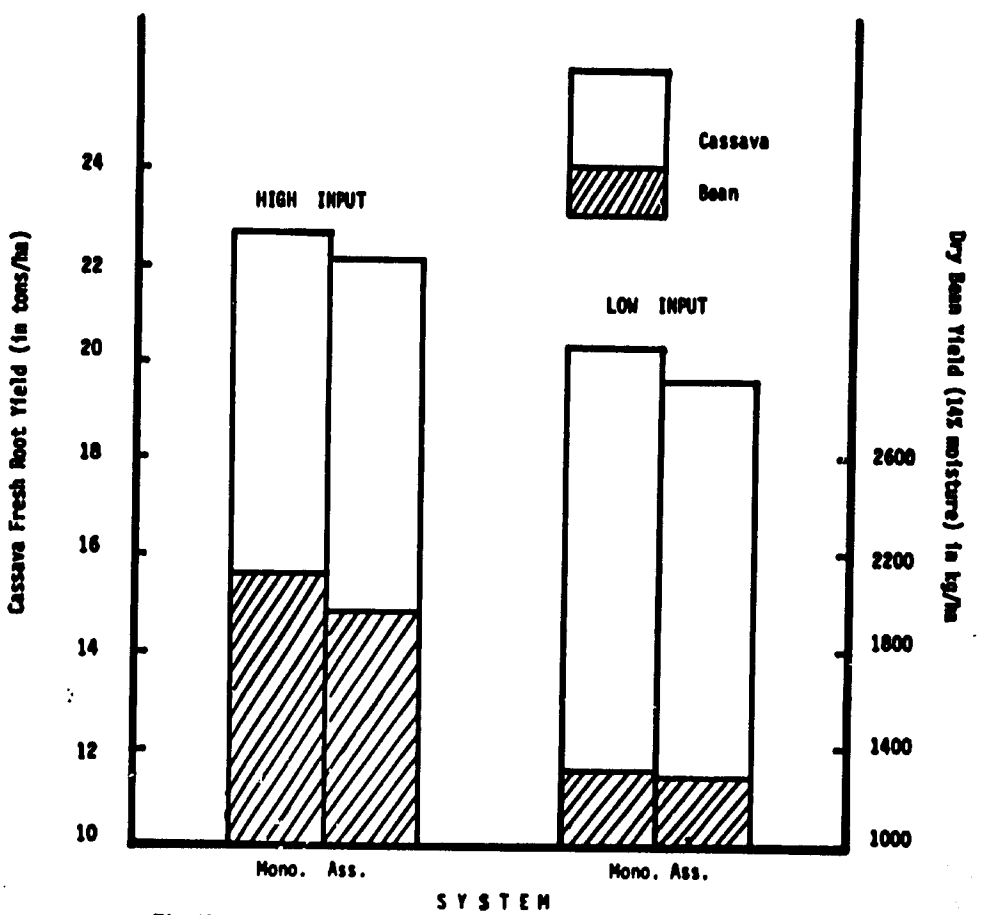

Fig. 12. The effect of different input on yield of cassava-bean in association.

Table 3. Insect population in bean monoculture vs. intercropping system cassava-bean, with and without insecticide treatment.

Insect	Cassava monoculture[a]		Cassava intercropped[b]		% in population reduction by different systems
	With insecticide[c]	Without insecticide	With insecticide[c]	Without insecticide	
Leaf hoppers (*Empoasca kraemeris*) /20 m²	89	229	80	216	6
Chrysomelides/20 m²	3	6	3	4	34
Trips/inch²	2	14	6	12	14
Scaphitophius/m²	25	35	20	36	-

[a]Cassava: M Mex 11.
[b]P 566 x M Mex 11.
[c]Endosulfan.

in the case of low inputs, the LER was very close to 2 (1.95) whereas in the insecticide-treated plots it was 1.89. This data suggest that under minimum input technology, multiple cropping will show the greatest advantage.

Conclusions

Cassava can successfully be grown with short growth cycle grain legumes. High yields of both crops can be obtained and LERs of the order of 1.5 are quite feasible. Planting date is a very important determining factor in the system, and simultaneous planting appears preferable. It appears possible to select for cassava varieties that are high yielding and also combine well with short growth cycle legumes; however, if the legume growth cycle is greater than 90 days this may be difficult. Both bean and cassava plant populations could be varied considerably with little effect on the LER, and normal monoculture densities gave good mixed cropping yields.

The relative advantage of mixed cropping with beans and cassava was greatest at low input levels of insecticides, suggesting that mixed cropping systems may be most suitable for small-scale producers with limited resources to purchase inputs.

Intercropping with Cassava in Central America

Raúl A. Moreno and Robert D. Hart

Annual Crops Program, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica

In Central America, cassava is grown mainly by small farmers. Most of its production is for direct consumption, although there is some industrial use of the crop. Cassava is an important plant component of some of the crop production systems practiced by small farmers. These production systems vary throughout Central America and depend on the local ecological and socioeconomic conditions.

In the humid lowland tropics, cassava may be intercropped with perennial or semiperennial crops, usually during the establishment phase of the latter, and frequently intercropped with maize in areas of lesser rainfall. Hernandez (cited by Rogers 1965) states that the area between southern Mexico and eastern Guatemala, where cassava is intensively grown, coincides with the distribution of certain primitive types of maize. Mayan farmers in this area cultivated cassava in a well-organized rotation with maize, in which the cultivars with a low cyanogen glucoside content were interplanted with maize, whereas bitter cultivars (with a high cyanogen glucoside content) were planted alone and away from the sweet cultivars. The tubers were normally harvested at a time when maize was out of season. As Maya civilization penetrated into the southern part of Meso-America, it seems likely that the cassava-maize association has its origin in this ancient Mayan agriculture.

Cassava is intercropped with common beans (*Phaseolus vulgaris* L.) and some horticultural crops (normally in areas of more than 700 m above sea level).

In subsistence agriculture, cassava is often intercropped with any of several different crops in a homestead garden and serves as a food source for the family. According to Wagner (1958) the majority of the homesteads in Nicoya, Costa Rica, include cassava in association with plantain (*Musa acuminata* × *M. balbisiana*), pigeon peas (*Cajanus* sp.), maize, and sugarcane (*Saccharum officinarum*). In semi-arid areas, its ability to survive prolonged dry periods is utilized; there it is planted on small plots of land in monoculture or intercropped, as a subsistence crop. Cassava is usually intercropped if it is to be used for semicommercial purposes. This reduces some of the risk involved in its production because of the unstable cassava market conditions prevailing in local markets throughout Central America. If the market tends to be stable and production resources are diverse, cassava is grown by itself and not intercropped, but always in rotation with other species.

Traditionally, agricultural research in Central America has been directed toward resolving the technical problems of the export crops such as coffee, cacao, banana, cotton, etc., while basic food crops have received comparatively little attention. There has been a tendency in the last few years for this to change. In Central America the majority of food crops, with the exception of rice, are produced by small farmers (SIECA 1972). These small farmer production systems and their relative importance have only recently been studied (Moreno et al. 1976) but there is a paucity of data on the ecological and socioeconomic variables that determine the predominance of a given system in a specific area.

From the purely technical point of view, the production potential of cassava, whether intercropped or in monoculture, is high. Agronomic problems do not seem to limit increased production and productivity but the lack of an adequate commercialization policy on cassava is the principal obstacle to the expansion of its cultivation. Cassava will remain a subsistence crop in Central America unless new marketing alternatives open up.

Some Cropping Systems Including Intercropped Cassava used by Small Farmers

Cassava as an Intercrop in the Establishment of Perennial Plantations

The establishment of a perennial species in the humid lowland tropics is a challenge for the small farmer. From the ecological viewpoint, it is necessary to cover an area with shade-providing plants to reduce a high rate of weed biomass production. From an economic standpoint, few perennial species show any yield for several years, so that the necessary additional income must be obtained through intercropping other plants within the perennials. For the management of some perennial species, notably cacao and coffee, shade is required at certain stages of development to regulate their growth. Cassava, because of its rooting characteristics, has to be planted a short distance away from young cacao plants, unlike other shade crops like castor bean (*Ricinus* sp.) and pigeon pea (*Cajanus* sp.), which are planted closer. However, cassava still gives effective shade and produces a yield.

In Central America, cassava is frequently planted during the first year in the establishment of a plantain or banana plantation in order to occupy all the available land area until the plantain or banana plantation reaches maturity.

Cassava and Maize

Cassava interplanted with maize is a commonly used system in the lowland humid tropics, when both are sown at the same time at the beginning of the rainy season. Planting distances depend on the characteristics of the varieties used, erect varieties of cassava needing less distance between plants. The maize is "doubled" at 120–150 days after planting, by which time the canopy of the cassava occupies all available space. The main problems of this cropping system are weeds at the establishment stage and later on interspecific competition between the crops evidenced by some leaf fall by the cassava and occasionally by slight chlorosis of the maize.

A variation on this production system is also practiced in the lowland tropics. Maize is grown in monoculture until it is near its physiological maturity, when the lower leaves and the tassle are removed and left as mulch on the ground. Cassava is then planted in rows between the maize, immediately after this practice. The maize is doubled-over at approximately 150 days and the cassava occupies the available space. Farmers frequently mention that the doubled-over maize under the cassava is not as vulnerable to bird attack as maize in monoculture, and gives greater flexibility for the harvest to be planned to coincide with times of greater labour availability.

If the market conditions for fresh corn are favourable, the young ears may be harvested in either of these cropping systems. Generally, the ears that look the best are selected for this harvest, and the maize plant is then immediately doubled-over. Occasionally, young ears are harvested from alternate rows and the stand density halved after doubling.

Cassava and Beans

Beans harvested either fresh or dry are intercropped with cassava at higher elevations (approximately 700 m above sea level). Bush bean varieties are normally used for harvest as dry beans and are planted at the same time at one or two rows between the cassava rows, depending on the varieties used. A few farmers plant beans for dry grain at the end of the vegetative period of the cassava. These farmers use the cassava stems as a support for climbing beans and normally cultivate cassava varieties that begin to lose part of their foliage at approximately 200 days after planting. Beans planted within the cassava can also be snap beans, but as with fresh maize, market conditions are an important factor. Snap beans are almost always fast-growing bush-type varieties and a maximum of two harvests between the cassava rows can be obtained. This system is largely restricted to farmers living close to the market and frequently requires relatively large amounts of inputs. The extra fertilizers and fungicides required to control diseases attacking the young bean pods are also beneficial to the cassava remaining in the field after the harvest of the snap beans.

Cassava, Maize, and Rice

A common pattern of land use in Panama is a pasture-crop rotation. The large cattle rancher often has difficulty maintaining pastures over a long period of time. When removing weeds from pastures becomes too difficult or expensive, the pasture is allowed to return to secondary successional natural vegetation. To return the land to pasture, the owner permits neighbouring small farmers or landless farmers to use the land for a 3-year period, on the condition that the farmer plant pasture at the end of the cropping period. The 3-year cropping system often consists of 1-year cycles of maize intercropped with rice, followed by cowpea or maize planted in monoculture. Cassava may be planted with the maize and rice during the first 2 years, but this three-crop cropping system is more commonly planted during the 3rd year. The farmer plants pasture in the cassava after the maize and rice have been harvested.

Cassava and Other Tuber Crops

One of the most interesting intercroppings with cassava is practiced in medium-sized farms in the

southern part of Nicaragua close to the Costa Rican border where rows of cassava are interplanted with rows of taro (*Colocasia esculenta*), yam (*Dioscorea* spp.), and sweet potatoes (*Ipomoea batatas*). Cassava is an important constituent of the Nicaraguan's diet and this intercropping practice provides a significant part of the national cassava consumption.

Research Review

Very little research has been carried out on cassava in Central America. A review of the papers presented at the Annual Meeting of the Central American Cooperative Program for the Improvement of Food Crops (PCCMCA) reveals that in 24 years, only five papers have been concerned with cassava. Two of these papers were presented by scientists from CATIE and described multispecies systems including cassava. The three papers not from CATIE all reported experiments with cassava in monoculture. Although national research institutions have conducted research on cassava not reported at the PCCMCA meetings, the overall paucity of papers on this crop suggests that very little research has been done on cassava in Central America. Moreover, research on cropping systems including cassava has been largely confined to cassava and maize systems.

Oelsligle et al. (1974) conducted an experiment in Costa Rica on different levels of nitrogen applied to cassava alone, maize alone, and cassava and maize intercropped. Land Equivalent Ratios (LER) of over 2.0 were obtained for the intercropped systems indicating a high level of land utilization potential.

The Agricultural Research Program of the Ministry of Natural Resources of Honduras conducted an experiment with cassava and maize cropping systems in conjunction with CATIE's Central American Small Farmer Cropping System Project (CATIE 1976–77). Two varieties of cassava were intercropped with two varieties of maize at two planting distances (spatial arrangement). Monocultures of both varieties of cassava and maize were also planted. The results indicate that there is interaction between the morphological characteristics of the varieties and the spatial arrangement of the crops.

An experiment with cassava and maize intercropped on the Atlantic Coast of Costa Rica (CATIE 1977–78) was conducted as part of CATIE's Small Farmer Cropping System Research Project. A Land Equivalent Ratio (LER) of 1.71 was obtained when intercropped cassava yielded 78% as much as cassava planted alone, and intercropped maize yielded 93% as much as maize planted alone.

An economic analysis of cassava and maize planted in 0.7-ha plots was conducted as part of CATIE's Annual Crops Program in Turrialba, Costa Rica (Mateo et al. 1975). It costs U.S. $223 to produce 1 ha of cassava intercropped with maize. The system produced a total output valued at U.S. $909, of which 63% was from cassava and 37% from maize production. The maize in this system was harvested half for fresh consumption and half for dry grain. Approximately 50% of the total maize value was from the fresh maize.

Research has also been conducted with cassava intercropped with maize and another crop in a three-crop system. Hart (1975a, b) compared three cassava, maize, and common bean intercropping systems to the three crops planted in monocultures. Two fertilizer and two weeding treatments were applied to each system. The highest net economic return was obtained from an intercropping system of the three crops planted at the same time with no fertilizer applied and no weeding of the system. The morphological characteristics of the system were such that the beans did not allow weed invasion during the first 2 months, the maize successfully excluded the weeds during the 3rd and 4th months, and from the 5th through the 8th month when the cropping period ended, the cassava canopy was developed enough to exclude weed invasion.

Holle (1976) compared four cropping systems with cassava, maize, and snap beans. The maize and snap beans were planted both at the same time as the cassava and 3 months before harvesting the cassava. Cropping systems with only maize or only snap beans intercropped with cassava were compared with both crops intercropped with cassava. Snap bean varieties were also evaluated. Snap beans did not reduce cassava yields and yielded 80% as much as the bean monoculture. Adding maize to the cassava and snap beans reduced bean yield to 70% of the monoculture. When all three crops were intercropped, maize had to be harvested fresh rather than as dry grain.

Dos Santos (1978) intercropped cassava with maize, maize and snap beans, maize and lima beans, and maize, snap beans, and lima beans. Cassava yields were not reduced by maize alone, but were reduced by approximately 30% when either snap beans or lima beans were added to the cassava and maize. Maize yields were reduced by 60% when intercropped with cassava and snap beans or lima beans as compared to the maize yields obtained in the systems without cassava. A comparison of total food energy and protein produced by the different cropping systems shows that the cassava, maize, and lima beans cropping system produced the most carbohydrates and that the maize and snap beans crop-

ping system produced the most protein. The highest protein total from cropping systems including cassava was obtained when it was intercropped with maize and beans.

A few experiments have compared different cassava legume cropping systems. In El Salvador, the Multiple Cropping Program of CENTA (a research institute of the Ministry of Agriculture) conducted experiments comparing cassava intercropped with common bean and cowpea (Bieber 1975). Cassava yields were reduced more by cowpea than by common bean, and intercropping with cassava reduced the yield of cowpea more than that of beans.

In Turrialba, Costa Rica, CATIE's Annual Program (CATIE 1977–78) conducted an experiment to evaluate the possibility of intercropping snap beans, lima beans, and cowpea with cassava during the last 3 months of the cassava growth period. None of the legumes significantly lowered cassava yields. Cowpea and lima bean yields were 67% and 65% of their respective monoculture yields. One common bean variety produced as high a yield when intercropped as when planted alone.

Very few experiments evaluating the potential of cassava intercropped with perennials have been reported in Central America. However, preliminary results from an experiment in progress in Turrialba, Costa Rica, suggest that more research should be conducted with this type of cropping system. Cassava intercropped with plantain yielded only 23% less than a cassava monoculture (Enriquez 1978). The cassava–plantain association was planted at a density of 8890 plants/hectare, compared with the monoculture at 10 000 plants/hectare. Based on weight per plant the intercropped cassava produced only 13% less than the cassava monoculture.

Morales et al. (1949) investigated the economics of using cassava or maize in the establishment of rubber (*Hevea* sp.) on the Atlantic coast of Costa Rica. During early development of the rubber seedlings, maize offered less competition than the cassava. However, after the 3rd year of seedling development, cassava was preferred as an intercrop because it produced higher economic returns on investment than maize. An important advantage of intercropping the rubber was a saving of U.S. $24/ha on the usual total weed control costs.

All of the experiments described above involve only short-term cropping periods of 1 year or less. A long-term evaluation and comparison of up to 4 years of different intercropping systems with cassava was conducted in Turrialba by CATIE's Annual Crops Program. All land preparation and weeding was done by hand and the only "fossil fuel" inputs used were insecticides and fertilizer. The cropping patterns tested that included cassava are shown in Fig. 1. The crop species, varieties, planting distances, and densities are summarized in Table 1.

The average yields over a 3-year period of the different crops in the different cropping systems are summarized in Table 2. The yield of cassava intercropped with maize was only 50% of that in monoculture. Maize yields were also reduced when intercropped with cassava. Cassava and beans may be intercropped with no reduction in yield of either crop, but when maize is included in the system the yields of both beans and cassava are reduced to half their monoculture yield, whereas that of maize is not affected.

When cassava was intercropped with sweet potato and both crops are planted at the same time, cassava yields are 58% and sweet potato yields 60% of their respective yields in monoculture. When sweet potato was planted during the later half of the cassava vegetative period, sweet potato yields were not reduced, and cassava yields were actually increased.

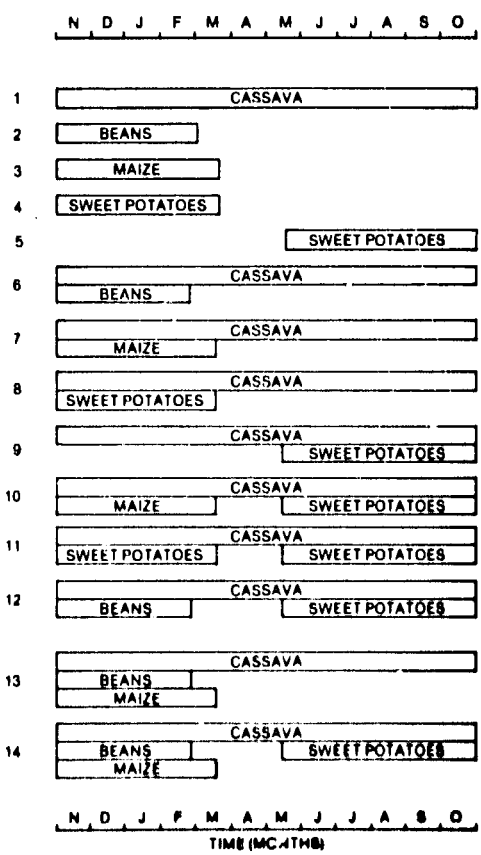

Fig. 1. Cropping patterns tested at Turrialba, Costa Rica, 1974–78.

Table 1. Species, varieties, planting distances, and density of planting of different cropping systems tested from 1974 to 1978 in Turrialba, Costa Rica.

Species	Varieties	Planting distance (*m*) On the row		Between rows	Density plants/ha
Beans (*Phaseolus vulgaris*)	CATIE-1	0.5	×	0.2	100000
Maize (*Zea mays*)	Tuxpeño	1.0	×	0.5	40000
Sweet potatoes (*Ipomoea batatas*)	C-15	0.5	×	0.4	50000
Cassava (*Manihot esculenta*)	Valenca	1.0	×	0.5	20000

An economic analysis of the cropping systems including cassava is presented in Table 3. Economic data were obtained at the experimental station but later modified using field data from small farmers cultivating similar cropping systems. An estimate of the energy inputs in terms of GJ/ha (GJ = Gigajoule, or 10^9 joule) from labour, fertilizers, and insecticides and output energy of the edible yield of the plant components of each cropping system is also summarized in Table 3.

One important advantage of conducting long-term experiments with different types of cropping systems is that it is possible to use the experimental results to formulate general principles for cropping system design. The relationships between number of crops in a system, efficiency of resource use, and stability of yield are shown in Fig. 2 and 3. The LER, a measure of efficiency in resource use, has been reported for these cropping systems (Soria et al. 1975) and a positive linear relationship between LER and number of crops up to three in a cropping system is shown in Fig. 2. Stability of the different cropping systems, as measured by the coefficient of variability of total biomass produced by a cropping system, is summarized in Table 4 and graphically related to number of crops in a cropping system in Fig. 3. Stability is greatly increased by changing from one to two crops, but does not seem to be affected by increasing this to three crops.

Suggestions for Future Research

Most of the research on cassava intercropping in Central America has been done at CATIE in Turrialba during the last 5 years. Most emphasis has been placed on studying the agronomic characteristics of the many existing traditional cropping systems to more fully understand them. Studies in depth of the interactions among the components of the systems are largely lacking, although plant pathology seems to be the exception to this situation (Moreno 1978). The switch from a disciplinary or crop-oriented approach to a more integrated or systems-oriented type of research has only recently begun at

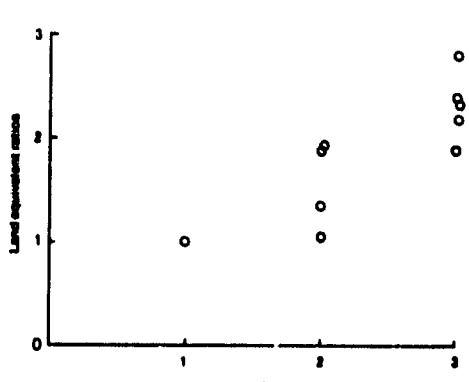

Fig. 2. Land equivalent ratio values and number of crops in different cropping systems tested at Turrialba, Costa Rica, 1974-78.

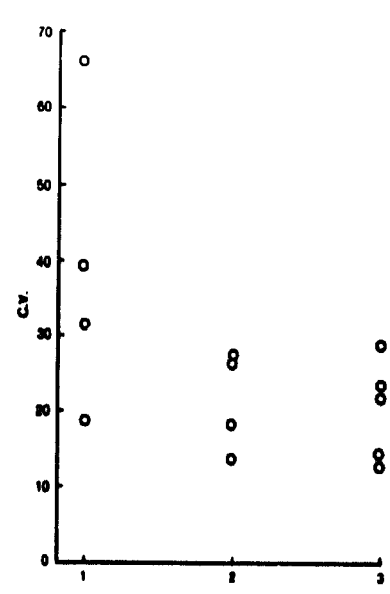

Fig. 3. Coefficient of variability of cassava, common bean, sweet potato, and maize in monoculture and different intercropping of these cultivars, Turrialba, Costa Rica, 1974-78.

Table 2. Yield (metric tonnes/ha) per plant component and Land Equivalent Ratios (LER) of 14 cropping systems, Turrialba, Costa Rica, 1974–78.

Cropping systems		Cassava	Beans	Maize	Sweet potato[e]	Sweet potato[e,f]	% monocrop					LER
							C	B	M	SP	SP[e]	
01C[a]		16.827					100					1.0
B			1.389					100				1.0
M				2.955					100			1.0
SP					10.536					100		1.0
	SP[e]					4.718					100	1.0
02C+B[b]		15.230	1.448				90.51	104.25				1.95
03C+M		7.801		2.766			46.36		93.60			1.40
04C+SP		9.719			6.282		57.76			59.62		1.17
05C+	→ SP[e,c]	18.671				4.171	110.96				88.41	1.99
06C+M	→ C+SP[e,d]	8.684		3.475		3.595	51.61		117.60		76.20	2.45
07C+SP	→ C+SP[e]	11.497			5.560	3.496	68.33			52.77	74.10	1.95
08C+B	→ C+SP[e]	18.570	1.259			1.914	110.36	90.64			40.57	2.42
09C+B+M		11.088	0.775	2.911			65.89	55.80	98.51			2.20
10C+B+M	→ C+SP[e]	7.832	0.766	2.938		3.826	46.54	55.15	99.43		81.09	2.82

[a]C = cassava; B = common bean; M = maize; SP = sweet potato planted at first planting season; SP[e] = sweet potato planted at second planting season.
[b]+ = association of crops.
[c]→ = double cropping.
[d]Sweet potato intercropped in cassava.
[e]Planted at first planting season.
[f]Planted at second planting season.

Table 3. Economic evaluation and energy analysis of cassava-based cropping systems tested at Turrialba, Costa Rica, during 1974–78.

Variables	Cropping systems									
	01	02	03	04	05	06	07	08	09	10
Man-days/ha	127.51	167.09	153.38	145.12	182.97	197.79	170.30	248.54	175.57	214.88
Cost of labour (CA $/ha)[a]	447.93	586.97	538.81	509.79	642.75	694.81	598.24	873.09	616.76	754.85
Cost of inputs (CA $/ha)										
Fertilizer	179.7	141.74	148.59	193.42	179.47	237.69	235.54	237.71	215.62	281.91
Insecticide	0.9	11.32	13.47	17.45	5.93	26.48	19.04	17.25	19.28	7.92
Total inputs cost	180.6	153.06	162.06	210.87	185.40	264.17	254.58	254.96	234.90	289.83
Other										
Interest and depreciation 10%	62.85	74.00	70.09	72.07	82.82	95.90	85.28	112.81	85.17	104.47
Cost of land	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Total other costs	112.85	124.00	120.09	122.07	132.82	145.90	135.28	162.81	135.17	154.47
Total costs	293.45	277.06	282.15	332.94	318.22	410.07	389.86	417.77	370.07	444.30
Income										
Gross income (CA $/ha)	771.01	1527.21	850.30	1244.91	1655.09	1916.98	1679.38	1230.14	1470.65	1456.81
Net income (CA $/ha)	477.56	[illegible]	568.15	911.97	1336.87	1506.91	1289.52	812.37	1100.58	1012.51
Family income (CA $/ha)	590.41	[illegible]	688.24	1034.04	1469.69	1652.81	1424.80	975.18	1235.75	1166.98
Efficiency index (gross income/total costs)	2.63	5.51	3.01	3.74	5.20	4.67	4.31	2.94	3.97	3.28
Input energy GJ/ha[b]	13.23	13.60	14.40	15.41	15.19	23.04	22.34	27.83	22.12	29.50
Output energy GJ/ha	107.09	118.01	89.47	92.36	139.07	117.13	122.77	145.81	123.77	118.00
Energy out/in	8.09	8.68	6.21	5.99	9.16	5.08	5.50	5.24	5.60	4.00

[a]1 CA $ = U.S. $1.
[b]1 GJ = 10^9 joules.

Table 4. Variability (coefficient of variability) registered in different cropping systems during 3 years and three replicates each year, Turrialba, Costa Rica, 1974-77.

Cropping system	Average individual crops	Crop association
Cassava monoculture	39.93	-
Beans monoculture	18.78	-
Maize monoculture	13.46	-
Sweet potato monoculture	30.29	-
Sweet potato monoculture[a]	65.78	-
Cassava + beans[b]	33.04	27.54
Cassava + maize	28.76	18.09
Cassava + sweet potato	23.87	13.42
Cassava + sweet potato[a]	41.14	27.45
Cassava + maize + sweet potato[a]	31.05	21.44
Cassava + sweet potato → cassava + sweet potato[c]	26.91	23.79
Cassava + beans → cassava + sweet potato	35.34	28.51
Cassava + maize + beans	25.04	14.95
Cassava + maize + beans → cassava + sweet potato	27.57	13.25

[a]Sweet potato cultivated at the second planting season.
[b]+ = association of crops.
[c]→ = Sweet potato cultivated at the second planting season and intercropped in the cassava; └─┘ = same crop.

CATIE. The initial field experiments with cassava intercropped with other species were designed mainly to develop a methodology to study systems of mixed crop production rather than to improve on existing systems in the short term or to develop new ones.

Small farmers are the most important cassava producers in Central America. Studies of the ecological as well as the socioeconomic determinants of cassava-based production systems in specific locations are required to identify and delimit specific complexes and to evaluate their production potential throughout Central America. Simultaneously, alternative marketing channels should be investigated for each production complex both at the farm community and at the Central American level.

The integration of cassava-based systems and animal production has not been thoroughly investigated and consequently has not been promoted in Central America. Most of the rural population of this area (85%) live in regions under the climatic influence of the Pacific Ocean (IDB 1977). As a consequence, they suffer dry periods ranging from 5 to 7 months when no grass is available for animal feed. The potential of cassava as a food source under these circumstances, combined with forage trees, should be also investigated.

The role of cassava as an intercrop in the establishment of perennial plantations in the lowland tropics also deserves greater attention. Alternative mixed cropping systems including cassava should be developed for rural communities facing an unstable market as a means of reducing production risk.

Cassava Intercropping in Brazil

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Brazil is the world's greatest cassava producer, accounting for 30% of all cassava root production. Cassava is grown throughout the country's 8.5 million km², from the south at 33° latitude to the equator. In area planted, cassava ranks sixth behind other crops in Brazil (Table 1).

Table 1. Areas planted for main crops in Brazil, 1975.

Crop	Area ('000 ha)
Corn	10473
Soybean	5824
Rice	5150
Beans	4052
Coffee	2251
Cassava	2082
Sugarcane	1899
Cotton	1410

Source: IBGE 1976.

The Northeast Region of Brazil grows 51% of the country's cassava (Table 2), the greatest amount being produced in the section with 650–1000 mm annual average rainfall. A long dry season occurs for one in each cycle of 4 or 5 years, and the annual average temperature is 24–26 °C with annual sunlight of 2700 hours.

Cassava is grown in this region on small farms using family labour and is either consumed by the family or made into cassava flour and sold at the local market.

It is usually grown in two or three crop associations, probably to reduce the risk of harvest loss by a prolonged absence of rain and to improve the intensive use of a small area and family labour force. It is usually intercropped with beans (*Phaseolus* or *Vigna*) and corn, and sometimes with cotton, rice, tobacco, coco palm, rubber trees, and *Opuntia* sp. (forage cactus). In the typical multiple crops association in this area, advanced agricultural practices, such as selected cultivars, pest and disease control, and the use of fertilizer, are not used.

Generally, the planting has been done by family labour at the same time or in the interval of weeks or months between the planting of different species. Farmers most commonly plant intercropped species simultaneously to take advantage of soil moisture conditions. The irregular rainfall distribution is not predictable enough to permit the general use of separate planting periods for each intercropped species. Plant distribution in the area has varied according to the species combination.

Cassava Intercropping Types

Cassava and Beans

This crop combination has been the one most used by farmers in the Northeast Region because it produces protein and carbohydrate in the same area. *Phaseolus* or *Vigna* species have been chosen according to regions and seasons.

Generally, beans are planted between the cassava rows. Cassava row spacings are in the range of 1.00 m × 0.50 m to 2.00 m × 1.00 m, depending on the bean species and the number of rows used. Commonly, there are one or two bean rows between the cassava rows, and 15 seeds per linear metre or 0.50 × 0.20 m with two seeds in each hole. Sometimes beans are planted 0.5–3 months before the cassava planting.

Cassava and Corn

Corn is seeded in row spacings of 1.00 m between two cassava rows, and 0.50 m between corn plants.

Cassava, Corn, and Beans

Cassava, corn, and bean crop combinations are widespread in Brazil. Cassava plant spacing is 1.00 m × 0.50 m, 2.00 m × 1.00 m, with one or two

Table 2. Areas planted in cassava, production, and yield by region and by state in Brazil, 1975.

Region	State	Area ('000 ha)	Production ('000 t)	Yield (t/ha)
North	Pará	83	835	10
	Amazonas	13	256	20
	Acre and Territórios	-	134	-
		96	1225	12.7
Northeast	Bahia	301	5110	17
	Maranhão	217	1843	8
	Pernambuco	157	1575	10
	Ceará	145	1451	10
	Piauí	144	1136	8
	Paraíba	73	642	9
	Alagoas	48	493	10
	Rio Grande do Norte	62	488	8
	Sergipe	35	416	12
		1182	13154	11.1
Southeast	Minas Gerais	138	2246	16
	São Paulo	38	720	19
	Espírito Santo	43	608	14
	Rio de Janeiro	25	344	13
		244	3918	16.0
Central west	Goiás	35	487	14
	Mato Grosso	74	479	6
		109	966	8.8
South	Rio Grande do Sul	266	3166	12
	Paraná	99	1953	19
	Santa Catarina	86	1430	16
		451	6549	14.5
Totals		2082	25812	12.3

Source: IBGE, 1976.

corn rows between two cassava rows. Beans are planted alternately with corn rows. To guarantee good plant stands, three bean or three corn seeds are put in each hole.

Cassava and Rubber Trees

The agricultural finance institutions do not recommend the use of cassava in association with rubber tree plantations due to the risk of increasing the damage potential of insects like "mandarova" (*Erinnyis ello*). However, biological control of the "mandarova" will make this type of crop association feasible if such control is balanced so that an adequate population of "mandarova" is available to support the control insects that are introduced.

Observations have been made on rubber tree plantations in the State of Bahia where cassava has been cultivated between rows of young rubber trees for 2 years. Those rubber trees that are associated with cassava have shown higher growth than the rubber trees without cassava intercropping.

Cassava and Coco Palm

In 1975, in the state of Sergipe, a cassava starch factory was built, and this has given farmers the incentive to grow cassava. This crop has been extended into coco palm plantations and has occupied the space between the coco palm rows in the zone due to the commercial influence of the factory.

Cassava, Tobacco, and Cowpea

In some areas in the Northeast Region, small farmers have used manure, castor bean cake, and chemical fertilizer to grow tobacco that is planted in April. Before the tobacco harvest ends in October-November, farmers have planted cassava or cassava and cowpeas. These crops have been improved by the residual effect of fertilizer applied to tobacco.

Other Cassava Intercropping Types

In some areas, rice, cotton, and *Opuntia* sp. (forage cactus) have been employed in intercropping with cassava. Also, cassava has been used to shade young cocoa plants.

Cassava Plantations and Intercropping

The increase in 1973 in the international price of oil prompted the Brazilian Government to establish in 1975 the National Alcohol Program, an endeavour to replace a great portion of imported oil with alcohol to be used in motorcars and for industrial purposes.

This program has given incentive to private enterprise to produce alcohol from biomass. Sugarcane, cassava, sweet potato, and sweet sorghum have been mentioned as important raw materials for the alcohol industry. The first large cassava alcohol plant was built recently by PETROBRAS, a government enterprise, who constructed this factory to promote alcohol production from cassava. The factory production capacity is 60 000 litres of ethyl alcohol per day.

As of September 1978, the National Alcohol Committee approved 12 agro-industrial projects for alcohol production from cassava. The total production capacity (the total of the 12 projects) is 1.14 million litres of cassava alcohol per day. These projects must be established within 2 or 3 years.

These recent events are changing cassava production from a peasant crop to a plantation crop. On this scale, agricultural cropping systems involving short plants such as beans, soybeans, and rice, in alternate multiple rows with cassava will permit frequent inspections for pests, diseases, and general management conditions. As well, the row space occupied by cassava will be intensive in capital (machinery, fertilizer, herbicides, etc.) and probably will make better use of the soil, water, and light, and will reduce tillage and soil erosion and contribute to better the income of the farmer.

Research

The Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA; the Brazilian Enterprise for Agricultural Research), created in 1972, is a government institution in charge of the planning, coordination, and execution of agricultural research in Brazil. In 1975, EMBRAPA founded the Centro Nacional de Pesquisa de Mandioca e Fruticultura (CNPMF; the National Research Center for Cassava and Fruit Crops), which is responsible for the programing, coordination, and execution of cassava, citrus, banana, pineapple, and mango research in Brazil. The CNPMF is located at Cruz das Almas, State of Bahia, at 12°40'19"S and 39°06'22"W. The local altitude is 220 m above sea level; the annual average rainfall is 1200 mm, the annual average temperature 24 °C, and the relative humidity 80%. The land is level to undulating with well-drained sandy clay loam red-yellow latosol soils. The soils present low to medium natural fertility, are acid, and have a very low phosphorus content.

There are 42 researchers at the CNPMF, half of whom work with cassava in cooperation with about 35 other researchers in selected areas in Brazil.

The intercropping with cassava research project is directed basically at improving the use of scarce production factors and at intensifying the use of abundant production factors to increase income for farmers and to intensify cropping systems by adequate use of production factors available on large farms.

The trials on intercropping with cassava will evaluate the cultural practices effects that were determined formerly on each crop that is integrated with the cassava intercropping.

EMBRAPA's Agriculture Research Center for Humid Tropics (CPATU), Agriculture Research Center for Semi-Arid Tropics (CPATSA), and Agriculture Research Center for the "Cerrado" Region are responsible for developing farming systems for the Amazon, semi-arid, and "Cerrado" regions, respectively. These three have worked with EMBRAPA's other centres, such as the National Research Center for Cassava and Fruit Crops (CNPMF). These centres have carried out some field trials and are preparing designs for new experiments during the next 5 years on cassava in association with perennial and annual crops.

In 1977/78, the CNPMF performed one field experiment to evaluate effects of double row planting on cassava yields, combining double rows of 7000–16 000 cassava plants per hectare. The results indicate that a spacing of 2.00 × 0.60 × 0.60 m produces the greatest root yield, approximately 37 metric tonnes (t) per hectare.

Experiments with Intercropping in the Amazon Region[1]

The Manaus Experimental Station is located in the Amazon Region of Brazil at 02°54'01"S and 60°01'03"W with an altitude of 40 m, an annual average precipitation of 2.1 mm, an annual average temperature of 26.7 °C, and predominately yellow latosol soils. The soil texture is clay of low fertility. The research of the unit involved the intercropping of cassava with other crops, and results were as follows.

[1]This work was planned and executed by UEPAE/Manaus, under the coordination of Eng° Agr° Expedito Ubirajara Peixoto Galvao.

The experiment was composed of combinations of cassava, rice, beans, and corn, in 15 intercropping systems that followed a random block design with three replications (Table 3).

Table 3. Treatment, population of plants per area, and spacing used in the experiments at Manaus, 1975/76.

Treatments	Plants/ha	Spacing (*m*)
1. Cassava	10000	1.00 × 1.00
2. Cassava	10000	1.00 × 1.00
Beans	100000[a]	1.00 × 0.20
3. Cassava	10000	1.00 × 1.00
Corn	40000	1.00 × 0.50
4. Cassava	10000	1.00 × 1.00
Rice	40000	1.00 × 0.25
5. Cassava	6666	1.50 × 1.00
Beans	66666[a]	1.50 × 0.20
Corn	26666[a]	1.50 × 0.50
6. Cassava	6666	1.50 × 1.00
Corn	26666[a]	1.50 × 0.50
Rice	26666	1.50 × 0.25
7. Cassava	6666	1.50 × 1.00
Beans	66666	1.50 × 0.25
Rice	26666	1.50 × 0.25
8. Beans	200000[a]	0.50 × 0.20
9. Beans	100000[a]	1.00 × 0.20
Corn	40000[a]	1.00 × 0.50
10. Beans	100000[a]	1.00 × 0.20
Rice	40000	1.00 × 0.25
11. Beans	66666[a]	1.50 × 0.20
Corn	26666[a]	1.50 × 0.50
Rice	26666[a]	1.50 × 0.25
12. Corn	40000[a]	1.00 × 0.50
13. Rice	160000	0.25 × 0.25
14. Corn	40000[a]	1.00 × 0.50
Rice	40000	1.00 × 0.25
15. Cassava	5000	2.00 × 1.00
Rice	20000	2.00 × 0.25
Corn	20000[a]	2.00 × 0.50
Beans	50000[a]	2.00 × 0.20

[a]After the planting, each hole had two plants.
Source: UEPAE/Manaus.

The natural fertility of the soil was maintained and no fertilizer was added to the experimental area. Planting was by hand and was done according to the following criteria of distribution and quantity of seeds in the holes: cassava, one stake per hole; beans, three seeds per hole; corn, three seeds per hole; rice, five seeds per hole.

The results presented in Table 4 show that the cassava crop when intercropped with corn and rice decreased in yield by 450 kg of table flour per hectare or 1286 kg of fresh roots per hectare (considering that 1 t of roots produces about 350 kg of flour), compared with production obtained when monocropped. Nevertheless, in the intercropping of cassava with beans an increase in flour yield of 800 kg/ha, or 2286 kg/ha of roots, was noted. Production of rice and bean crops decreased when intercropped with cassava, and corn increased production by 570–1102 kg/ha when intercropped with cassava.

The best land use equivalent value was obtained with double intercropping with a combination of cassava and corn (275), followed by cassava and beans (147), and rice and cassava (106). The best food production was obtained with the intercropping of cassava and beans.

When cassava was planted with rice + corn or rice + beans there were yield losses in cassava flour. When planted with beans + corn, this reduction was only 250 kg/ha of flour compared to cassava monoculture; this indicates a reduction of 10%. The other crops, in general, also suffer in their production when grown in association, with rice being especially affected when interspecifically associated, with losses up to 90% in association of rice + cassava + corn, and rice + beans + corn. Corn when planted with rice and beans had its best production of grain when compared to monoculture, with an increase of 40%.

The best land use equivalent value of triple intercropping was obtained with the combination of cassava + beans + corn (209), followed by the combination of cassava + rice + corn (140), and cassava + rice + beans (113).

When cassava was utilized in quadruple intercropping, that is, planted with rice + corn + beans, the production of flour fell by 1250 kg/ha, a 50% decrease in production in monoculture. The other crops also decreased in production, with rice again being the crop that suffered most.

The economic analysis of the different treatments is presented in Table 5. Within the intercropping systems for two crops, the combination of cassava + beans, cassava + corn, and cassava + rice were the most efficient, in decreasing order, considering total production, and this shows that in all these systems, cassava is the major component crop.

The highest economic efficiency index, as a function of gross weight yield, was obtained with the combination of cassava + beans; this index was 1771% compared to 1222% for cassava alone and 238% for beans alone.

The results obtained show that the best percentage of participation of total production of food was due to the cassava crop.

The intercropping system giving the best return was cassava + beans, which presented a return of approximately U.S. $600/ha. The intercropping with

Table 4. Production of rice, beans, cassava, and corn under diverse systems at Manaus, 1975/76.

Production system	Total production of food	Production (*kg/ha*)				LER[a]
		Rice	Beans	Cassava flour	Corn	
Rice	1378	1378				100
Beans	268		268			100
Cassava	2500			2500		100
Corn	570				570	100
Rice + cassava	2385	335		2050		106
Cassava + corn	3152			2050	1102	275
Cassava + beans	3475		175	3300		197
Rice + corn	394	139			255	54
Rice + beans	876	540	336			164
Corn + beans	989		161		828	205
Rice + cassava + corn	2569	139		2175	255	140
Rice + beans + cassava	2438	292	21	2125		113
Beans + cassava + corn	2815		103	2250	462	209
Rice + beans + corn	1155	139	66		950	200
Cassava + rice + beans + corn	1850	70	53	1250	477	157

[a]Land use equivalent ratio.

Table 5. Gross income per system,[a] with its formation percentage and economic efficiency index, Manaus, 1975/76.

	Cassava		Beans		Rice		Corn		Total per system		Economic efficiency index (%)
	Gross income	%	Gross income	%	Gross income	%	Gross income	%	Gross income	%	
Cassava	8240	100							8240	100	1222
Beans			1608	100					1608	100	238
Rice					2893	100			2893	100	429
Corn							855	100	855	100	127
Cassava + rice	6765	90.58			703	9.41			7468	100	1108
Cassava + corn	6765	80.36					1635	19.42	8418	100	1249
Cassava + beans	10890	91.20	1050	8.79					11940	100	1771
Rice + cassava					292	43.32	382	56.67	674	100	100
Rice + beans			2016	64	1134	36			3150	100	467
Corn + beans			966	43.75			1242	56.25	2208	100	327
Cassava + rice + corn	2177	76.35			292	10.24	382	13.39	2851	100	423
Cassava + rice + beans	7012	90.46	126	1.62	613	7.9			7751	100	1150
Cassava + corn + beans	7276	84.73	618	7.19			693	8.07	8587	100	1274
Rice + corn + beans			396	18.74	292	13.81	1425	67.43	2113	100	313
Cassava + rice + corn + beans	4125	77.75	318	5.99	147	2.77	715	13.47	5305	100	787

[a]Actual prices: Cassava flour, Cr$3.30/kg; bean, 6.00/kg; rice, 2.10/kg; corn, 1.50/kg. (1 Brazilian cruzeiro (Cr$) = ca. U.S. $0.14).
Source: UEPAE/Manaus.

the cassava crop produces more than when grown alone.

There is an equal economic disbursement of cultural practices in intercropping and monoculture. As well, there is better use of family labour when the intercropping system includes cassava, and this better use is in the postharvest stage, during the preparation of table flour. Another factor that contributes is the use of family labour over longer periods and the staggering of crop cycles for the different components of the intercropping system studied.

Table 6. Yields (*t/ha*) of cassava roots and soybean, sorghum, peanut, corn, rice, and bean intercropping, Felixlandia, 1976/78.

	Treatments[a]				
	1	2	3	4	Mean
Cassava	21.49	22.37	18.34	19.19	20.35
Cassava	15.73	15.42	16.80	15.22	15.79
Soybean	-	-	-	-	
Cassava	16.85	18.19	13.47	9.05	14.39
Sorghum	0.89	0.73	0.71	0.31	
Cassava	15.82	18.94	13.92	19.45	17.03
Peanut	0.04	0.63	0.10	0.12	
Cassava	16.82	21.16	17.50	13.25	17.18
Corn	-	-	-	-	
Cassava	16.31	21.36	14.48	12.31	16.11
Rice	-	-	-	-	
Cassava	17.59	20.28	16.98	18.67	18.38
Bean	0.04	0.19	0.14	0.19	

[a]Treatments: 1, without fertilizer and lime; 2, with fertilizer and without lime; 3, with fertilizer and lime, 3 t/ha; 4, with fertilizer and lime 6 t/ha.

Intercropping Experiment with Cassava carried out by EPAMIG

The intercropping experiment of cassava with soybean, sorghum, peanut, corn, rice, and bean was carried out by the Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG) and the Escola Superior de Agricultura de Lavra - MG (ESAL), at the Felixlandia Experimental Station in Minas Gerais.

The soil fertility conditions varied according to the treatments:

1 — No fertilizer or lime
2 — 300 kg simple superphosphate/ha
100 kg potassium chloride/ha
150 kg ammonium sulfate/ha (dressing)
40 kg aldrin/ha (2.5%)
3 — The same as no. 2, plus 3 lime/ha
4 — The same as no. 2, plus 6 lime/ha

The cassava was planted in double rows, 2.00 m × 0.50 m × 0.60 m apart, corresponding to 13 330 plants/ha.

The crops planted with cassava were as follows: (*a*) bean, soybean, rice, and peanut: three rows 0.50 m apart between each double row; (*b*) sorghum and corn: 2 rows 1.00 m apart between each cassava double row.

The quantities of seeds used per 1-m furrow were: (*a*) bean, 12; (*b*) soybean, 20; (*c*) rice, 50; (*d*) peanut, 15; (*e*) corn, 7; (*f*) sorghum, 18.

The total plot area was 600 m² (24 m × 25 m), while the utilized cassava plot was 420 m² (20 m × 21 m), and the other crop plots were 472.5 m² (21.0 m × 22.5).

The lack of humidity in the soil drastically affected the results, especially for soybean, corn, and rice; it was caused by a "veranico" (lack of rain) in the period from 31 Jan to 19 Mar (Table 6).

With cassava, the best yields were obtained with treatment 2. The addition of 3 t of lime reduced the yields and with 6 t these yields were even more reduced, except for the treatments: cassava monocrop, cassava + peanut, and cassava + bean.

The median yield of monocrop cassava was 20.35 t/ha. The intercrop experiencing the least reduction was the one with bean (18.38 t/ha), followed by those with peanut (17.03) and sorghum (14.39).

Due to the problems that occurred in the experiment, we cannot draw conclusions about it, but we can say that cassava, when intercropped, had its yield reduced by 18.43% when competition occurred, and by 19.61% when this competition was affected by the lack of production of the interplanted crops.

Intercropping Systems with Cassava in Kerala State, India

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In Kerala State, India, about 42% of farmers have less than 0.2 ha of land. These small and marginal farmers, out of necessity, have to adopt intercropping systems to obtain maximum returns per unit area. Cassava, predominantly used as a subsidiary food, with less than 10% made into starch, is grown here with coconut, mango, jack fruit, and other annual crops like *Colocasia*, *Amorphophallus*, ginger, pineapple, and banana. Such a cropping mixture can be widely found throughout the length and breadth of Kerala, which has a rural population density of 549 people/km^2; every available space is well utilized. The common inputs in more than 80% of the cassava farms are confined to the application of cattle manure and wood ash. Commercial fertilizers are seldom used in these farms and even if they are used, it is not the recommended dosages.

The farmers widely practice intercropping of cassava in coconut gardens. However, cassava is not adapted to shade, and plants grown under shade are etiolated with poor tuber development. The results of the experiments conducted in coconut gardens indicate that this is not an economic proposition. However, new technology has now been developed to grow high-value crops like clove, nutmeg, and cocoa in coconut gardens.

Cassava as a monoculture is being practiced in major areas, especially on marginal lands with undulating topography. The farmers generally plant cassava during the premonsoon showers in the month of May until July as a first season crop and at some places during September–October as a second season crop, taking advantage of the southwest and northeast monsoon showers, respectively (Appendix 1). The most common method of land preparation is forming mounds using human labour. Power-driven implements are seldom used for land preparation.

Cassava is planted with a spacing of 90 × 90 cm and the crop slowly builds up a canopy during its early stage of growth; it takes 3–3$^1/_2$ months to grow enough canopy to cover the entire field. The solar radiation available in between the rows at the early growth phase of cassava can be well exploited by raising short-duration leguminous/nonleguminous crops.

Trials were conducted at the Central Tuber Crops Research Institute Farm with the object of developing suitable technology for an intercropping system with cassava.

Materials and Methods

An experiment was carried out using a split-plot design, with the combinations of method of planting and level of fertility in the main plot and the intercrops in the subplots.

Treatment — Main plot: (*a*) The main methods of planting were, for M1, 90 × 90 cm and for M2, paired-row method; (*b*) levels of fertility were for F_1, FYM @ 12.5 metric tonnes (t)/ha and recommended dose of NPK for main crop, i.e., 100:100:100 kg/ha, and F_2, recommended dose of the main crop plus recommended dose for intercrops. Subplot: The intercrops were green gram (*Phaseolus aureus*), groundnut (*Arachis hypogea*), maize (*Zea mays*), soybean (*Glycine max*), and sunflower (*Helianthus annuus*).

For comparison, a control plot without any intercrop was also maintained.

The physicochemical properties of the soil were: type, sandy clay loam; texture, medium; pH, 4.5; available N, 238 kg/ha; available P_2O_5, 16.8 kg/ha; available K_2O, 94 kg/ha.

A high-yielding semibranched variety of cassava, H-97, evolved at the Central Tuber Crops Research Institute, was planted during May–June. The seeds of intercrops were sown immediately after the planting of cassava. In the M1 treatment, one row of maize and two rows of other crops were maintained in between two rows of cassava. In the M2 treatment, two setts of cassava were planted at a spacing of 45 cm leaving 135 cm space in between two consecutive paired rows. Two rows of maize and four

rows of other crops were maintained in the M2 treatment. Under both treatments, the plant populations were maintained uniformly.

Plant height, plant spread (canopy diameter), tuber yield, and yield of intercrops were recorded. As well, the economics of intercropping were calculated.

Results and Discussion

Canopy diameter and plant height are presented in Fig. 1 and 2.

Maximum canopy diameter recorded in the control plot was on a par with cassava intercropped with green gram. The control was significantly superior to the rest of the treatment combinations. Plant height (Fig. 2) increased significantly when cassava was intercropped. However, the effect on maize was more pronounced as compared to other crops. The results also suggest that the increase in plant height of cassava was in proportion to the height of the intercrops. This is probably due to mutual shading and competition for sunlight.

There were significant differences in tuber yield among treatments (Fig. 3). The control registered significantly increased tuber yield over intercrop treatments. In all cases, application of fertilizers to both crops (F_2 treatment) resulted in maximum tuber yield.

The gross returns of the intercropped treatment indicated that maximum gross returns were obtained when groundnut was intercropped with cassava. These values were significantly superior to all other treatments and the control.

Of those crops intercropped with cassava for 4 years at this institute, groundnut alone has given consistently good results. The performance of soybean was poor, probably due to the low pH of the soil. Although green gram faired well, the yield was not remunerative. In the case of maize, there was a reduction in yield due to lack of vigour, indicating its poor compatibility with cassava. Though sunflower established well under prolonged dry spells, the crop growth, seed set, size of head, and, consequently, the yield were reduced considerably. This indicated that economic cultivation of sunflower as an intercrop with cassava is not feasible under Kerala conditions due to the poor moisture-holding capacity of the soil.

Fig. 1. Lateral spread of cassava due to intercropping.

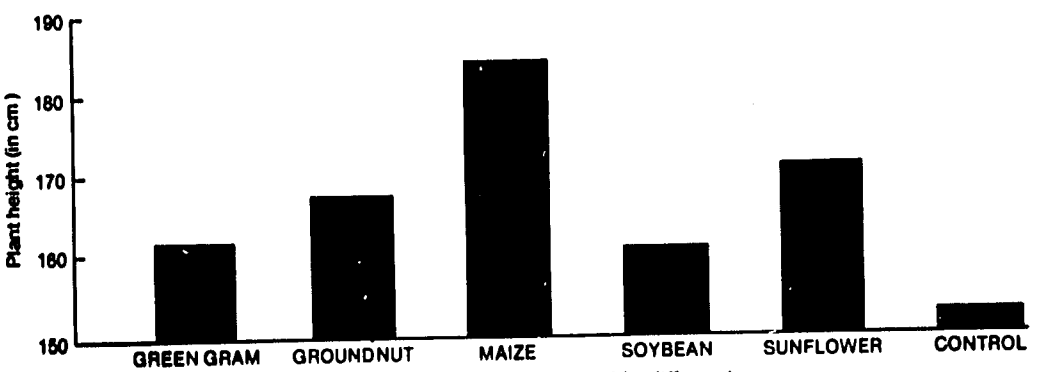

Fig. 2. Height of cassava at harvest as affected by different intercrops.

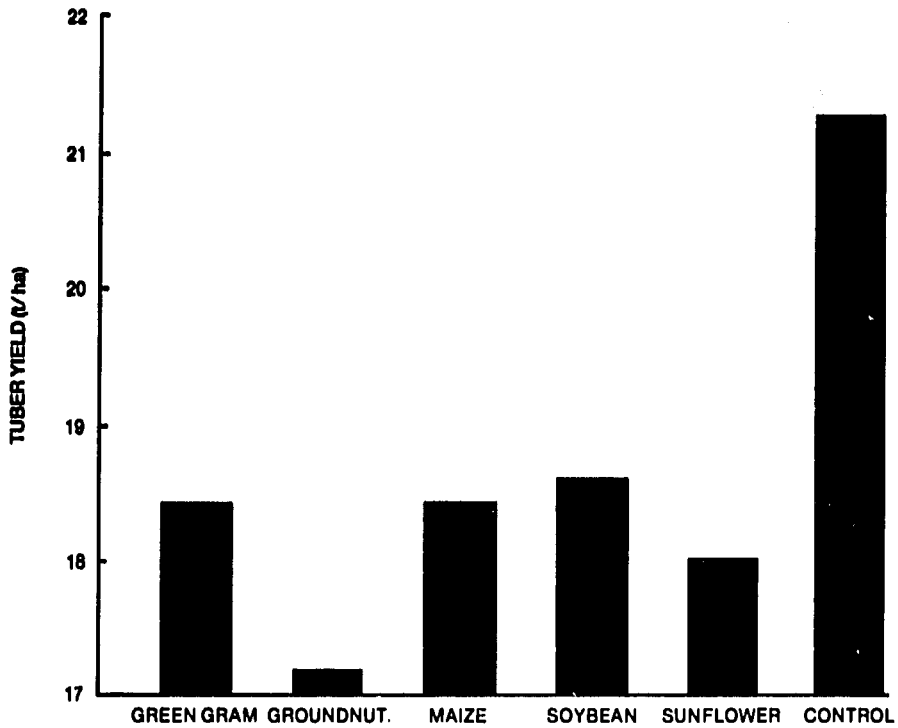

Fig. 3. Yield of cassava (t/ha) as affected by different treatments.

Agronomic Practices to be followed for Groundnut Intercropping with Cassava

A bunching variety of groundnut is preferred to a spreading type. After planting the cassava setts, the seeds of groundnut are sown at a spacing of 30 cm between rows and 20 cm within rows, so that two rows of groundnut intercrop can be accommodated in between two rows of cassava. A seed rate of 40–50 kg/ha is recommended by dibbling two seeds per hill. In the acid laterite soils of Kerala, application of 1000 kg of lime as basal dressing was found to give higher yields for both groundnut and cassava. If the calcium status of the soil is poor, proper pod formulation may not take place. A basal dose of 50:100:50 kg each of NPK/ha should be given uniformly to both crops. One month after sowing the seed, a fertilizer mixture containing 20 kg/ha each of P and K and 10 kg N has to be given to the intercrop along with earthing up. Once the pod formation has started, the soil should not be disturbed as it will adversely affect the development of the pods. The groundnut crop matures within 120 days. After the harvest of the pods, the hulums are incorporated in the soil along with top dressing (50 kg each of NK/ha) for the main crop. Cassava can be harvested 10 months after planting.

The major problems encountered by farmers wishing to follow the above practices are high cost of fertilizers and lack of quality seeds of desirable varieties of groundnut.

Acknowledgments

The authors are thankful to Smt. K.R. Lakshmi and Shri R.S. Biradar for helping in statistical analyses of the data and to Shri C.S. Antonisamy for preparing the graphs and slides for the presentation of the paper.

(Appendix I follows)

Appendix 1.

Environmental description of Kerala State, India.

Month	Max temp (°C)	Min temp (°C)	Rainfall (*mm*)	Evaporation (*mm*)	Sunshine (*h*)	Relative humidity (%)
Jan	31.1	20.4	Trace	141.3	292.9	71/60
Feb	31.3	21.2	10.5	147.3	253.1	68/61
Mar	32.3	23.8	26.0	177.8	288.5	79/37
Apr	32.3	24.4	193.2	128.2	187.0	83/77
May	31.0	23.9	210.6	137.4	188.2	85/77
Jun	30.2	23.5	113.3	110.9	175.1	87/77
Jul	29.1	22.6	359.2	114.2	127.3	92/83
Aug	29.0	22.6	354.6	116.2	165.3	91/81
Sep	29.0	22.7	361.3	104.1	144.3	91/84
Oct	29.7	22.6	114.1	119.6	217.8	85/77
Nov	31.0	22.9	14.7	109.9	204.2	81/70
Dec	32.3	22.3	8.4	141.8	258.3	67/64

Cassava Intercropping Patterns and Management Practices in Indonesia

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Cassava, which follows rice and corn as the third most important food crop in Indonesia, is most commonly grown in combination with other crops. It covers approximately 1.4 million ha or about 8% of the total crop production area in the country, and is mostly grown with low levels of inputs on soils with lower land capability classes. The average yield for Indonesia is about 9 metric tonnes (t) per hectare of wet root.

Cassava may be cultivated either as a single crop or in an intercrop combination with upland rice, peanut, corn, rubber, coffee, and other crops. In the wetter regions with year-round rainfall, cassava can be planted any time of the year, as the crop is not season bound.

Cassava production in Indonesia can be divided according to the intended use. It is grown by small-farm families for their main or supplemental food, for fresh roots for the local market, or for starch and pellet factories. It is also grown on plantations for large-scale production.

Small-Farm Family Cassava Production

Main Food for Family

Even where cassava is grown as a main food source, the farmers usually try to intercrop it with rice or corn. They may also grow sesame and pigeon pea around the border of their land. The cropping pattern used may be as follows.

Early maturing corn (±80 day) is planted with upland rice at the same time in an upland rice + corn intercrop combination. The corn may be either randomly spaced or in rows at a population of not more than 10 000 plants per hectare.

Cassava is usually relay planted into the intercrop combination 30–40 days after rice has been planted at a 100 × 100-cm spacing to give 10 000 plants per hectare.

Usually no more than 100 kg of urea is used to fertilize the corn and rice. The first harvested crop will be corn at about 80–85 days. The corn stover will be used for cattle feed. The second crop harvested will be rice at about 140 days after planting. Cassava is harvested whenever there is a need for food for home consumption. It is usually made into dried cassava chips called "gaplek," which may be precooked and granulated. This product, called "oyek," can be kept for a long period of time (6 months to 1 year).

Even in Madura and East Java where corn is used as a main food, cassava is usually intercropped with the corn 30–40 days after corn is planted. Or the cassava may be intercropped with peanut and planted 30 days after peanut. In these systems, farmers use about 10 000 cassava plants per hectare. This is a fairly dry area where the rainfall ranges from 1500 to 2000 mm/year. They can usually only grow one or two main food crops a year. They may use a sesame intercrop whenever possible even if the population per hectare is very low. Sometimes if the population of the coconut trees is low the farmers grow cassava intercropped with corn under the coconut plants.

Cassava as Supplemental Food for the Family

If cassava is grown mainly for supplemental food (leaves as well as roots), it is usually grown in the home garden, and is usually planted among perennial tree crops like mango, coconut, and other fruits. Farmers in Java may have only 0.5 ha of land. They try to grow rice as much as possible. If the water is enough to grow only one crop of lowland rice, then cassava is planted following the rice. The cassava is usually intercropped with other kinds of crops like peanut, soybean, red pepper, onion, corn, mungbean, or sweet potato. Usually the cassava is planted at low populations or around 5000 plants per hectare. This gives enough space for the other crops to grow between the rows.

In areas where there is flooding and too much water in the rainy season and later a long dry season,

secondary crops are very important sources of food. The farmers control the water by using a ridge and furrow system called a "sorjan." This system permits the farmers to grow rice in the low lying furrow and secondary crops on the high lying ridge. The width of the ridge can be from 4 to 8 m, depending on the intensity of the floods. The length of the beds can be as long as the plot of land permits. In the low lying furrow, lowland rice is usually followed by soybean. Cassava is grown on the border of the ridge. Red onion, peanut, soybean, red pepper, corn, cucumber, mungbean, and sometimes sweet potatoes are planted on the bed between the borders of cassava. Sometimes string beans and mungbeans are grown using the cassava as poles.

In the mountainous and sloping land areas, the farmers usually make terraces. The width of the terraces varies depending on the slope of the land. Cassava, along with vegetables, is usually grown close to or on the borders of the terraces when lowland rice is being grown in the adjacent field. If the terraces are wide enough, they are used as beds and the cassava is grown at the edge of the bed. For this the cassava is usually intercropped with garlic, leaf onion, carrots, red pepper, white potatoes, corn, green beans, cabbage, chinese cabbage, and other crops.

Cassava Grown for Fresh Market

In areas close to the cities, farmers grow cassava as a crop for the fresh market. The crop is very profitable because of the high yield and good price.

In lowland rice areas the cassava is grown after harvest of the rice. In upland rainfed areas it is grown at the beginning of the rainy season.

There seems to be an increasing demand for cassava for this purpose. Medium-size roots are preferred compared to the large ones. There is also a good market for young leaves. The cassava roots and leaves may be used for animal feed also.

Cassava Grown for Starch and Pelleting Factories

For these purposes, cassava may be grown as a single crop or in an intercrop combination with corn and rice. As a single crop the plants are usually spaced 100 × 100 cm to 80 × 80 cm. If the cassava is intercropped with rice, the spacing of the cassava is usually about 100 × cm. Rice and corn are planted at the same time and then cassava is relayed 30 days afterward into the combination. After harvesting the corn and rice, the cassava is allowed to grow as solid cassava. In these areas small amounts of cassava are used for home consumption and the rest sold as dry cassava chips for pelleting, or as fresh roots for starch factories.

Cassava is grown for these purposes usually in regions that have enough rainfall to grow cassava any time of the year except at the onset of the dry season. By doing this the farmers have a continuous supply of cassava roots available for the whole year round.

Large-Scale Production

Large-scale production of cassava is carried out by a few private enterprises that usually cover an area of more than 2000 hectares. The purpose of the large-scale production is to provide a consistent supply of raw material for starch or pelleting factories. Cassava may be grown continuously as a sole crop. This is especially true on land located outside Java. Soon after opening the new land, high production is obtained even without fertilizer. But this high yield cannot be maintained over time. After 3–4 years, fertilizer must be used or the land allowed to revert to *Imperata cylindrica*.

Conclusions

Farmers usually grow cassava in an intercrop combination. This system is more stable if compared to monoculture. They generally do not use fertilizer on cassava, but they may use crop residues from rice and corn to mulch the soil. There is still an opportunity to increase cassava production by using better agronomic practices and fertilizer and by expanding the harvested area, especially outside Java.

Cassava Intercropping Patterns and Management Practices at Tamil Nadu Agricultural University, Coimbatore, India

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Cassava (*Manihot esculenta* Crantz) is grown both under rainfed and irrigated conditions in Tamil Nadu and accordingly the planting season varies. October–November is the planting season for rainfed crops and June–July is the best season for growing the irrigated crops. However, planting is done throughout the year under the irrigated conditions taking advantage of the nonseason-bound character of this crop.

Pattern of Intercropping

Intercropping with cassava offers great scope to increase the unit production as well as increasing the net income. Integration of crops with sugarcane, cotton, turmeric, etc., is now an accepted practice but data for cassava are meagre. The choice of intercrop varies depending on the method of growing, i.e., the crop is either rainfed or irrigated, and also on the type of soils.

An array of crops with durations not exceeding 4 months have been tested at the Cassava Experimental Plots of the Tamil Nadu Agricultural University, Coimbatore, for their suitability. The following intercrops were assessed under irrigated conditions (Table 1):

(1) *Bulb crops*: onion (*Allium cepa* var. *cepa* L.); aggregate onion (*Allium cepa* var. *aggregatum*).

(2) *Leguminous crops*: green gram (*Phaseolus aureus* L.); cowpea (*Vigna sinensis* L.); Co.8 Lablab (*Lablab niger* L.).

(3) *Fruit vegetable crops*: okra (*Abelmoschus esculentus* (L.) Moench);

(4) *Oilseed crops*: groundnut (*Arachis hypogea* L.); sunflower (*Helianthus annuus* L.).

Onion (*Allium cepa* L.)

The roots of onion are shallow, penetrating only to a depth of 5–8 cm. Bulb information and maturity are completed within 85 days before root bulking in cassava. Onion does not affect the growth of cassava as judged by height of plants. The tuber yield of cassava is not affected. Raising onion provides an additional profit of Rs. 1036 (1 rupee = ca. U.S. $0.08) per hectare.

Table 1. Particulars of intercropping in cassava at Tamil Nadu Agricultural University, Coimbatore, India.

Sl.No. + Crop combination	Growth of cassava, *cm* (height of plants)	Yield (*t/ha*)		Income	Profit (+) Loss (-)
		Cassava	Inter-crops		
1. Cassava + onion	180.82	24.60	2.02	13711	+ 1036
2. Cassava + aggregate onion	170.10	20.65	1.26	10827	- 1848
3. Cassava + green gram	160.15	19.17	0.27	10246	- 2429
4. Cassava + cowpea	138.22	16.64	2.03	9537	- 3188
5. Cassava + Co.8 Lablab	150.21	17.78	1.49	9781	- 2944
6. Cassava + okra	140.21	16.90	1.77	9333	- 3392
7. Cassava + groundnut	165.20	19.67	0.62	11075	- 1600
8. Cassava + sunflower	142.16	16.50	0.73	10084	- 591
9. Cassava pure	185.20	24.85	-	12425	-

Aggregate onion (*Allium cepa* var. *aggregatum*)

Under irrigated conditions, aggregate onion affects the growth and yield of cassava accounting for a reduction in net income of Rs. 1848 per hectare. Even though the bulb development is shallow (3–5 cm) and earlier (60–75 days), its association reduces the yield of cassava by 16.9%. In addition, the yields of onion bulbs are very low (1255 kg/ha) and hence the low ultimate income.

Green gram (*Phaseolus aureus* L.)

The tuber yield of cassava was reduced by 22.9% when green gram was raised as an intercrop. The yields of green gram were also less (270 kg/ha) and hence there was a loss of Rs. 2429 per hectare.

Cowpea (*Vigna sinensis* L.)

Reduction in tuber yield by 33.1% has been recorded with cowpea as an intercrop, accounting for a loss of Rs. 3188 per hectare. The tuber yield is the result of retardation of plant growth by 47 cm more than pure cassava.

Co. 8 Lablab (*Lablab niger* L.)

The growth of plants of Co. 8 Lablab (dwarf beans) is vigorous and the crop duration is 120 days; this affects the tuber bulking with an ultimate yield reduction of 28.5%. The low yield of lablab (1485 kg/ha) did not compensate the loss in tuber yield, thus resulting in a reduction in the net income of Rs. 2944 per hectare.

Okra (*Abelmoschus esculentus* (L.) Moench)

Even though okra is a short duration crop (90 days) the deep root system (15–20 cm) affects tuber initiation at the early stages. The growth of cassava plants is also reduced, resulting in a reduction in yield by 32%. The performance of okra as an intercrop is poor as evidenced by a low yield of 1765 kg/ha. Thus okra as an intercrop reduced the net income by Rs. 3392 per hectare.

Groundnut (*Arachis hypogea* L.)

Groundnut affects the growth of cassava plants and yield by 20.9% and such low yield is due to a severe competition of groundnut with cassava for the nutrients. The low yield of groundnut as an intercrop also exhibits its unsuitability for growing with cassava. The reduction in the net income for this combination is Rs. 1600 per hectare.

Sunflower (*Helianthus annuus* L.)

Sunflower, being an exhaustive and quick-growing crop, affects the growth and yield of cassava to a considerable degree. The yield reduction in cassava is as high as 59%. However, the ultimate reduction in income was only Rs. 591 per hectare due to the encouraging returns from sunflower.

Thus it is apparent that onion (*Allium cepa* L.) is the most suitable intercrop for cassava, resulting in an additional net income of Rs. 1036 per hectare within a short duration of 85 days.

Table 2 shows the crop combinations and the planting seasons prevalent in Tamil Nadu at present, and the characteristics of soils in this area and suitable intercrops are shown in Table 3.

The economics of intercropping with cassava in farmers' holdings are given in Table 4.

Under rainfed conditions, cassava intercropped with black gram, green gram, and tomato have been found to increase the net income by Rs. 150 and Rs. 100 respectively. Under irrigated conditions, bellary onion has been found as a suitable intercrop and

Table 2. Crop combinations and the planting seasons prevalent in Tamil Nadu at present.

Cassava (*Manihot esculenta* Crantz)	Oct-Nov	Jun-Jul and throughout year also
Intercrops:		
Black gram (*Phaseolus mungo* L.)	Oct-Nov	Jul-Aug
Green gram (*Phaseolus aureus* L.)	Oct-Nov	Jul-Aug
Bengal gram (*Cicer arietinum* L.)	Oct-Nov	-
Coriander (*Coriandrum sativum* L.)	Oct-Nov	-
Groundnut (*Arachis hypogea* L.)	Oct-Nov	Jul-Aug
Ragi (*Eleusine coracana* Gaertn.)	Oct-Nov	May-Jun
Tomato (*Lycopersicon esculentum* Mill)	Oct-Nov	Jul-Aug
Onion (*Allium cepa* var. *aggregatum*)	Oct-Nov	May-Aug

Table 3. Characteristics of soils in the Tamil Nadu district and suitable crops.

Available nitrogen (*kg/ha*)	147 (low)	84 (very low)	165 (low)
Available phosphorus (*kg/ha*)	16 (medium)	23 (medium)	14 (medium)
Available potash (*kg/ha*)	327 (medium)	105 (low)	323 (medium)
Organic matter (%)	0.58	0.34	1.17
pH	50.70	7.0–7.5	8.5–9.5
Suitable intercrops		Black gram Green gram Groundnut Ragi Tomato Onion	Coriander Bengal gram

Table 4. Economics of growing intercrops as practiced by farmers.

Crop combinations	Duration of intercrop	Income (*Rs./ha*)			Net profit (*Rs./ha*)	Profit (+) or loss (-) due to intercrops
		Cassava	Inter-crops	Total		
Rainfed						
Cassava + black gram	80	6000	1625	7625	3125	+ 375
Cassava + coriander	80	5250	1500	6750	2500	- 250
Cassava + groundnut	100	5250	1500	6750	2250	- 500
Cassava + green gram	80	6000	1500	7500	3125	+ 375
Cassava + bengal gram	90	5250	1250	6500	2500	- 250
Cassava + tomato	105	5625	1875	7500	3000	+ 250
Cassava pure	360	6000	-	6000	2750	-
Irrigated						
Cassava + black gram	85	7125	3440	10565	4315	+ 565
Cassava + groundnut	110	6750	2500	9250	2750	- 1000
Cassava + green gram	85	8250	2500	10750	4500	+ 750
Cassava + tomato	115	6750	4375	11125	4625	+ 875
Cassava + ragi	110	6000	3500	9500	3625	- 125
Cassava + onion (small)	75	8250	2500	10750	4250	+ 500
Cassava + onion (big)	85	8250	3750	1200	5750	+ 2000
Cassava pure	300	9000	-	9000	3750	-

brings in an additional income of Rs. 750 per hectare.

Characters of Cassava Cultivars

Brief descriptions of the popular cassava cultivars grown where intercropping is practiced are furnished in Table 5.

Land Preparation and Agronomic Practices

Preparation of Land

When it begins to rain, the field is prepared for the rainfed crop with four ploughings. A quantity of 25 t of farmyard manure is applied per hectare before the last ploughing and incorporated into the soil.

Under irrigated conditions the field is prepared to a fine tilth by ploughing four times. A quantity of 25 t of farmyard manure is applied per hectare before last ploughing. The field is thrown into either ridges and furrows or beds of convenient size, preferably 5 × 5 m.

Preparation of Setts

Cuttings of 15 cm length with 6–8 buds are prepared from mosaic-free clones with thickness usually less than one-half of the diameter of the thickest part of the stem. The top portion of sett so prepared is dipped in red earth to facilitate easy planting. The setts are also dipped in a mixture containing metasystox or rogor and copper fungicides as a plant protection measure against pests and diseases.

Planting

The prepared setts are planted in the ploughed field immediately after rains for the rainfed crop with a spacing of 75 × 75 cm and supported with

Table 5. Characteristics of cassava cultivars in relation to intercropping.

Particulars	Co.1	H.97	H.165	H.226	H.1687	H.2304	Malabar	Burma
Vigour	Medium	High	Medium	High	High	High	Medium	Medium
Branching[a]	NB	SB	SB	B	B	SB	B	B
Period for canopy formation (*days*)	80	90	85	90	90	90	100	100
Period for initiation root bulking	110	120	110	120	120	120	120	120
Period for full maturity	260	300	270	300	300	300	320	325
Root characters:								
Skin	Very light brown	Light brown	Light brown	Light brown	Brown	Brown	Brown	Brown
Rind	White	White	White	White	White	White	White	Pink
Flesh	White	White	White	White	Cream	White	White	White
Yield (*t/ha*)	35	32	35	36	35	35	30	28

[a]NB, nonbranching; SB, semibranching; B, branching.

soil on the sides. The seeds of intercrops are sown in between cassava setts.

For the irrigated crop the field is prepared with ridges and furrows or beds and is irrigated. The setts are planted at a spacing of 75 × 75 cm. Seeds/seedlings of intercrops are sown/planted in between two rows of cassava. A quantity of 18 000 setts are required for planting 1 ha.

Spacings Adopted

Cassava	75 × 90 cm or 75 × 75 cm
Onion	15 × 15 cm
Groundnut	25 × 25 cm
Tomato	60 × 60 cm
Ragi	20 × 20 cm
Coriander	15 × 15 cm
Black gram	20 × 10 cm
Green gram	20 × 10 cm
Bengal gram	45 × 10 cm

Manures and Manuring (per hectare)

	FYM (*t/ha*)	N (*kg/ha*)	P (*kg/ha*)	K (*kg/ha*)
Rainfed				
Basal	25	25	25	50
Top (3 months after planting)	-	25	25	50
Top (additional dose)	-	10	10	20
Irrigated				
Basal	25	25	25	50
Top (3 months after planting)	-	25	25	50
Top (additional dose	-	10	10	20

Intercultivation

Three hand weedings are given to keep the field clean. The shoots are thinned 45 days after planting, leaving two healthy and vigorous shoots per sett. One hand weeding and earthing up is given 3 months after planting and fertilizers are applied when rains are received. After 7 or 8 months, the leaf fall from the crop serves as a mulch and keeps weeds away.

Four hand weedings are given for the irrigated crop up to 6 months after planting. Thereafter the fallen leaves serve as a mulch. The shoots are thinned 45 days after planting, leaving two healthy and vigorous shoots per sett. Two hand weedings and earthing up, one in 3 months and another 5 months after planting are given and the fertilizers are applied.

Irrigation

Under rainfed conditions the establishment of the setts and the further growth and development of the plants entirely depend upon the subsequent rainfall.

For the irrigated crop the field with ridges and furrows or beds is irrigated and setts are planted. It is followed by a life irrigation on the 3rd day, at weekly intervals up to full establishment, and then at a frequency of 12–15 days.

Water stagnation adversely affects the crop considerably due to rotting and, as such, proper drainage has to be ensured.

Plant Protection

Two important diseases of cassava are mosaic virus and *Cercospora* leaf spot. Four sprayings of Dimethoate (Rogor) 0.03% are given at monthly intervals up to 4 months against the vector *Bemisia tabacii* (white fly) for virus disease and other insects. The *Cercospora* leaf spot is controlled by spraying any copper fungicide or Bordeaux mixture (5:5:50).

Harvest

The duration of the cassava is 9–10 months under irrigation and 10–12 months under rainfed crops depending upon the varieties. The symptoms of maturity are cracking of soil near the plant, yellowing of bottom leaves, and leaf fall.

Conclusions

(1) As cassava is grown mostly under rainfed and semi-irrigated conditions, intercrops with adequate drought tolerance need to be evolved.

(2) A suitable fertilizer combination compatible with the intercrop as well as with the main crop has to be standardized.

(3) The prevalence of mosaic virus disease is common, in particular in the rainfed crops. As a result, the tubers become unfit for the industry. Even though development of virus-resistant varieties is a long-range process, it is a fruitful line of work deserving priority. As an interim measure, investigations on the virus vector relationships and effective methods of control have to be intensified.

Cassava Intercropping Patterns and Practices in Malaysia

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Malaysia lies close to the equator (between latitudes 1 and 7° N and longitudes 100 and 119° E), and consists of two distinct geographical regions: (*a*) Peninsular Malaysia, which consists of 11 states, and (*b*) the states of Sarawak and Sabah on the northwestern coast of Borneo Island. The two regions are separated by about 650 km of the South China Sea.

As cassava areas in Sarawak and Sabah are relatively small, and information on intercropping in the region is practically nonexistent, this paper deals primarily with intercropping in the Peninsula; however, information from the latter region is generally applicable to Sarawak and Sabah.

Cassava Cropping Systems

As cassava is a relatively minor crop (occupying only about 13 000 ha or 0.47% of cropped land in Peninsular Malaysia in 1972 (Anon. 1974)), little attention has been given to its intercropping in cassava-growing areas. Most of the cassava is, in fact, planted by smallholders, usually illegally on state-owned land, as cash crops for sale to local feed and starch factories. As such, it is seldom intercropped, the most widespread cropping system being monocropping, which in many cases has continued for 10–20 years or more (Chung 1975, 1976). In 1972, for example, 72% of cassava land was sole cropped, with the remainder (28%) under mixed or intercropping (Anon. 1974); however, information on the crop combinations and arrangements with cassava is unfortunately not available.

Intercropping Cassava with Rubber

Cassava is often grown as a cash intercrop in rubber small holdings during the first 2–3 years of its immature period, but the extent of cassava/rubber intercropping is small; e.g., in 1964 only 156 ha (3.8%) of a total of 4080 ha of intercropped rubber was planted with cassava (Lim 1969). Moreover, cassava may not be the only intercrop in a rubber small holding; it is often mixed or rotation cropped with one of a large number of other cash crops such as maize, groundnut, sweet potato, hill rice, tobacco, ginger, chili, and watermelon. Lim (1969) attempted to secure data on the crop combinations adopted but these were so diverse that no meaningful general pattern could be constructed.

Detailed information on cassava planting dates is not available but they appear to vary from state to state and from farmer to farmer. However, the generally preferred time of planting is shortly before the two annual rainy seasons, which start in October and April (Lim 1969).

Most rubber small holdings intercropping cassava grow the local sweet cultivars, such as Medan and Jurai, which are consumed as human food locally, unlike the higher-yielding but bitter cultivar Black Twig, popularly grown for production of feedstuff or starch. Cultivars intercropped usually produce a complete canopy in about 2–3 months after planting, and rarely branch, each stem growing straight up to a height of about 3.5 m at maturity (10–12 months), and yielding 20–40 t/ha fresh tubers in sole cropping (Chan 1970; Chew 1977); when intercropped with rubber, yields ranging from 22.5 to 47.5 t/ha have been reported (Pushparajah and Tan 1970).

A conventional rubber planting system (6–9 m between rows, and about 3.7 m within the row) is usually adopted, wider rows being used on steeper slopes. Although hedge or avenue systems (15–24 m between rows) are an advantage to intercropping, they are not recommended because of the higher incidence of wind damage and lower rubber yields (Lim 1969).

The space available for intercropping is limited not only by the system of rubber planting, but also by its age, i.e., the extent of shade and root devel-

opment. However, cassava is normally grown soon after, and in some cases even some months before the rubber has been transplanted, when competition is minimal. The rubber interrow area is dug manually to remove weeds and loosen the soil. The cassava is then planted at a spacing of about 1 m square to about 0.6–1.2 m (4–6 ft) from the rubber row. According to Pushparajah and Tan (1970), cassava planted 1.06 m from the rubber resulted in slightly reduced rubber growth rate, compared with planting 1.52 and 1.98 m away.

Stem cuttings for planting (about 11 500/ha, 20 cm in length, usually obtained free of charge (Lim 1969)) and fertilizers, if any, are the only material inputs used. As regard fertilizers, Lim (1969) found in a nationwide survey that about 92% of rubber smallholders growing cassava as an intercrop do not fertilize the cassava; those who did obtained about 30% more tuber yields. Fertilization is particularly important in the second and subsequent crops of cassava, as cassava has high nutrient requirements — an 11-month crop removes about 218 kg/ha N, 22 kg/ha P, and 278 kg/ha K (Pushparajah and Tan 1970).

Farmers usually do not carry out any crop protection measures (Lim 1969) as cassava is relatively free from pests and diseases in Malaysia; however, it may suffer from white root disease (*Fomes lignosus*), which can be controlled by removal of infected plants and the source of inoculum (usually old stumps or roots). The rubber termite (*Coptotermes curvignathus*), known to cause severe damage to intercropped cassava, is controlled by the use of chlorinated hydrocarbon insecticides (Rao 1970).

Labour is the major input cost; smallholders' families provide most of the requirement, with hired labour contributing about 13.2% (Lim 1969). About 168 man-days/ha (1 day = 8 hours) is needed during a cassava growth cycle of about 11.2 months (average of 15 man-days/month); of this, 37% is used for preplanting operations, 8% for planting, 36% for weeding, 18% for harvesting, and 1% for other maintenance activities.

One disadvantage of cassava intercropping with rubber is that the emergence of lallang (*Imperata cylindrica*), a noxious weed, is not easily noticed. This results in great difficulty in the control of this weed in affected areas when the cassava has been harvested. In Lim's (1969) survey, 37.5% of smallholdings under rubber–cassava intercropping recorded the presence of lallang after harvesting.

Cassava is feared to have a retarding effect on the growth of immature rubber. Pushparajah and Tan (1970), however, stated that this fear is unfounded, for with adequate fertilization and planting of the cassava intercrop at least 1.5 m from the rubber row, the effect on rubber is minimal. This is in agreement with Lim's (1969) finding that only 12.5% of rubber–cassava holdings reported any retarding effects of cassava on rubber, which may be caused by the lack of fertilizers and the prevalence of lallang (see above). Nevertheless rubber growth can decrease when intercropping with cassava, resulting in delay in opening for tapping and consequent losses of returns to the farmer. However, since with cassava intercropping the expenditure incurred in establishing and maintaining leguminous ground covers in the intercropped area is saved, and with yearly return to labour of about M$993/ha (ca. U.S. $467) (Table 1) for 2–3 years, it is generally considered worthwhile to intercrop with cassava. Any delay in tapping the rubber or loss in rubber yield is well compensated for.

Table 1. Cost and returns from intercropping cassava in rubber (from Lim 1969).

Item	M$/ha/crop[a]
Gross returns	1018
Cost of labour	389
Cost of materials	25
Net return	604
Return to labour	993

[a]M$1.00 = ca. U.S. $0.47.

Intercropping Cassava under Other Perennials

Cassava is cultivated as an intercrop to a very small extent under oil palm and coconut, which are two other major perennial crops in Malaysia. In oil palm, as in rubber, intercropping is possible only during the first immature 2–3 years of growth, because of the dense canopy of mature stand. In coconut of the tall type, both immature and mature stands may be intercropped.

Cassava Intercropping with Annual Crops

Until recently, little work has been carried out in Malaysia on cassava–annual crop intercropping, although in the state of Perak, where most of Peninsular Malaysia's cassava is produced, groundnut (*Arachis hypogea*) is a major monocultural crop that has great potential as a profitable intercrop with cassava. In peat, where cassava is envisaged as a major crop for potential wide-scale development (Chew 1977), there is much current interest in suitable annual intercrops for increasing productivity and reducing the risk of monocropping. Results from a preliminary experiment on relay cropping based on

work at the MARDI peat station at Jalan Kebun are presented below.

Between June 1975 and April 1978, cassava (cult. Black Twig) was relay-cropped experimentally with groundnut (cult. Local Spanish), sorghum (*Sorghum bicolor*, cult. E178), chili (*Capsicum annuum*), flue-cured tobacco (cult. NC195), and long bean (*Vigna sesquipedalis*, also called string bean), giving 10 treatments (Fig. 1) but including 15 crop combinations consisting of relays of the five annual crops in (*a*) mature, (*b*) immature, and (*c*) both mature and immature, cassava. All treatments, which were replicated thrice in a randomized complete block design in plots of 8 × 5 m, were relayed twice — in May/June 1976 and April/May 1977 (Fig. 1). A relay period of 1 month between crops was planned initially for all combinations, but this had to be modified from season to season, and according to the specific combination and relative growth of cassava and its relay crop. At each planting date of each crop, two similar monoculture plots were planted for comparison with the relay treatments in the calculation of Land Equivalent Ratios (LERs) (i.e., the land area under monoculture giving yields equivalent to that of 1 ha under relay cropping regardless of time and economic factors (Sanchez 1976)).

The experimental area was mechanically rotovated after removal of undecomposed logs in the peat topsoil. Lime was broadcast to raise soil pH from 3.7 to about 4.5. Planting materials consisted of 60-cm long mature cassava stem cuttings, planted vertically; groundnut and sorghum seeds; and $1^1/_2$-month-old chili and tobacco seedlings. The planting pattern and density of each crop (Fig. 2) were the same whether relay-cropped or monocultured. After planting, fertilizers were broadcast at rates as in Table 2, and a wooden trellis was provided for the climbing long bean.

Cassava–Annual Crop Relays

In the first relay of May/June 1976 (Fig. 1), all annual crops except long bean did not perform successfully when planted under 11-month-old cassava (Table 3). In the case of chili and tobacco, failure was because of lack of seedlings due to poor seed germination; however, these two crops gave reasonably good growth and yield when relayed under mature cassava in the second relay of April/May 1977 in the chili–cassava–chili and tobacco–cassava–tobacco relay treatments, the first seasons of which were not planted (Fig. 1), also because of lack of seedlings. The failure of groundnut and sorghum, which germinated well, was primarily because of poor establishment rate under the poor light regime under mature cassava and also as a result of uprooting when the cassava was harvested.

From the above, only relay cropping of chili, tobacco, and longbean under cassava could be compared (Table 3). LER values of the cassava-chili

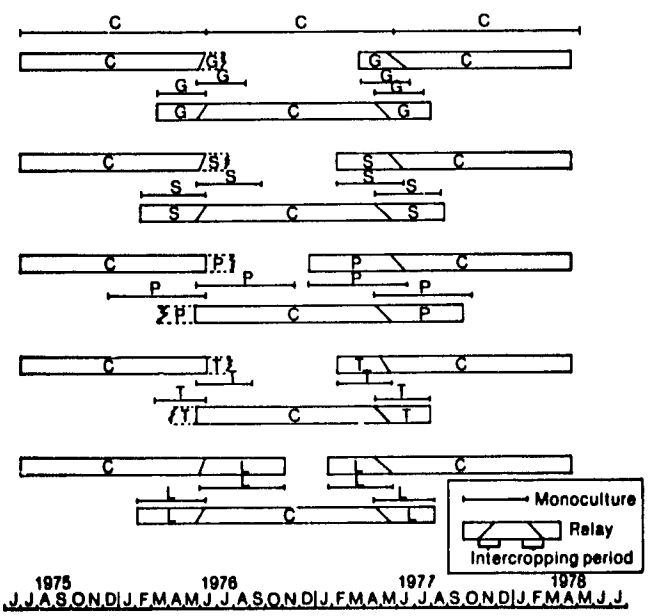

***Fig. 1.** Relay cropping treatments, showing actual crop combinations and schedules of cassava (C), groundnut (G), sorghum (S), chili (P), tobacco (T), and longbean (L) on peat; incomplete bars in broken lines show the unsuccessful seasons, and monoculture plots are included for comparison.*

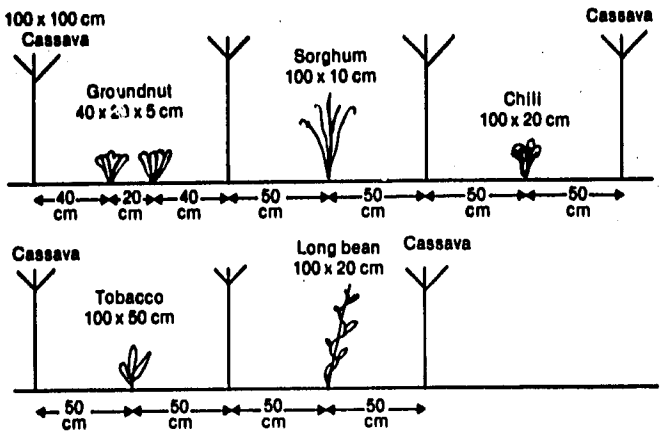

Fig. 2. Planting patterns and plant spacings in cassava relay cropping with groundnut, sorghum, chili, tobacco, and longbean.

(1.58) and cassava–tobacco (1.52) treatments were lower than that of cassava–longbean (1.78). Furthermore, the former two treatments could be relayed for 30 days compared to only 10 days for cassava–longbean.

Annual Crop–Cassava Relays

In April/May 1977, planting cassava as a relay crop in mature stands of the five annual crops resulted in relatively good yields of all crops involved (Table 4). Tobacco, longbean, and groundnut gave significantly higher LERs (1.76, 1.74, and 1.70, respectively) than sorghum and chili (1.53 and 1.52, respectively). The relay period that was successful for these crops averaged 35 days for groundnut and longbean, 25 days for sorghum and chili, and 17 days for tobacco.

Annual Crop–Cassava–Annual Crop Relays

As the precassava crops of chili and tobacco were not planted because of lack of seedlings (see above), only groundnut, sorghum, and longbean, each double-relayed (before and after cassava), were compared, the LER values being 2.01 for sorghum, 2.22 for groundnut, and 2.48 for longbean (Table 5). The relay periods were the same for all three annual crops: 15–19 days in the precassava relay of May/June 1976 and 30 days in the postcassava relay of April/May 1977.

Conclusions

Relay cropping of cassava following groundnut, sorghum, chili, tobacco, and longbean is more likely to succeed than relaying these five annuals after cassava. However, the success of annual crop–cassava relays may partly be attributed to the use of long (60-cm) stakes, which result in better development of cassava shoots at levels higher than the maturing annual crop canopy.

In maturing cassava, the competition for space and nutrients is usually too great for normal establishment and growth of relay annual crops grown

Table 2. Crop duration and fertilization rates for each of six crops under relay cropping on peat.[a]

		Nutrient rates (*kg/ha*)		
Crop	Crop duration (*months*)	N as urea (45% N)	P as superphosphate (24% P)	K as sulfate of potash (40% K)
Cassava	12	200	30	135
Groundnut	3	30	20	70
Sorghum	4	120	20	85
Chili	4–6	150	30	125
Tobacco	3.5	45	15	60
Longbean	4–5	40	30	80

[a]Before planting the first crop, 20 kg/ha copper sulfate was broadcast in the experimental area.

Table 3. Yields (of fresh cassava tubers, sorghum and groundnut dry seeds, fresh chili and longbean fruits, and fresh tobacco leaves), returns, relay periods, and land equivalent ratios (LER) of cassava-annual crop relays on peat; values in parentheses are the yields under monoculture in the corresponding seasons, and land equivalent ratio values with the same letter are not significant at $P = 0.05$; F = failure.

Relays	Season	Relay period (*days*)	Yields (*t/ha*)		Returns (*M$/ha*)[a]	LER
			Cassava	Annual crop		
Cassava/groundnut	1975/76	-	45.3(52.8)	F(1.21)	-	-
Cassava/sorghum	1975/76	-	42.4(52.8)	F(1.54)	-	-
Cassava/chili	1975/76	-	41.9(52.8)	F(10.67)	-	-
Cassava/chili	1976/77	30	33.0(44.0)	2.15(2.60)	3069	1.58a
Cassava/tobacco	1975/76	-	40.0(52.8)	F(6.9)	-	-
Cassava/tobacco	1976/77	30	35.8(44.0)	4.29(5.9)	3205	1.52a
Cassava/longbean	1975/76	10	47.8(52.8)	11.50(13.20)	4287	1.78

[a]M$1.00 = ca. U.S. $0.47.

Table 4. Yields (of fresh cassava tubers, sorghum and groundnut dry seeds, chili and longbean fruits, and tobacco fresh leaves), returns, relay periods, and land equivalent ratios (LER) (values with the same letter are not significantly different at $P = 0.05$) of annual crop–cassava relays on peat in 1977/78; values in parentheses are yields under monoculture in the corresponding seasons.

Relays	Relay period (*days*)	Yields (*t/ha*)		Returns (*M$/ha*)[a]	LER
		Annual crop	Cassava		
Groundnut/cassava	36	1.51(1.70)	37.8(46.2)	2290	1.70a
Sorghum/cassava	24	1.27(1.59)	33.6(46.2)	1959	1.53b
Chili/cassava	25	1.69(2.42)	37.8(46.2)	3005	1.52b
Tobacco/cassava	17	5.81(6.60)	40.7(46.2)	3952	1.76a
Longbean/cassava	34	10.8(12.1)	39.0(46.2)	3732	1.74a

[a]M$1.00 = ca. U.S. $0.47.

Table 5. Yields (of fresh cassava tubers, sorghum and groundnut dry seeds, chili and longbean fruits, and tobacco fresh leaves), returns, relay periods, and land equivalent ratios (LER) (values with the same letter are not significantly different at $P = 0.05$) of annual crop-cassava-annual crop relays on peat in 1976/77; values in parentheses are yields under monoculture in the corresponding seasons; F = failure.

Relays	Relay periods (*days*)	Yields (*t/ha*)			Returns (*M$/ha*)[a]	LER
		Annual crop	Cassava	Annual crop		
Groundnut/cassava/groundnut	15, 30	1.78(2.04)	35.2(44.0)	0.93(1.70)	2478	2.22
Sorghum/cassava/sorghum	15, 30	0.97(1.70)	35.5(44.0)	1.07(1.55)	2223	2.01
Chili/cassava/chili	-, 30	F(14.9)	33.0(44.0)	2.15(2.60)	-	-
Tobacco/cassava/chili	-, 30	F(7.0)	35.8(44.0)	4.29(5.9)	-	-
Longbean/cassava/longbean	19, 30	9.17(10.55)	33.5(44.0)	9.80(11.80)	4805	2.48

[a]M$1.00 = ca. U.S. $0.47.

from seeds, except in the case of longbean, for which the relay period nevertheless has to be reduced to 10–15 days. However, in the case of chili and tobacco, where seedlings are relay-planted amongst mature cassava, a longer relay period of about 30 days is then possible.

Double-relaying of cassava with annuals (annual-cassava-annual) proves to be quite successful, one promising relay crop being longbean.

Further work is needed to study the interaction of cassava with each of the annual crops under different agronomic factors, such as planting date, plant density, and fertilization.

Environmental Description

Rainfall: The rainfall per month in the principal areas of cassava and rubber-cassava associations

averages around 300 mm/month, with a drier period during June–August (100–200 mm/month), and wetter seasons in March–May and October–January, when the rainfall is about 250–500 mm/month.

Temperature: The average daily temperature varies from 65 to 95 °F in the lowlands, and is maintained throughout the year.

Solar radiation: Bright sunshine hours per month range from 150 to 310 hours.

Soil characteristics: Soil texture varies from light to heavy but is usually well drained; topography is level to hilly and soil pH is below 5.

Socioeconomic Factors

Farm size and area cropped: According to Lim (1969), rubber holdings intercropped with cassava had an average size of 2.0 acres (0.81 ha); detailed information on the proportion of each farm intercropped with cassava is lacking.

Capital investment: Compared to other crops in the region, e.g., oil palm, capital investment is very low, hardly any inputs being used for growing cassava, apart from planting materials and labour.

Power input: Most operations are carried out manually, except for land preparation.

Markets for output: Cassava intercropped with rubber is predominantly grown for sale as fresh roots for human as well as animal consumption.

Intercropping with Cassava in Africa

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In Africa, cassava-growing areas are located from Senegal in the west, through Nigeria and Zaire, east to Malagasy and from 15°N–15°S latitude, according to de Viliers (1965). Optimum production requires an annual rainfall of 1000–2000 mm; average annual temperatures of 25–29 °C; daylengths not greater than 15 hours; altitudes less than 2000 m above sea level; and freely draining sandy loam soils dominated by oxisols, ultisols, and alfisols. The diversity of cassava cropping systems in the lowland humid tropics is based on high population densities, personal tastes, economic and political factors, and the overall level of technological development and resource availability.

Cassava is grown not only as a sole crop but is often mixed intercropped (i.e., grown simultaneously with one or more different crops on the same field with no distinct row arrangement) or relay intercropped (i.e., grown with one or more different crops simultaneously during part of the life cycle of each crop).

Statistics on intercropped cassava tend to be underestimated, especially if the shorter term annuals planted with cassava have been harvested before the data have been collected. The number of plants in the intercrop is highly variable. On many family farms, sole cropping is dominant in the outer fields, while intercropping reaches its maximum complexity in the compound garden where cassava and other annual staples, vegetables, and perennial fruit trees are intercropped. Farm size tends to vary between 1 and 4 ha in both the rain forest and savannah areas. Although there is a preponderance of larger farms in the drier savannahs, the number of plants in cassava mixed croppings tends to decrease. Although intercropping is widely practiced, the patterns are location-specific, especially in the range of crop species that may be intercropped. A traditional farming practice, intercropping provides stable yields, though this can change in accordance with population densities and socioeconomic and agricultural conditions.

Cassava is an important food for man and animals in the producing areas and is now being traded on the international market. The attributes of cassava in indigenous farming systems include: high yield compared to other crops per unit of time and land (de Vries et al. 1967); a long planting season (8 months) allowing for greater flexibility in work schedules; and good storage properties in the ground. Additionally, cassava is well adapted to a wide range of ecological conditions (Jones 1959), and is valued for its drought tolerance and ability to grow in suboptimal soils.

Philips (1974) forecasts cassava deficits and carbohydrate shortages for some African countries by 1980. The prospects of increasing cassava production and achieving self-sufficiency in the consumer nations of Africa will be enhanced by the introduction of improvements based on an understanding of the mechanics, economics, advantages, and disadvantages of traditional systems.

Cassava in Traditional Farming Systems

Cassava, a long-duration crop (9–18 months), is suited to intercropping with shorter-duration crops (2–5 months) such as maize, cowpeas, melons, and leaf vegetables. These crops mature when the cassava is just attaining its maximum leaf area development and is initiating an increased rate of bulking in its roots. As reported by Andrews (1970 and 1975) and Kassam and Stockinger (1973), the yields of relay and intercropping systems are highest when there is a competition gap between the periods when the crops involved are making maximum demands on environmental resources (light, nutrients, and moisture).

In southern Nigeria, cassava is often intercropped with principal staples, such as yams, cocoyams, and

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maize, and subsidiary crops, such as okra (*Hibiscus esculentus*), melons (*Colocynthis vulgaris*), leaf vegetables (*Telfairia occidentalis* and *Corchorus olitorus*), and beans (*Sphenostylis stenocarpa* and *Vigna unguiculata*). Cassava and intercrops are also grown with oil palms and rubber and cocoa trees.

The sequence of intercropping with cassava is based on the compatibility of species in the mixture that can produce reasonable yields in relation to soil fertility and environmental conditions during the cropping cycle. Examples of cassava crop combinations and sequences from Nigeria, Sierra Leone, Liberia, and Zaire are summarized in Fig. 1–5 (Floyd 1969). With the exception of Liberia and Sierra Leone, where cassava is intercropped with upland rice (Spencer 1973), it may be concluded that cassava intercropping systems in West Africa and Zaire (de Schlippe 1956; Reining 1970) are similar in production techniques, diversity of crops grown, and the dominance of cassava in terminal crop sequences.

Cassava Intercropping Research at IITA

The International Institute of Tropical Agriculture (IITA) is now emphasizing intercropping systems that produce good yields, maintain soil fertility, and minimize disease and pest buildup (IITA 1975).

The first stage in the IITA strategy was the use of village-level studies of traditional farming systems to determine dominant crop mixtures, planting patterns, practices, and productivity of land and labour in various ecological zones. The studies also examined farmers' attitudes, experience, and constraints, as well as the possibility of increasing profitability in a given area (Ezeilo et al. 1975).

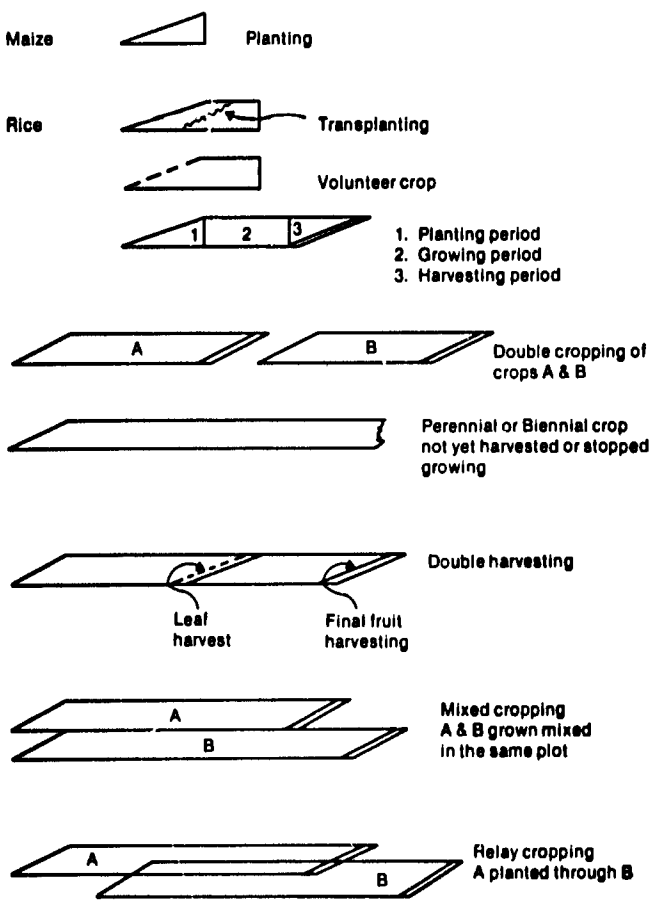

Fig. 1. Key to cropping schedules and combinations.

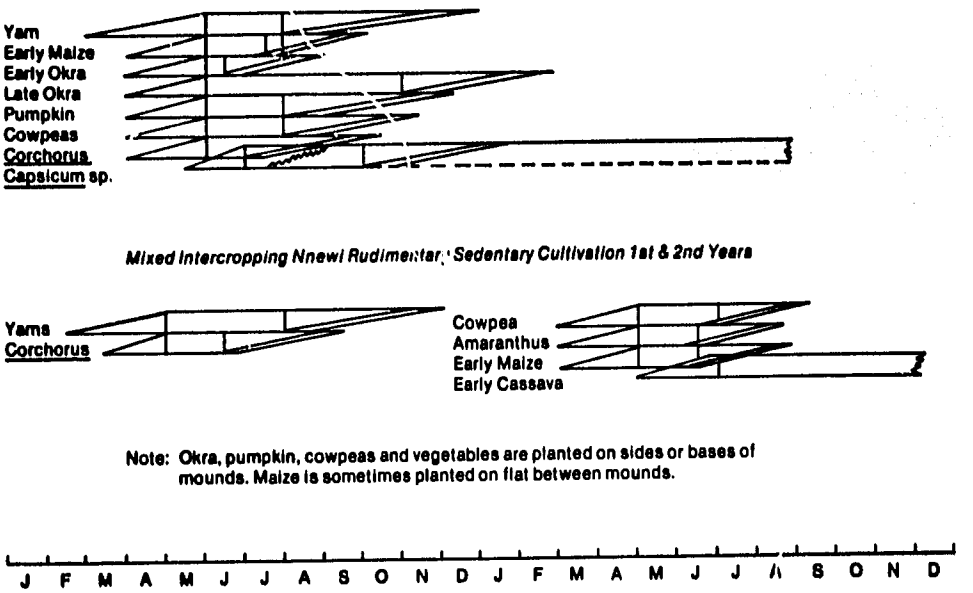

Fig. 2. Mixed and relay intercropping, Nnewi, first year bush fallow.

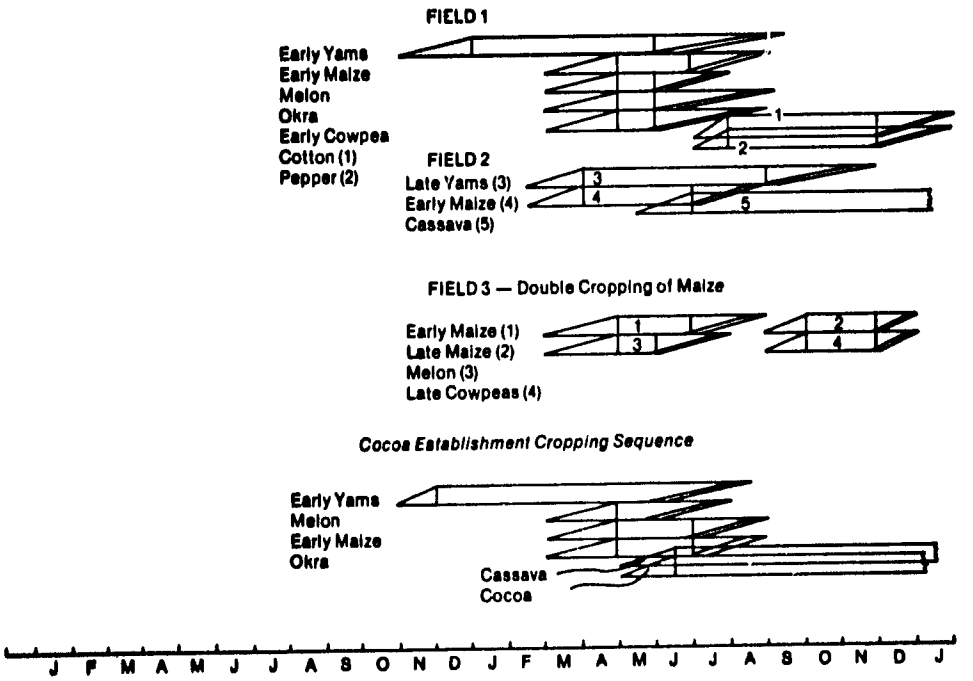

Fig. 3. Cropping schedules in Ibadan area, Western Nigeria.

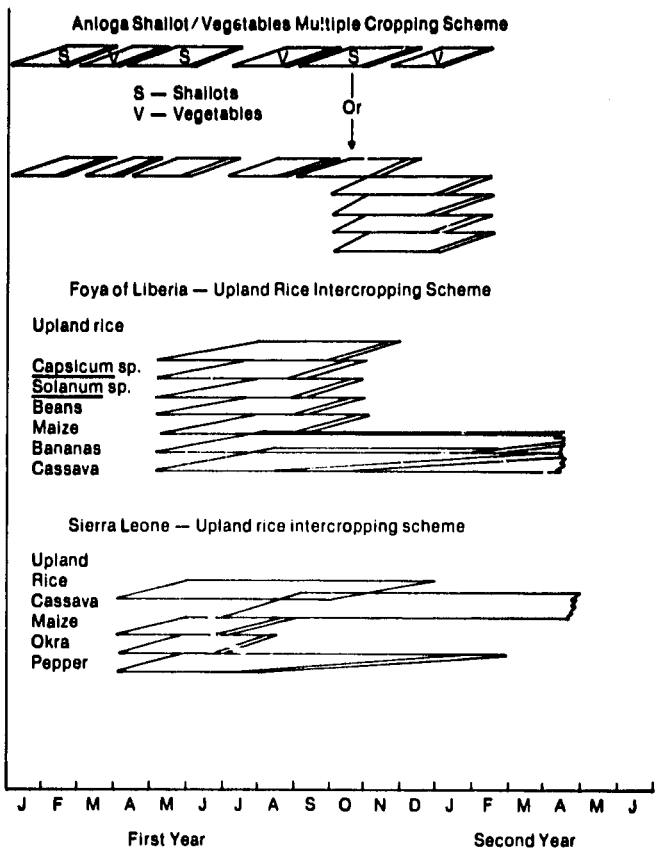

Fig. 4. Anioga: shallot/vegetables multiple cropping scheme; Foya of Liberia: upland rice intercropping scheme; Sierre Leone: upland rice intercropping scheme.

The results showed that 50% of farmers interviewed consumed over 70% of their cassava at home. Dominant combinations of cassava with principal staples were cassava/maize; cassava/yams; and cassava/yam/maize. The frequency of occurrence of more than three crops in the mixture was higher in the compound farms than in distant farms. Cassava populations ranged from 15 000 in intercrops, to 30 000 per hectare in sole crops. With the exception of compound farms that receive household refuse, soil fertility was maintained by bush fallowing. Higher human population densities, and consequently shorter fallows, resulted in lower levels of organic matter, nitrogen, and phosphorus, particularly in distant farms.

Cassava was planted throughout the rainy season commencing with the early rains. Clearance was accomplished by the "slash and burn" technique and the primary cultivation implements were the hoe and the machete. Human power proved to be the sole energy source. The majority of cassava with interplants was grown on light soils. Over 77% was grown on mounds, 11% on ridges, and 11% on the flat. The major economic constraints that farmers felt prevented them from increasing production were: lack of working capital and access to credit, lack of land, and high labour costs. These factors and the biological constraints of diseases and pests resulted in recorded low modal yields of 6 tonnes per hectare.

Okigbo (1977) concluded from cassava intercropping trials at IITA, Ibadan, that relay intercropping of cassava through maize gives high yields of component crops when cassava is planted at the same time as the maize or not more than 2 months after maize planting. In addition, relay planting cassava through maize (beyond 2 months after maize planting) resulted in reduced plant population and root yields. Intercropping provided higher calorie yields and gross returns than sole cropping of component

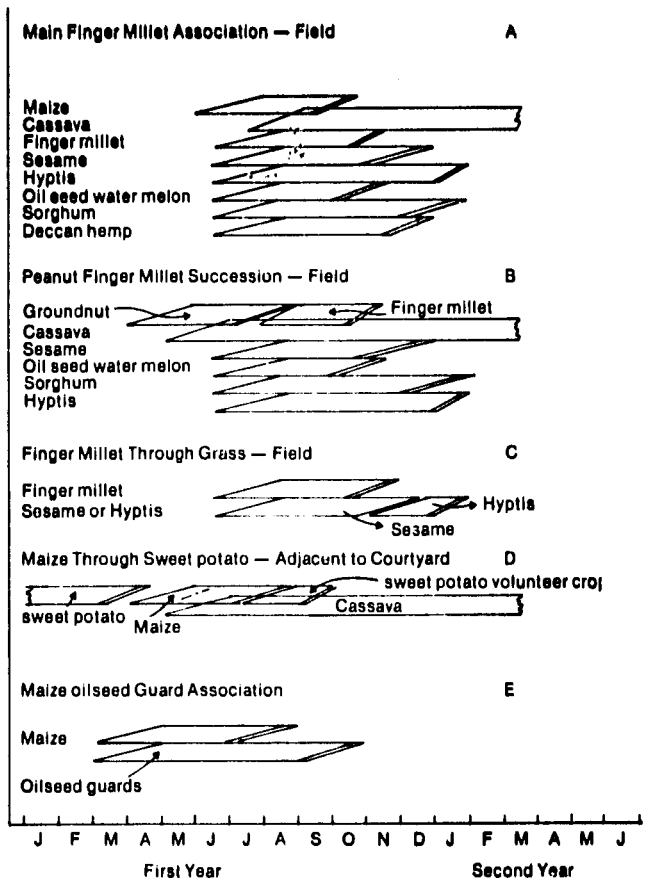

Fig. 5. Various associations of crops: A, main finger millet association, field; B, peanut finger millet succession, field; C, finger millet through grass, field; D, maize, through sweet potato, adjacent to courtyard; E, maize oilseed guard association.

crops (Appendix 1). Similar yields were obtained from cassava interplanted (1 month later) on the same row with cowpeas.

Recent work at IITA has produced high-yielding, disease-resistant cassava varieties that have ideal characteristics for intercropping with maize and cowpeas. These characteristics include medium height plant that resists lodging and branches at approximately 1 m. In addition, a narrow angle of branching permits increased plant population density and good canopy cover, which helps to reduce weed growth. Additionally, these varieties exhibit good root types (fat compact with short neck), shallow placement in the soil to facilitate manual or mechanical harvesting, and acceptable qualities for traditional food preparation (Table 1).

Farm-Level Adoption of New Technology

IITA is involved in cooperative research projects in Cameroon, Liberia, Sierra Leone, Tanzania, Upper Volta, Zaire, and Nigeria.

In Nigeria, the National Accelerated Food Production Project (NAFPP) was established in 1973 to increase the production of staple foods such as cassava. At that time production was increasing at a rate of 1% per annum against a demand of 4% and a population growth rate of 2.5%. The NAFPP aims to stimulate the rate of production of cassava (to about 3.2% per annum) through the integrated use of high-yielding planting materials, agrochemicals, improved agronomic practices, credit, storage, marketing, and other infrastructures.

Table 1. Characteristics of some IITA cassava varieties suitable for intercropping with maize and cowpeas, 5-year average.

Variety	Branching habit 1-3	Canopy 1-3[a]	CMD 1-5[b]	CBB 1-5	Fresh tuber yield (t/ha)	Tuber shape 1-5[c]
TMS 30572	2	2	2.2	1.8	46.7	4
TMS 30555	2	2	2.7	1.8	41.5	4
TMS 30395	1	3	2.0	2.0	35.2	3
TMS 30211	1	3	1.9	1.8	33.2	4
TMS 30337	2	2	2.7	1.8	45.8	4

[a]Maximum canopy: 1, small; 2, medium; 3, large (after 5 months).
[b]Lower figure is the ideal.
[c]Tuber shape: 1, round; 2, oval; 3, medium long; 4, long fat; 5, very long and thin.

Workshops organized by the NAFPP provide a forum for researchers, farmers, and change agents on innovations and improved technology. The annual plan of work includes farmer level "minikit" trials aimed at involving farmers in decision-making regarding the relevance and acceptability of the new technology. "Production kits" are also planned to study the profitability of improved versus traditional practices and to evaluate farmer reaction. The adoption of the full "package" of improved technology is promoted by means of farmer-conducted demonstrations on individual farms of closely related farmers organized into NAFPP groups.

One NAFPP "package" consists of improved cassava varieties interplanted with improved maize. Combined with recommendations for ridging, spacing, fertilizer, and insecticides (Tables 2 and 3), the package has demonstrated yield increases over local practices of 3:1 for cassava and 6:1 for maize. The estimated increase in net proceeds totaled ₦368.30

Table 2. Returns from NAFPP 1975/76 cassava-maize demonstrations.

Yield/ha	Traditional practice	NAFPP improved practice
Maize	36 kg @ ₦130/t = ₦47[a]	2442 kg @ ₦130/t = ₦317.50
Cassava	4.8 mt @ ₦40/t = ₦192	14.23 mt @ ₦40/t = ₦569.00
Gross Proceeds - cassava + maize	₦239	₦886.50
Ratio	1 :	3.7

[a]₦1 = ca. U.S. $1.54.
Source: Ezeilo (1977).

Table 3. Estimated increased net returns/ha (₦) from improved NAFPP package of technology cassava-maize 1976 (based on 1975/76 cassava-maize demonstrations).

Incremental cost over local practice:	
Labour (estimated): 100 man-days @ ₦[a] 2/man-day	200.00
Cassava: 70 bundles of 50 sticks @ ₦ 0.50/bundle	35.00
Maize: 37 kg @ ₦ 0.21/kg.	7.77
Fertilizer: 400 kg NPK 15:15:15 @ ₦ 2/50 kg	16.00
Aldrin: 2½% Dust 5 kg @ ₦ 1/kg	5.00
Interest: 6% maximum loan	15.82
Total incremental cost	279.20
Total gross proceeds from improved practice	886.50
Gross proceeds from local practice	239.00
Gross proceeds accruing from incremental cost	647.50
Increased net profits from improved practice	368.30

[a]₦1 = ca. U.S. $1.54.
Source: Ezeilo (1977).

Table 4. Proportion of farmers who have adopted fertilizers and improved cassava and maize.

Items adopted	Successful localities		Less successful localities		All localities
	NAFPP members	Non-members	NAFPP members	Non-members	
Cassava alone	-	12.2	-	·	3.6
Cassava + maize	-	3.5	5.9	-	2.3
Cassava + fertilizer	-	3.4	10.7	0.8	3.6
All 3 items 95.3		0.9	67.9	0.8	31.6
Maize alone	-	7.8	-	-	2.3
Maize + fertilizer	-	2.6	2.4	-	1.6
Fertilizer alone	-	2.6	-	10.1	3.9
No. item adopted	4.7	67.0	13.1	88.3	51.1
No. farmers adopted items	62	38	73	14	187
No. farmers in sample	65	115	84	119	383

Source: Okali and Bortei-Doku (1978).

(U.S. $566) per hectare. Recent farm level minikit trials resulted in farmers selecting even higher-yielding disease-resistant elite cassava clones (Appendix 2). Farmers have also shown interest in interplanting late season cassava with cowpeas (Ezeilo 1976) requiring an integrated and timely use of planting materials, fertilizers, and insecticides.

A study of the impact of the NAFPP program by Okali and Bortei-Doku (1978) showed that the adoption of the total improved intercrop "package" was highest in family-related farmer groups (Table 4) who were closely supervised by a change agent. Performance was also linked to the capability of the change agent. Outside of the supervised groups, the new cassava cultivars were usually planted according to traditional practices. The major constraint to adoption, of both supervised and nonsupervised groups, was the scarcity of planting materials and other inputs. To solve this problem, Agro-Service Centers are being introduced (IITA 1977).

Future Trends

The experience of NAFPP indicates that self-sufficiency in cassava and intercrops can be attained by an integrated, cooperative effort of government, researchers, farmers, and private industry.

In order to improve traditional technology, research analyzes the existing crop staples, intercropping patterns and sequences, profitability, the farm resource base, production constraints, and farm supports. On the basis of this research, more profitable crop combinations and varieties are being developed and disseminated by change agents trained in these technologies.

The adoption of new technology by farmers is best promoted by means of an integrated "package" of farm support measures to overcome constraints. These measures include: the services of motivated change agents, location-specific farm-level trials, and farmer-conducted demonstrations. Success will also depend on the availability of credit, marketing, input supply services, improved transportation, price incentives, and the establishment of cooperative agrobusiness ventures.

Such a high-level farm infrastructure support system, applied selectively to agricultural zones with the best potential, will maximize productivity in the immediate impact zone and to a lesser degree in neighbouring zones. Organizations with necessary finance and expertise for successfully organizing and operating such autonomous management units are seldom lacking in the private sector of most African nations. The achievement of self-sufficiency in cassava and intercrops depends on the determination of the people and their governments in adopting policy guidelines that support a truly integrated approach to agricultural development.

(Appendices 1 and 2 follow)

Appendix 1.

Total dry weight yields, calorie values, and gross returns of maize and melon relay cropped with cassava at different crop combinations and dates of cassava planting in 1974/75.

	Treatments Cassava planting: 16th day of each month indicated	Total yield (t/ha)	Calorie 10^7				Gross returns (t/ha)			
			Maize	Melon	Cassava	Total	Maize	Melon	Cassava	Total
1	Maize alone (Apr)	4.49	16.03	-	-	16.03	991.8	-	-	992
2	Melon alone (Apr)	1.02	-	0.53	-	0.53	-	71.7	-	72
3	Cassava alone (Apr)	14.95	-	-	39.77	39.77	-	-	2000.3	2000
4	Maize/melon (Apr)	4.66	16.60	0.03	-	16.63	1027.2	3.9	-	1031
5	Maize/cassava (Apr)	15.17	16.42	-	28.12	44.54	1016.1	-	1416.4	2433
6	Maize/melon/cassava (Apr)	16.15	14.96	0.04	31.79	46.79	925.6	5.64	1601.3	2533
7	Cassava alone (May)	15.79	-	-	42.00	42.00	-	-	2115.9	2116
8	Maize/cassava (May)	15.63	17.28	-	28.70	45.98	1069.2	-	1445.9	2515
9	Maize/melon/cassava (May)	15.96	15.21	0.10	31.07	46.38	941.0	13.7	1565.1	2520
10	Cassava alone (Jun)	11.84	-	-	31.49	31.49	-	-	1586.6	1587
11	Maize/cassava (Jun)	16.59	16.92	-	31.52	48.44	1047.1	-	1587.9	2635
12	Maize/melon/cassava (Jun)	23.73	16.39	0.07	50.89	67.35	1013.9	9.1	2563.4	3586
13	Cassava alone (Jul)	10.47	-	-	27.85	27.85	-	-	1403.0	1403
14	Maize/cassava (Jul)	14.15	16.39	-	25.43	41.82	1013.9	-	1281.0	2295
15	Maize/melon/cassava (Jul)	12.99	17.74	0.04	21.12	38.90	1097.9	3.5	1063.9	2167
16	Cassava alone (Aug)	7.46	-	-	19.84	19.84	-	-	999.6	1000
17	Maize/cassava (Aug)	11.73	16.07	-	19.23	31.51	994.1	-	968.8	1963
18	Maize/melon/cassava (Aug)	10.30	15.82	0.16	15.53	31.51	970.6	21.2	782.6	1782

Source: Okigbu (1977).

Appendix 2.

Tuber yield, NAFPP minikit trial, Uzuakoli, Imo State, 1978.

Variety	Fertilized	Unfertilized
TMS 30211	18.4	11.2
60506	17.8	13.2
TMS 1525	14.8	7.2
Local	13.2	6.8
TMS 30395U	12.2	8.6

Cassava and Cassava-Based Intercrop Systems in Thailand

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Thailand is the principal cassava exporting country in the world, earning over U.S. $370 million in 1977. Cassava is Thailand's second major export crop, next only to rice.

Cassava has become popular with farmers because it is easy to grow and has higher yield stability. Even in years of severe drought such as 1972–73 and 1977–78 the crop does not fail. In fact the range of yields is from 16.30 t/ha in 1969–70 (best year) to 12.12 t/ha in 1972–73 (the worst year) (Table 1). Other advantages are a high flexibility in planting time (May to November) and no major pests or diseases; as well, the farmers can wait up to a month for better prices even after the tops are cut, and the harvesting time is from 8 to 14 months after planting.

It is for these reasons that the area under cassava has progressively increased from about 100 000 ha in 1965–66 to well over 800 000 ha in 1977–78 (Table 1). Next to rice and corn, cassava occupies the largest area. The minor fluctuations from year to year are due to the price differential between cassava and sugarcane in the East or kenaf in the Northeast. When the price of cassava goes down relative to kenaf or sugarcane, the area under cassava comes down.

In the past, the main cassava area was in the East Region of Thailand. Today, the major cassava area is in the Northeast Region accounting for 64% of the area, followed by the East Region (29%), and the rest of the country (7%).

Cassava Intercropping Patterns and Management Practices

Crop Combinations and Arrangement

Cassava is grown in Thailand essentially as a sole crop. The crop is planted square 1 m × 1 m. The planting date is from May to as late as November; the majority of the area is planted in May–June.

Intercropping of cassava is practiced to a very limited extent: with corn in the uplands and with young coconut or rubber plantations. A 1:1 row ratio of cassava–corn is most frequently used, the corn

Table 1. Cassava-planted area, production, and farm value, 1965/66–1977/78.

Year	Planted area ('000 ha)	Avg yield (t/ha)	Production ('000 t)	Far price ($/t)	Farm value (million $)
1965/66	101	14.59	1475	-	-
1966/67	129	14.67	1892	-	-
1967/68	140	14.33	2000	20.0	40.0
1968/69	170	15.39	2611	16.5	43.1
1969/70	189	16.30	3079	27.0	83.1
1970/71	224	15.32	3431	23.5	80.6
1971/72	220	14.15	3114	26.0	81.0
1972/73	328	12.12	3974	23.5	93.4
1973/74	432	13.12	5668	17.0	96.4
1974/75	473	13.19	6240	15.0	93.6
1975/76	593	13.65	8100	20.5	166.0
1976/77	697	14.54	10138	23.0	233.2
1977/78[a]	960	12.88	12372	17.28	213.8

[a]Preliminary figures.
Source: Division of Agricultural Economics.

row being 50 cm from the adjacent rows of cassava. A population density of 10 000 plants of cassava per ha and of 10 000 plants or less of corn per ha is common. Both cassava and corn are planted simultaneously either in May or June.

Current research on cassava-based cropping systems using mungbean, peanut, and soybean as component crops is described later in this paper.

Characteristics of Cassava used in Intercropping

Almost all the cassava grown in Thailand is the "bitter type" for processing as animal feed. The most popular variety is Rayong, a local variety, which grows to a height of 3 m; none of the introduced varieties have proved superior.

The variety produces one to two branches close to the ground level. The expression, however, is influenced by spacing. The wider the row spacing, the higher is the number of branches.

"Diameter" of the canopy increases from 34 cm at the end of 1 month to 66, 104, and 138 cm at the end of 2, 3, and 4 months respectively. Subsequent canopy increases are small.

The crop is ready for harvest 12 months after planting and may be kept in the field up to 14 months, beyond which the roots become too fibrous for processing.

At harvest, there are three to seven marketable roots per plant; their average diameter is 6.3 cm, length varies from 20 to 50 cm, and specific gravity is 1.10. Harvest index is 0.50.

Potential yield is about 37 t/ha.

Land Preparation and Agronomic Practices

Field preparation starts with rains in the month of May and consists of ploughing 15–20 cm deep with a tractor once or twice, followed by one or two disc harrowings. Hills, 1 m apart, are marked by hoes.

Cuttings 25 cm long taken from suberized (not green) stem excluding the lowest 20 cm are planted one per hill. Planting may be vertical, inclined, or horizontal. In slightly heavy texture soils, vertical planting is preferred as it facilitates harvesting of the roots.

Intercrop is planted by hand dibbling in furrows between the cassava rows.

Interculture and weeding is done manually, the first one about 1 month after planting and the second 45–60 days later. Some farmers practice earthing up the individual plants by hand or the entire row using animal power.

Harvesting is also done manually around 12 months after planting.

Common Inputs and their Levels

Cassava is rarely fertilized. If any, fertilizers are applied immediately after the first interculture. The crop does not need and, therefore, does not receive any plant protection measures. The inputs are mainly the family labour, except for hired labour at planting, weeding, and harvesting. Planting material is obtained from the previous crop. Thus cassava is a low monetary input cash crop in Thailand.

Major Problems, their Effect and Control

The most serious field problem is weeds; this has been aggravated by a rapid increase in the area under cassava and a consequent labour shortage. This is perhaps one of the main reasons why farmers are averse to intercropping cassava.

Another serious field problem is the declining soil fertility as the crop is rarely fertilized and the yield of cassava is steadily declining. Fertilizer costs are prohibitively high. Till recently, farmers made use of cleared virgin lands but such lands are becoming scarcer.

The low price of cassava, dictated by foreign markets, is a problem over which neither the individual farmer nor the individual country has any control. Prices dropped from U.S. $23.00 per metric tonne in 1977 to $17.28 in the early part of 1978.

Some of the more recent approaches to meet the problems of weeds and declining soil fertility are described later in the paper. The price problem remains unsolved. Price negotiations held between Thailand and the importing countries have not proved beneficial to the producers.

Environmental Description

Rainfall

Climatic data for the 25-year period 1951–75 for the two major cassava-growing regions are given in Table 2.

In both major cassava-growing regions, the normal onset of major rains (over 100 mm/month) is in May and termination is in October. The rainfall is heavier and more reliable in the East Region than the Northeast Region. Both the regions are dominantly dry with 6 consecutive months (November to April) receiving less than 100 mm rainfall per month.

Temperature and Solar Radiation

In no month is the mean temperature less than 20 °C either in the East Region or in the Northeast Region, although the latter tends to be cooler in the winter months.

In both the regions cloudiness is 6.0 or more from May to September. The East is cloudier (mean 5.4) than the Northeast Region (4.9), the maximum difference being in October.

Table 2. Climatological data of cassava-growing area in the Northeast Region of Thailand (6 stations)[a] for the period 1951–75.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature (°C)													
Mean	23.3	25.9	28.4	29.8	29.1	28.2	27.9	27.7	27.1	26.6	25.0	23.2	26.8
Mean max	30.3	32.7	35.0	36.1	34.6	33.0	32.5	31.9	31.4	31.0	30.3	29.6	32.4
Mean min	16.0	18.8	21.8	23.7	24.4	24.3	23.9	23.8	23.7	22.4	19.6	13.6	21.6
Ext. max	37.8	41.0	41.8	43.9	42.6	40.1	38.0	37.7	38.0	35.9	37.2	35.8	43.9
Ext. min	2.5	9.4	10.0	11.8	20.0	19.7	19.6	20.0	19.3	14.0	8.4	5.5	2.5
Relative humidity (%)													
Mean	63.7	61.8	61.1	64.4	73.1	76.4	77.6	79.9	82.1	77.9	71.5	66.9	71.4
Mean max	86.6	84.3	83.0	84.5	89.5	91.1	91.4	92.7	94.0	91.5	89.3	88.0	88.8
Mean min	42.9	41.5	41.0	44.2	54.4	60.6	61.8	64.5	66.7	61.6	53.1	46.9	53.3
Ext. min	11.0	10.0	12.0	18.0	23.0	28.0	36.0	37.0	36.0	26.0	21.0	15.0	10.0
Cloudiness (0–8)													
Mean	2.9	3.2	3.6	4.4	5.8	6.5	6.6	6.9	6.4	5.0	3.9	3.2	4.9
Rainfall (mm)													
Mean	5.2	18.6	42.1	77.4	180.3	175.5	178.5	200.5	290.1	110.0	17.9	2.4	1303.5
Mean rainy days	1.1	2.5	4.8	7.5	15.2	15.6	16.8	18.2	19.5	10.1	2.4	0.7	114.0

Source: Meteorological Department, Ministry of Communications.
[a]Udon Thani, Khon Kaen, Roi Et, Surin, Nakhon Ratchasima, Chaiyaphum.

Soil Characteristics

The major Great Soil Group on which cassava is grown in Thailand is Gray Podzolic Soils. In the Gray Podzolic Soils, the Korat Soil Series is the most extensive.

As a rule the cassava soils are light, moderate to excessively drained, with level to undulating topography.

pH is 5.0–6.0 in the surface soil and decreases with depth. The pH of subsoil ranges from 4.5–5.0 in the subsurface to as low as 3.8–4.0 at the lowest depth.

The soils are highly leached with low base saturation (35–50%) and with low N, available P, and possibly K.

Soils are droughty. Available moisture storage ranges from 60 to 80 mm per metre of soil.

Location of Area

The Eastern area is located between 12° 30′ and 14°N, 101° and 103°E. Rayong, the main cassava research centre, is situated in this area (12° 40′, 101° 15′). The Northeast Region lies between 14° and 18°N, 101° 30′ and 105° 30′E.

Socioeconomic Factors

Farm Size and Area Cropped

The average farm holding in the Northeast increased from 3.5 ha in 1962 to 5.1 ha in 1974, of which about 70% is planted.

Information on the proportion of farm in cassava and its associates is not easily available. In the Northeast Region about 10% of the cropped area is under cassava; among the upland field crops, cassava occupies 30% of the area.

Rural Population Density

The population of the Northeast Region was 14.7 million in 1976. Of this, 95.7% is rural population. The density works out to about 88/km². Khon Kaen and Nakhon Ratchasima are the only two cities in the Region.

Capital Investment

The major input for crops in Thailand including cassava is labour. Cassava is more labour intensive.

Power Input

Power input consists of the following: mechanical power for primary tillage and transport; animal power for some of the secondary tillage; and hand labour for planting, weeding, and harvesting.

Markets for Output

Cassava in Thailand is predominantly for sale, mostly as pellets. The farmer sells all his cassava. Thailand exports about 95% of the production; domestic use is about 5% as animal feed, flour etc. (Table 3).

Research Highlights

None of the cassava introductions outyielded Rayong No. 1, a selection from the local variety. Hybrids have been developed and are in the testing stage. Screening of cassava varieties suitable for intercropping will be initiated.

Spacings of 80 × 100 cm², 100 × 100 cm², and 120 × 100 cm² were not significantly different. Recommended spacing is 100 × 100 cm² for a sole crop. Best planting time is from May to June and from September to October. If moisture is adequate, cassava may be planted from April to November.

Yield remained the same whether the cuttings were planted vertically, inclined, or horizontally. The roots were easier to harvest in slightly heavy soils when cuttings were planted vertically.

The root yields progressively increased from 6 to 16 months. The recommended harvest time is 12 months after planting, although the highest marketable yield is obtained at 14 months.

Harvest at 14 months shifted the planting date of the crops in the following year and if the crop came to harvest at the end of October no crop could be taken that year. Thus three crops of 14 months' duration used, in effect, 4 years. From Table 4 it is clear that four 12-months' crops planted in June yielded (31.50 × 4) 126.0 of root whereas three 14 months' crops yielded (38.69 × 3) 116.1. Even if this difference was not statistically significant, a 14 months' crop upsets the normal schedule of operations and may have peak labour demand at times when it was not available or when it was needed for rice, the staple food crop.

Rapid propagation methods are under study.

Highest response was obtained to N, medium response to P, and least to K. Up to 50–50–25 kg N, P_2O_5, K_2O per ha were recommended for medium fertility soils and twice these levels for poor soils. The exact levels of P and K depended upon soil tests.

Recent Approaches and Current Research

Year-round tillage for effective weed control and preparation of land well in advance, making use of the off-season rains are recent approaches to improving cultivation. Tillage just before the heavy

Table 3. Volume (tonnes) and values (U.S. $'000) of cassava products exported, 1968–77.

Year	Chips		Pellets		Flour		Other		Total	
	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value
1968	323209	11040	–	–	532416	2 167	33229	997	888854	38184
1969	56394	2115	752751	30462	148939	10089	17057	608	975141	43274
1970	8111	361	1163985	49353	148681	10430	6088	263	1326865	60407
1971	2500	122	962294	48148	151558	12573	5338	329	1121169	61172
1972	2404	106	1177422	64567	129797	11652	1415	84	1311038	76409
1973	18198	1240	1638677	104191	176793	19624	2568	206	1836236	125261
1974	105328	7090	2031484	143768	253190	38415	2153	167	2392155	189440
1975	70594	5946	2168742	198909	144703	22015	1407	114	2385446	2$6984
1976	42544	4004	3441327	329228	236517	38422	322	77	3720710	371731
1977	65604	5799	3678530	342999	201263	32250	827	182	3946224	381230

Source: Division of Agricultural Economics.

Table 4. Yield of cassava fresh root planted from May to October and harvested at 6–16 months (1974).

Planting date	Harvested ages (months) 6	8	10	12	14	16	Avg
			t/ha				
May	13.00	15.87	19.87	28.25	40.44	43.87	26.87b
Jun	11.06	17.31	24.12	31.50	42.25	52.56	29.81a
Jul	9.56	13.50	21.06	26.50	41.12	50.12	27.00b
Aug	6.75	10.31	17.00	20.87	35.81	42.12	22.12c
Sep	3.44	8.44	14.81	23.12	41.81	44.75	22.75c
Oct	0.94	5.37	13.19	24.81	30.50	36.37	18.56d
Avg	7.44 f	11.81 e	18.37 d	25.87 c	38.69 b	44.94 a	C.V. = 11.93%

L.S.D. (0.05) for planting date × harvested ages = 5.44 t/ha.

Table 5. Intercropping of cassava with food legumes (mean of 9 locations, 1973-75).

Planting pattern	Yield: Intercrop (kg/ha)	Yield: Cassava (t/ha)	Relative to sole cassava (%)
Sole cassava	-	27.64a	
Cassava + mungbean	767	26.42a	95.58
Cassava + soybean	686	26.74a	96.74
Cassava + peanut	910	24.51b	88.67

rains merely redistributes the weeds without controlling them.

Studies on restoration of soil fertility and productivity through cropping systems with major emphasis on intercropping were initiated in 1970. The first 2 years were devoted to identification of suitable intercrops. From 1972 to 1976 cassava-based systems using peanut, soybean, mungbean, and corn were studied using 50–50–25 kg N, P_2O_5, and K_2O/ha with two rows of legume or one row of corn between two rows of cassava 100 cm apart. The spacing of legumes within the row was 20 cm and of corn 50 cm. There was no significant reduction of cassava yield with mungbean or soybean (Table 5). The yield reduction was highest with corn for grain (Table 6).

However, the most promising intercrop systems for the Northeast and East Region appeared to be cassava–peanut and cassava–mungbean.

Having established promising cropping systems, the next step will be to recycle the legume residues either through an animal or to incorporate them directly into the soil.

Crop Geometry and Planting Patterns

Interculture of an intercropped cassava is difficult particularly when the row number of intercrops increases. To overcome this, planting the intercrop in the same row as cassava (leaving interrow space vacant for easy interculture by using animal power) was tested alone and in combination with intercrops between two cassava rows.

Table 6. Intercropping of cassava with corn for cobs and for grain.

Planting pattern	Yield: Intercrop	Yield: Cassava (t/ha)	% relative to sole
Sole cassava	-	25.89a	
Cassava + corn (cob)[a]	27144 cobs/ha	24.17a	93.35
Sole cassava	-	28.26a	
Cassava + corn (grain)[b]	1117 kg/ha	22.56b	79.83

[a]Mean of 4 experiments (1974–76).
[b]Mean of 2 experiments (1973).

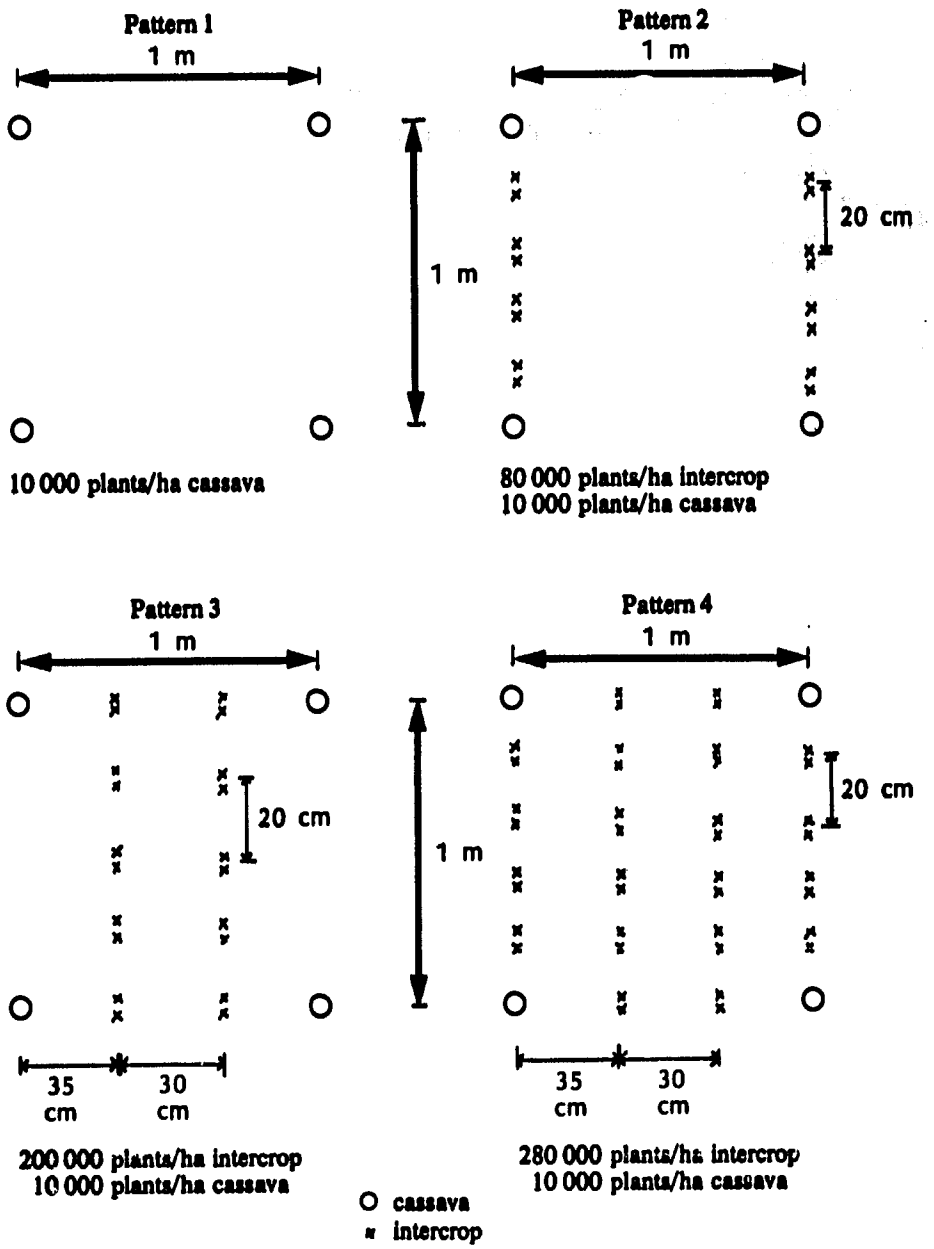

Fig. 1. Planting patterns.

The four planting patterns are given in Fig. 1. The intercrops were mungbean, soybean, and peanut; yield data are given in Table 7. The yield of cassava was not significantly reduced by the planting pattern of mungbean or peanut, unlike soybean. The data also bring out clearly the need for increasing the plant population density (or row number) of mungbean and peanut to make the system more productive. For mungbean, the density may be higher than 280 000 plants/ha and for peanut at least 200 000 plants/ha. Optimum plant density of soybean needs confirmation.

In all these studies, square planting (1×1 m^2) of cassava was adopted, which imposes a severe re-

Table 7. Planting patterns of mungbean (mean of three experiments, 1975-76), soybean (mean of four experiments, 1975-76), and peanut (mean of four experiments, 1975-76) with cassava.

Planting patterns	Yield				% Relative to sole cassava
	Mungbean (kg/ha)	Soybean (kg/ha)	Peanut (kg/ha)	Cassava (t/ha)	
Mungbean					
Sole cassava	-	-	-	27.55a	-
Cassava+1-row mungbean	425a	-	-	26.08a	94.66
Cassava+2-row mungbean	679b	-	-	24.16a	87.69
Cassava+3-row mungbean	809c	-	-	24.62a	89.36
Soybean					
Sole cassava	-	-	-	32.35a	-
Cassava+1-row soybean	-	584a	-	26.37b	81.51
Cassava+2-row soybean	-	648a	-	26.21b	81.02
Cassava+3-row soybean	-	745a	-	27.77b	85.84
Peanut					
Sole cassava	-	-	-	30.46a	-
Cassava+1-row peanut	-	-	467a	30.42a	99.86
Cassava+2-row peanut	-	-	722b	28.94a	95.01
Cassava+3-row peanut	-	-	752b	27.22a	89.36

striction on crop geometry of the intercrops. A new approach will be to determine how much widening of the cassava rows is possible without significantly affecting its yield and superimpose the best crop geometry of the intercrop. The population density of all the component crops will be maintained as close to the optimum as possible.

Relay Cropping

Existing information shows that it is best to plant both the component crops simultaneously. This is because of the general reduction in yield with delayed planting. However, as cassava has a flexible planting time (unlike most other crops), it was felt that there would be some advantage in planting the intercrop first and delay the planting of cassava. Peanut, soybean, and mungbean were planted in May, July, and August respectively and cassava was planted 0, 20, and 40 days after planting the legumes.

Data are given in Table 8. The C.V.'s are high and it is difficult to draw valid conclusions. However, the indications are that mungbean and cassava or soybean and cassava may be planted simulta-

Table 8. Cassava-mungbean, cassava-soybean, and cassava-peanut relay crop system.

Planting of cassava after other crop (days)	Yield			
	Mungbean (kg/ha)	Soybean (kg/ha)	Peanut (kg/ha)	Cassava (t/ha)
Mungbean				
0	1106a	-	-	27.44a
20	753a	-	-	18.87b
40	925a	-	-	24.50ab
C.V. (%)	23.10	-	-	28.30
Soybean				
0	-	612a	-	24.00a
20	-	837a	-	12.56b
40	-	650a	-	3.19c
C.V. (%)	-	27.8	-	33.38
Peanut				
0	-	-	719b	23.12ab
20	-	-	1262a	24.56a
40	-	-	1212a	20.50b
C.V. (%)	-	-	25.4	26.30

Table 9. Yield and gross income of cassava and cassava intercrop systems.[a]

Intercrop system	Yield		Gross income ($/ha)		
	Intercrop	Cassava	Intercrop	Cassava	Total
	kg/ha	*t/ha*			
Sole cassava	-	27.64	-	635.72	635.72
Cassava + mungbean	767	26.42	230.10	607.66	837.76
Cassava + soybean	686	26.74	226.38	615.02	841.40
Cassava + peanut	910	24.51	209.30	563.73	733.03
Sole cassava	-	28.26	-	649.98	649.98
Cassava + grain corn	1117	22.56	99.41	518.88	618.29
	cob/ha	*t/ha*			
Sole cassava	-	25.85	-	594.55	594.55
Cassava + cob corn	27144	24.17	670.46	555.91	1226.37

[a]Farm price (1976/77): Cassava $23.00/t; Mungbean $0.30/kg; Soybean $0.33/kg; Peanut $0.23/kg; Corn grain $0.089/kg; Corn cob $2.47/100 cobs

neously and peanut may be planted 20 days earlier than cassava. The indications await confirmation.

Testing of Cropping Systems

On the Experiment Stations, land equivalent ratios (LER) of 1.50–1.75 have been obtained with some of the intercrop systems of cassava (Table 10).

Table 10. Land equivalent ratio (LER) of three patterns of planting of mungbean, soybean, and peanut in cassava intercropping.

Planting pattern	LER of the system		
	Mungbean	Soybean	Peanut
Sole cassava	1.00	1.00	1.00
Cassava + 1-row	1.46	1.02	1.45
Cassava + 2-row	1.51	1.32	1.60
Cassava + 3-row	1.75	1. 2	1.44
Sole legume	1.00	1.00	1.00

They are also shown to generate more gross income than sole crops (Table 9). How these systems would perform in farmers' fields and under farmers' conditions needs to be ascertained. Operational difficulties at the farmers' level have to be solved before the cropping systems could be extended on a large scale.

Intercropping of cassava with mungbean or peanut has been tested on farmers' fields in large plots. The selected farmers have been growing a sole crop of cassava for years. According to them intercropping with legumes needs more attention because of pests and diseases than a sole crop of cassava. Weed management is particularly difficult. Besides, the season 1974–75 was not favourable for the legumes and the farmers could not see the economic advantage.

Acknowledgment

I am grateful to the staff of the Field Crop experiment Stations for the data on which this paper was prepared.

Cassava Intercropping Research: Agroclimatic and Biological Interactions

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A discussion of climatic and biological interactions associated with cassava intercropping logically must start with an analysis of the growth characteristics of cassava. This analysis discusses the crop adaptability of cassava in terms of climate and land qualities, the crop growth characteristics of cassava, evaluating total and root dry matter production in presence and absence of water stress for a representative, well-managed crop.

Because of the perfect indeterminate production characteristics of cassava, field duration is largely determined by management or climatic factors. Of the climatic factors, effects of rainfall distribution on production and planting time are evaluated. The introduction of intercrops into a cassava stand may modify the most appropriate planting and harvest time. Possible criteria for evaluating these are discussed.

In the process of comparing production levels of cassava at different locations it became evident that there are serious weaknesses in the reporting of cassava yields. Suggestions are made to improve this reporting to enable more adequate crop performance comparisons across sites.

Finally, for discussion purposes I have provided a few considerations that may be useful in the design of cassava intercropping patterns.

Crop Adaptability of Cassava

The growing period of cassava can vary from 180 days to more than a year. Often, tuber quality deteriorates after 12 or 14 months, but more often than not harvest time is dictated by management, climatic, or marketing considerations. Where cassava is produced for dried chips, harvest must coincide with the dry season. Planting of the next crop sequence limits duration of cassava to 10–11 months in Lampung (Imtiaz et al. 1977).

The crop has a C-3 photosynthetic pathway and is most adapted to a temperature regime of 25–30 °C. It cannot withstand exposure to frost, and growth ceases at temperatures below 10 °C. Tuber formation may be reduced under long day (more than 12 hours) regimes (Bolhuis 1966). The effect of long days on tuber initiation varies greatly with different varieties and may only be important during the early growth stages, so that once initiated, tuber formation tends to continue even under long day regimes (CIAT 1976). The climatic adaptability of cassava indicates that it may produce best between latitudes of 30°N and 30°S and may benefit from growing the crop such that the peak tuber formation stage 5–12 months after planting coincides with shorter daylength at latitudes greater than 15°. I have not encountered literature about the importance of day and night temperature differentials, but suspect that, as for other root crops, lower night temperatures will reduce respiration demands and increase tuber formation.

Cassava production is best suited to reasonably well-drained and well-drained soils that have low bulk density, or at least do not resist deformation by swelling tubers. Tolerance to excessive moisture is not well documented. Survey results of CIAT from areas with heavy textured (vertic) soils indicate substantial losses (CIAT 1975). Cassava grown on a clay loam toposequence at IRRI in a cassava + (corn + rice–rice bean) pattern did not yield substantially lower in the poorly drained positions (Table 1). Cassava is tolerant to drought and low soil fertility. This does not mean that the crop does not respond potentially to added fertilizer or that yield is not greatly reduced by severe drought stress. The crop responds to deep tillage, particularly in drought-prone areas with unfertile soils. In such conditions deep plowing will encourage deep root penetration (Kay 1973; Doorenbos et al. 1978; Loomis and Rapoport 1977).

Table 1. Yields (t/ha) at three slope positions on a toposequence of a July planted cassava+(corn + rice–rice bean) cropping pattern.[a]

Crop	Plants/ha	Row space (cm)	Yields[b]			
			Top	Slope	Bottom	Mean
Rice (var. C22)	100 kg seed rate	25	0.48	0.84	1.02	0.78
Corn (var. DMR-2)	30000	200	1.58	1.73	1.48	1.59
Cassava (lagkitan,[c] 9 month)	15000	200;22.7	15.9	18.0	18.9	
Rice–bean	300000	50	0.04	0.11	0.21	0.12

[a]Crop season rainfall 1158 mm. August, September, December rainfalls > 200 mm.
[b]Yields of crops between toposequence positions are not significantly different (t-test).
[c]Total fresh tuber yield.

Table 2. Monthly rainfall and fresh root production.

	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	5	19	42	77	180	175	178	200	290	110	18	2
Growing month	1–2	3	4	5	6–7	8	9–10	11	12	13	14	15–18
Fresh root production potential (t/ha)	0	1.7	3.7	4.7	5.2	4.7	4.3	4.2	4	3.8	3.7	3.5

Crop Growth Characteristics of Cassava

Cassava has a maximum crop growth rate of 30–40 g/m² per day. Dry matter allocation to tubers varies from none at early growth stages to possibly as high as 80% of daily dry matter production after 14 months growth. Loomis and Rapoport (1977) differentiate between balanced and phasic partitioning of photosynthate, indicating that cassava exhibits the latter. These theoretical parameters allow for a production of about 200 kg/ha per day of tuber dry matter. As pointed out by Cock (1974) these yields are far above average yields of 10 t/ha (world) and even substantially exceed experimental yields of 50–60 t/ha per year. Based on production figures from Umanah (1977), and IRRI experimental results and crop physiological relations (CIAT 1975, 1976), and Kassam (1977), Fig. 1 presents the accumulative total dry production and root dry matter production of an average cassava crop grown under intensive commercial management. I estimated total dry matter production at reasonable input levels (40–35–70 N, P_2O_5, K_2O), average weed control, and without moisture stress at 31 t/ha and 38 t/ha for a 12- and 16-month crop, respectively. Root dry matter production, based on dry matter allocation reported by Enyi (1973) was 15.5 and 21 t/ha for these durations. The root dry matter as a percent of total dry matter production at any time during the growing season (harvest index) increased from 25% after 4 months to 40%, 48%, and nearly 58% after 8, 12, and 18 months respectively. Root production is initiated at about 50 days after planting. The rate of total dry matter (TDM) and root dry matter (RDM) production at different growth stages of cassava is presented in Fig. 2. The highest rate of TDM production occurs after 4 months at 150 kg/ha per day, after which it reduces at a decreasing rate to 55 kg/ha per day at 18 months after planting. Maximum RDM production occurred after 6 months. This is 2 months later than the maximum TDM production because the percentage of dry matter allocated to the roots increases rapidly up to 7 months after planting. Daily RDM production leveled off at about 43 kg/

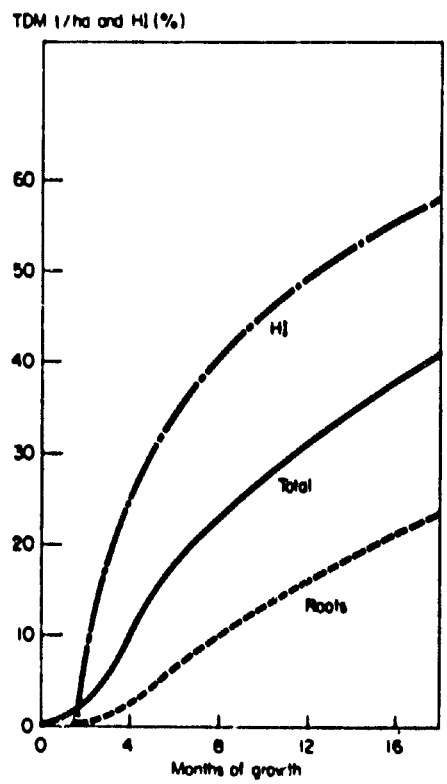


Fig. 1. Accumulative total and root dry matter production and harvest index (HI) of well-managed cassava at different growth durations.

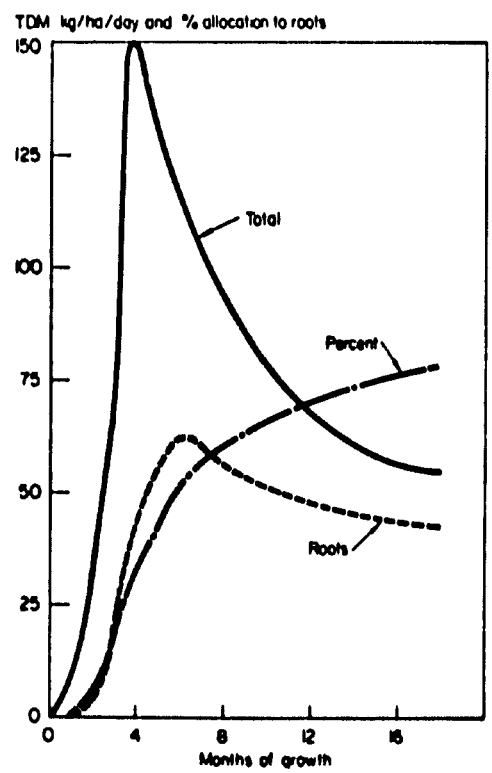


Fig. 2. Rate of total and root dry matter production and percent dry matter allocation to the roots at different growth stages of cassava.

ha after 16 months. This analysis of cassava production shows that because of the low dry matter allocation to the roots at early growth, root production does not reach a substantial level until after 3 months. Also, daily RDM production does not drop substantially beyond 10 months. Cassava harvest before 16–18 months must, therefore, be justified on the basis of deteriorating product quality such as unacceptable root size, increased fiber, and decreased starch contents (Cock 1974). Other reasons for earlier cassava harvest are climatic, such as drought, or management related, such as the need to prepare land for other crops.

Although this generalized description of cassava growth and production fits results obtained at various locations, there are substantial varietal differences in the times at which crops reach maximum total dry matter production and the percent dry matter allocation to the roots, such as those encountered for sweet potato cultivars by Wilson (1977) and for three cassava cultivars at CIAT (1976). Varietal differences in the rate of root formation with time can be important for cultivars intended for intercropping, particularly because intercropping tends to be concentrated during the early growth of cassava.

Rainfall Limitations to Cassava Production

Although there are no in-depth studies on the matter, cassava is generally considered to be a drought-tolerant crop. On the basis of general crop–soil–water relationship and evapotranspiration requirements of the soil and of different canopies (Fitzpatrick and Nix 1969; Doorenbos et al. 1978), approximate water requirements were estimated. Requirements are less during early growth stages (75 mm/month for 1 and 2; and 105 mm/month for month 3). After the initial 3 months, the water requirement can be taken at approximately 150 mm/month if water stress is to be avoided. Estimation of yield reduction due to drought stress requires evaluation of the available soil moisture and crop response to reduced water availability at different growth stages. Doorenbos et al. (1978) present a practical way for calculating yield losses. They use the formula:

$$\left(1 - \frac{Y_a}{Y_m}\right) = k\left(1 - \frac{ET_a}{ET_m}\right)$$

where: Y_a = actual yields; Y_m = maximum yields; k = yield response factor; ET_a = actual evapotranspiration; ET_m = maximum evapotranspiration.

To apply this relationship to cassava — a crop in which production is indeterminate and a function of growth duration — the following simplifications were made:

(1) It was assumed that crop establishment was not drought constrained, so that the conditioning effect of available moisture was applied only after the second month.

(2) Because rate of root production varies with the age of the crop, a vector of monthly fresh root production was used for Y_m (Table 2). Note that this vector assumes a 42 t/ha per year yield of unstressed sole-cropped cassava. For intercropping patterns it can be proportionally reduced if plant populations are reduced by wide row spacing.

(3) The yield response factor k was taken as 0.7, which may assume too great a tolerance to drought, similar to that of groundnut and safflower (Doorenbos et al. 1978).

(4) Maximum evapotranspiration was set at 150 mm/month and actual evapotranspiration was assumed to equal the rainfall.

(5) For each month, actual yield was calculated using the formula:

$$Ya_i = Ym_i \left(1 - k\left(\frac{150 - R_i}{150}\right)\right) \quad \text{For months in which } R_i < 150$$

$$Ya_i = Ym_i \quad \text{For months in which } R_i \geq 150$$

(6) Based on a 100 mm available water carry over, an additional total of 3 t/ha fresh tuber weight was allocated during the first and/or second month of drought-stressed growth if previous rainfall had been sufficient to accumulate 150 mm of water in the profile.

Using monthly rainfall for northeast Thailand (Table 2), yields were estimated for April, June, and August planting dates and crop durations varying from 7 to 17 months (Fig. 3). Results show that actual yields after 11 months were approximately 10–15 t/ha lower than yields that would be obtained without water stress. Early planting produced higher yields, particularly for harvests between 7 and 11 months. April planting may, however, not be feasible because of undependable rains during that month.

The same analysis for a bimodal rainfall distribution such as that at CIAT, Palmira, Colombia, indicates that for a 12-month crop, drought stress reduced yields by 10–15 t/ha, depending on the planting date (Fig. 4). Yield differences between planting dates were not as great as those obtained for

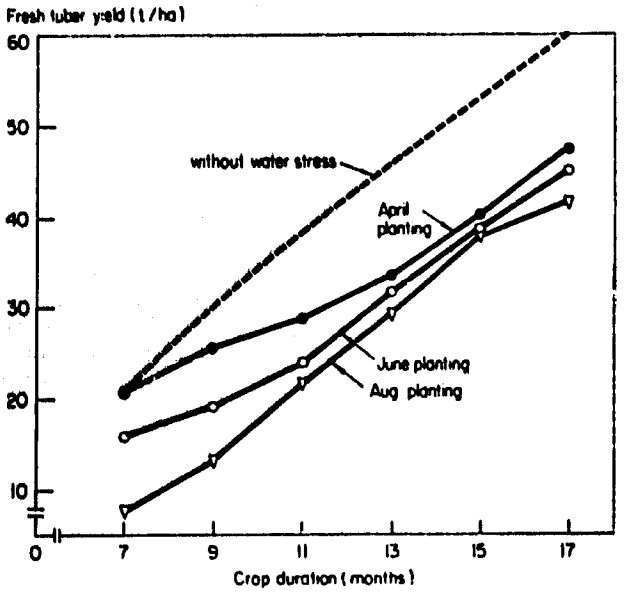


Fig. 3. Estimated cassava yield in northeast Thailand as influenced by date of planting and water stress based on the assumption given in Table 2.

northeast Thailand. The yields compared well with those obtained at CIAT under rainfed conditions (CIAT 1976). These calculations did not consider the yield-reducing effect of excess moisture, a possible problem on the heavier textured, level soils. This analysis indicates optimum planting times toward the end of the two rainfall periods. This is because for the plantings at the beginning of December and May, the peak rate of root production coincides with high rainfall periods.

This simple analysis of effects of drought stress on cassava yields shows that yield reductions due to lack of rainfall can be substantial, even if great drought tolerance is assumed. The effects of rainfall on crop production depends on cassava growth duration and planting time.

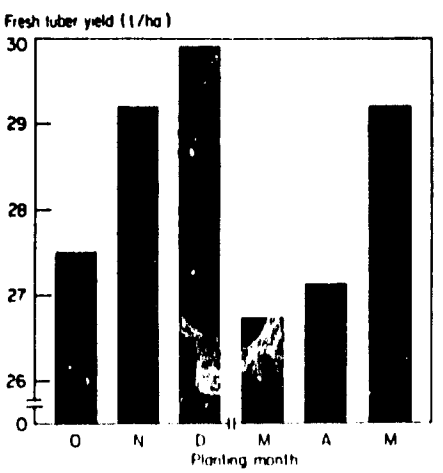


Fig. 4. Estimated yields of 12-month duration cassava crops grown under rainfed conditions at Palmira, Colombia. Planting dates are at the start of the month indicated. Based on long-term rainfall averages (CIAT 1976) and a 42 t/ha per year yield potential.

Cassava Intercropping

Intercropping is the growing of two or more cultivars simultaneously in the same plot. This can be done in alternating rows or sets of rows (row intercropping), or it can be done without a distinct row arrangement (mixed intercropping).

Where cassava is grown for family consumption, it can be grown in small sole-cropped plots, but is more commonly grown in small mixed intercropped plots or as a border crop around commercial plantings of other crops. Where cassava is grown as a commercial crop, for the sale of fresh tubers to local markets, intercropping is still common. But where it is produced for commercial processing into chips or starch, intercropping becomes rare. Recent research and production programs (Ismail and Suprapto 1977) have shown great benefits of cassava intercropping, and it is hoped that multiple cropping patterns can be designed that are suitable for commercial cassava producers.

Multiple cropping generally seeks to utilize more completely the production potential of the growing season. For determinate crops this implies careful scheduling of planting and harvesting dates. This is done by choosing genetic materials of different growth durations and by crop intensification techniques such as relay cropping, intercropping, early crop establishment, and residual soil moisture utilization techniques. Intercropping generally reduces the leaf area index (LAI) of the lower canopy crop and may reduce that of the upper canopy crop where competition for water or nutrients occurs. Although the leaf area duration (LAD) of each of the intercrop components is reduced, the overall LAD of the mixed canopy can be greatly increased, particularly where relay cropping is used. Major gains in LAD are obtained by allowing the following crop to develop while the LAI of the first crop is beginning to reduce. This, and the absence of a period of land preparation between crops, minimizes soil exposure.

For corn-rice intercropping, Sooksathan (1976) found no difference in the net assimilation rates (NAR) of corn and rice when grown as sole crops or as intercrops. Anwarhan (1977), however, found that NARs of soybeans reduced significantly when canopy density was increased by intercropping corn and by increased fertilization rates. Whereas in the case of the corn-rice intercrop study of Sooksathan, virtually all the differences between sole crop and intercrop yields could be explained by differences in LAD, Anwarhan found that 75% of the variation in dry matter production of corn was associated with differences in LAD and 25% with changes in NAR. For sole crop soybeans these were 63% for LAD and 37% for NAR. In the corn-soybean intercrop, however, as much as 51% of the differences in dry matter production could be attributed to changes in NAR.

In addition to the rate of canopy development, as measured by LAI or groundcover, the relative canopy height of crop components in an intercropping pattern affects the performance of that pattern in a major way. A comparison of three cassava intercropping patterns to sole crop cassava (Table 3) shows that total root dry matter production drops from nearly 7 t/ha for the sole crop to 3.5 t/ha where corn was row-intercropped at 30 000 plants/ha. When cassava (at the same planting density) was intercropped with rice — a crop with a canopy height that remains approximately equal or below that of cassava — cassava yields were as high as 5.6 t dry matter/ha. Introduction of corn into the system at a wide row spacing reduced cassava root dry matter yields by only 0.5 t/ha. This was because corn height, total dry matter, and grain production were substantially lower in the corn+rice+cassava pattern than in the corn+cassava pattern, indicating reduced competition of corn with cassava. The harvest index of cassava was significantly higher for all intercropped patterns than for the sole crop patterns. This is primarily due to an increased plant population of the sole crop pattern compared to the intercropping patterns. At CIAT (1974) increasing the plant population from 10 000 to 40 000 plants/ha reduced the harvest index by 35–40%, which agrees with the results obtained here (Table 5).

The increased harvest index at low plant populations is of benefit to intercrop patterns that are planted at wide row spacings and plant populations between 5000 and 15 000 plants/ha.

An important means by which the rate and height of canopy development of component crops in an intercropping pattern can be controlled is through small changes in planting times of each of the component crops. In a study at IRRI evaluating the cassava+((corn+rice)-soybean-cowpea) pattern, cassava planting varied from simultaneous with corn and rice to 80 days after corn and rice. Late plantings were closer to the dry season and resulted in lower cassava yields because of reduced growth duration (estimated at 68% of the yield reduction) and in-

Table 3. Effect of cassava intercropping on cassava performance, IRRI, 1975.

Cropping pattern	Tubers/ plant	Total dry matter (t/ha)	Root dry matter[a] (t/ha)	Harvest index
Cassava[b]	4.17c[e]	16.6a	6.98a	0.42a
Corn + cassava[c]	8.05a	5.4c	3.50b	0.65b
Rice + cassava[d]	6.00b	8.5b	5.57ab	0.65b
Corn + rice + cassava[e]	6.29ab	7.6bc	5.04ab	0.66b

[a]Root dry matter of .38% harvested at 10 months after planting.
[b]In rows at 1 m with 25 cm between plants within rows (40 K plants/ha).
[c]Corn in rows at 1 m with 3 plants/m. Cassava between corn rows at 1.5 plants/m (15 K plants/ha).
[d]Cassava in rows at 2 m at 3 plants/m (15 K plants/ha). Rice in 6 rows at 25 cm between each cassava row.
[e]Corn in rows at 2 m with 6 plants/m. Cassava between corn rows at 3 plants/m (15 K plants/ha).
[e]In any column, means followed by the same letter are not significantly different at the 5% probability level by DMRT.

Table 4. Crop, variety, spatial arrangement, and fertilizer rate of cassava planting date experiment, Los Baños 1976–77.[a]

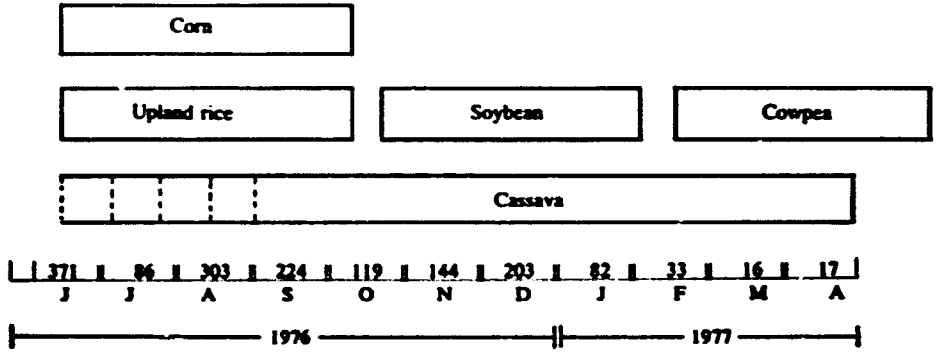
No.	Crop	Variety	Spacing (cm)	No. of plants or seeds/hill	Fertilizer (kg/ha)		
					N	P_2O_5	K_2O
1.	Corn	DMR-2	150 × 50	2	48.6	15.2	15.2
2.	Upland rice	C-22	25 × row	5	54.8	24.6	24.6
3.	Cassava	Malagkit	300 × 50	1	58.3	28.1	28.1
4.	Soybean	TK-5	50 × 10	2	24.6	24.6	24.6
5.	Cowpea	EG #2	50 × 20	2	24.6	24.6	24.6

[a]Plant populations of corn, upland rice, cassava, soybean, and cowpea are 54, 88, 67, 88, and 88% of normal solid population, respectively. Cassava planting time: 15 June, 26 July, 14 August, and 3 September.

Table 5. Yield[a] (t/ha) of corn, upland rice, soybean, cowpea, and cassava as affected by date of cassava planting into a cassava+((corn+rice)–soybean–cowpea)[b] pattern.

Cassava planting date	Yield (t/ha)				
	Corn	Upland rice	Soybean	Cowpea	Cassava
At the same time with rice+corn	4.50bc	1.96c	0.64c	0.83b[c]	33.15[d]
20 days after rice+corn	4.47abc	2.42ab	0.96b	0.15c	29.4a
40 days after rice+corn	4.75abc	2.41a	0.94b	0.14c	26.0b
60 days after rice+corn	4.83abc	2.50a	0.97b	0.14c	21.1c
80 days after rice+corn	4.92ab	2.52a	0.96b	0.14c	16.9d
Without cassava	4.98a	2.25b	1.46a	0.88a	-

[a]Yields within the same column followed by a common letter are not significantly different at the 5% level by DMRT.
[b]Actual rainfall pattern (mm/month) and the cropping pattern studied; broken lines refer to cassava planting dates:



[c]Unreliable, since the cassava from this treatment was stolen at the early stage of cowpea growth.
[d]Estimated.

creased drought stress (32% of the reduction) (Tables 4 and 5).

Delaying cassava planting by at least 20 days substantially increased yields of upland rice and the soybeans following rice. This was because plant height and canopy diameter of cassava were reduced and cassava did not compete as much with upland rice and soybean production. By delaying cassava planting until 20 days after rice planting, the cassava canopy will just break through the rice canopy when rice is ripening. It was found that substantial yield reduction of rice can be avoided if it is not shaded during the last 4 days of its growth cycle (Lohani and Zandstra 1977). As long as early maturing (85-90 days) corn varieties are used in combination with rice varieties of 125-130 days duration and cassava does not dominate the rice canopy until the last 10-15 days before rice harvest, the cassava+corn+rice intercrop should produce about 60%, 65%, and 75% of their sole crop yield, assuming cassava crop duration is longer than 10 months.

Conclusions

For the design of cassava intercropping patterns, the rate of cassava development, its tolerance to drought, its ability to yield at low plant populations and the variable crop duration are important traits. Some agronomic considerations for the design of cassava-based cropping patterns are:

(1) For intercropping, cassava varieties should be tolerant to early shading. The canopy should be small and reasonably tall. The LAI should be low to avoid self-shading. Varietal types for intercropping should be late- (after 3½ months) branching types if no late season intercrop is planned. Row pairing of cassava can also achieve rapid canopy expansion at later growth stages. The desired canopy density at later growth stages will be much lower if late season intercrops are contemplated.

(2) Cassava should be the superior canopy during its peak production period (after 120 days).

(3) If possible, cassava should remain below the canopy of the intercrop during the first 120 days of growth.

(4) Cassava planting can generally be delayed by 20-30 days to prevent excessive shading of the intercrop.

(5) Plant population of cassava can be kept low and row spacing wide without undue yield reductions. This tends to lead to relatively reduced early growth and increased late growth. The desired tuber size and growth duration of cassava should also be considered in the selection of plant population.

(6) Late season intercrops must be shade tolerant. They will compete with cassava for moisture, but benefit from the windrow effect of the taller cassava stand. At late growth stages, cassava is tolerant to water stress and very efficiently utilizes rain. Where monthly rainfall during the last 3 months of the cassava growing period is less than 50 mm/month, cassava should probably not be intercropped during the last part of its growing season, but instead shallow (sweep) intertillage can be applied to reduce surface moisture losses.

Soil Fertility Implications of Cropping Patterns and Practices for Cassava

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Cassava is a crop that can survive under conditions of low soil fertility and drought that would destroy many other food crops. It also has certain characteristics that make it a valuable component of cropping patterns in Indonesia and other places in the tropics: it thrives at low elevations on soils that may be too acidic and low in soil fertility for other crops; there is sufficient genetic variation to permit development of varieties that can be grown and harvested in areas with less than 3 months rainfall (150 mm per month) to those where the rainfall exceeds 200 mm for each of 12 months of the year; in the drier areas it can be planted in the wet season; it will continue to grow and utilize residual soil moisture as the rains decrease; it grows slowly soon after planting and the cuttings are spaced from 1 to 2 m apart to accommodate future growth and different crop combinations; consequently, two or three crops can be successfully interplanted in cassava without drastically reducing the yield of cassava or the interplanted crops; the harvest time is flexible and may range from 5 months to 1 year.

These characteristics make it highly desirable to include cassava in any cropping pattern in situations where farmers must depend each year upon production from their land to survive, as it provides food and economic stability. The next question is whether it can be grown in such a way as to provide agronomic stability over time.

Nutrient Removal

Cassava, like any high-yielding crop, does impoverish the soil. Large quantities of plant nutrients are removed with the harvested roots. When grown alone, serious problems with erosion and physical and chemical deterioration of the soil can occur. Table 1 shows the amounts of mineral nutrients that were removed by 6, 8, and 10-month-old cassava crops in Bogor, Indonesia (Nijholt 1935). The yields in Table 1 lower than the top yields represent reduced plant populations that occur when cassava is grown in intercrop combinations. The yields in these trials were high and are indicative of a high level of nutrition and rainfall. The total mineral nutrient uptake and subsequent removal from the fields does decrease the soil fertility (Howeler 1978). But if we calculate the total calories produced and then the amount of rice needed to produce an equivalent number of calories (expressed in metric tonnes/hectare of padi rice), the total nutrient removal is put in perspective and does not seem so large. Many of the leaves and the mineral nutrients contained in them are returned to the field. But usually the mineral nutrients in the roots and stems (except for cuttings) are lost. Rarely under field conditions are the yields and total mineral nutrients harvested as high as the maximum yields shown in Table 1. Management schemes must be developed that will promote cassava production but conserve the soil.

Cropping Systems with Cassava

Exploitative Systems

Continuous cassava — Formerly on Java and at present on Sumatra there are large areas of land set aside for plantations, several of which are cassava plantations. On newly opened land, usually no (or very little) fertilizer is used the first 3–4 years. The organic layer in the upper few centimetres of soil is quickly decomposed and the mineral nutrients released (Syarifuddin 1975). The land loses productivity with continuous cultivation and cropping with cassava. If available, new land is opened and the

Table 1. Balance sheet for food production and nutrient removal for different levels of production (or population) of cassava under optimum conditions harvested at 6, 8, and 10 months.

Yield wet root (t/ha)	Crude protein (kg/ha)	Calories[a] (KCal/ha)	Rice equiv.[b] (t/ha)	Mineral nutrients removed[c] N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
6 Months						*Roots*		
5	36	6000	2.5	6.0	1.83	24	2.71	1.02
10	71	12000	5.0	12.0	3.67	48	5.43	2.04
20	142	24000	10.0	24.0	7.34	96	10.86	4.08
30	213	36000	15.0	36.0	11.00	144	16.3	6.12
						Stems		
				32.0	6.68	76.4	38.8	10.00
						Leaves		
				59.6	4.76	40.9	26.7	5.18
						Total		
				127.6	22.4	261.3	81.8	21.3
8 Months						*Roots*		
5	36	6000	2.5	5.0	1.7	22	2.4	0.96
10	71	12000	5.0	10.0	3.4	44	4.8	1.92
20	142	24000	10.0	20.0	6.8	88	9.6	3.84
30	213	36000	15.0	30.0	10.2	132	14.4	5.76
40	284	48000	20.0	40.0	13.6	176	19.2	7.68
						Stems		
				40.8	9.6	125	57.8	12.42
						Leaves		
				50.7	3.9	34.2	22.6	4.47
						Total		
				131.5	87.1	335	99.6	24.57
10 Months						*Roots*		
5	36	6000	2.5	4.5	1.9	21	2.9	1.3
10	71	12000	5.0	9.0	3.8	42	5.8	2.6
20	142	24000	10.0	18.0	7.6	84	11.6	5.2
30	213	36000	15.0	27.0	11.4	125	17.4	7.8
40	284	48000	20.0	36.0	15.2	166	23.2	10.4
50	355	60000	25.0	45.0	19.0	208	29.0	13.0
						Stems		
				51.0	12.8	162	77.8	18.4
						Leaves		
				43.0	3.4	31	21.4	4.3
						Total		
				139.0	35.2	401	128.2	35.7

[a]Food value based on calculations using 0.71% crude protein and 1.20 KCal/kg for fresh root as reported by INCAP and taken from *A Literature Review and Research Recommendations on Cassava*, University of Georgia Team, AID Contract No. CSd/2497, 1972, p. 104.

[b]Calculated on basis of 3.60 KCal/kg for milled rice and 2.40 KCal/kg for gabah (unmilled padi rice) at 13% moisture.

[c]Based on analysis of 6-month-old cassava (when yield was 29.69 t/ha), 8-month-old cassava (when yield was 41.13 t/ha), and 10-month-old cassava (when yield was 49.57 t/ha) from Muara Experimental Field, Bogor, Indonesia. Nutrient removals for lower yields of roots were calculated for the different yield levels. (Taken from Nijholt 1935.)

older fields allowed to return to "alang-alang" (cogongrass) (*Imperata cylindrica*) or planted to other crops that are valued higher than cassava under the prevailing economic conditions. As crop yields decrease, small applications of urea and TSP may be used to stimulate growth of these crops.

In Indonesia the soils are commonly referred to as red-yellow Podzolic soils and are characterized as being low in inherent soil fertility. Obviously most of mineral nutrients are contained within the organic fraction of the top 15 cm of the soil. When infested with alang-alang, these soils have been described as "critical lands." Shifting cultivation and fire have destroyed the original forests and brought about the present condition.

Results of soil tests of samples taken from plantation land newly opened and from that which has been cropped for 1–4 years show that N and P fertilizers were used the 4th year for plantation I (Table 2). The data show clearly the effects of continuous cropping and the loss of mineral nutrients from the soil, decrease in pH, and increase in exchangeable aluminum.

Subsistence agriculture — When a farmer has virtually no money for inputs and must consume most of his farm production for sustenance for his family, his situation may be described as subsistence agriculture. This situation prevails in many of the upland areas of Indonesia and other tropical parts of the world where the land is either hilly or extremely low in mineral nutrients. Cassava is usually the last crop in the regression from food sufficiency to insufficiency.

Fortunately there is sufficient land in many countries to permit shifting cultivation. This practice permits recovery of the soil fertility during the fallow period. But as population pressures increase, much land is used for agriculture that should never be cultivated. It may be too steep, erodable, shallow, or rocky for satisfactory use.

Upland food crops production in Indonesia and much of Southeast Asia has not been the most favoured management practice. Lowland rice has been grown wherever possible. There are several reasons for this. Rice paddies tend to control water movement and erosion and enhance soil fertility. This method of rice culture has proved to be stable and productive over the years, even without use of fertilizers on most soils. On the other hand, upland crops production on the same land has rarely been as successful. New technology can help. The use of inorganic fertilizers and improved techniques for

Table 2. Soil test results from cassava plantations in Central Lampung, Indonesia, Cropping Systems Research, 1978.

	Plantation I				Plantation II		
Test[a]	New	1st yr	3rd yr	4th yr	New	1st yr	2nd yr
pH H_2O	5.5	5.7	5.2	5.4	5.7	5.3	5.6
pH KCl	4.4	4.6	4.2	4.1	4.4	4.3	4.2
Extr. Al-M.E. (1N KCl)	0.09	0.11	0.15	0.30	0.17	0.30	0.32
Exch. Bases - M.E.							
Ca	3.1	1.6	1.5	1.3	0.5	0.5	0.8
Mg	1.1	0.8	0.8	0.4	0.5	0.3	0.5
K	0.5	0.5	0.5	0.3	0.3	0.2	0.1
CEC-M.E.	10.1	12.2	9.2	10.8	7.6	7.6	8.9
% Base Sat.	25	25	26	19	18	13	17
Organic Matter							
C - %	4.37	2.92	2.23	2.80	2.00	2.36	2.45
N - %	0.31	0.10	0.18	0.21	0.18	0.18	0.17
C/N	14	15	12	13	16	18	14
$Bray_1$ - PPM	32.1	11.5	8.9	13.3	10.1	13.5	8.5
$Bray_2$ - PPM	50.8	15.7	11.6	18.2	13.2	10.5	9.0
Extr. Nutrients - PPM (1N NH_4 O AC at pH 4.8)							
P	2	1	1	1	1	1	1
K	223	208	203	56	138	72	31
Ca	529	206	222	73	60	20	41
Mg	131	97	43	40	40	41	46
Mn	4	3	3	3	1	2	2
Fe	9	8	8	15	7	7	6

[a]Soil tested by the Soil Research Institute, Bogor, Indonesia. No replication.

crop and pest management permit upland crops production and economic returns comparable to those from lowland rice culture and in the temperate regions. This approach requires capital and material inputs and increases the risk the farmer must face. Use of land only for lowland rice and shifting cultivation are low-risk, stable, and practical management systems for low populations and excess land. But with increasing population there seems to be no alternative but to intensify use of all available land. The crop that is the "anchor man" for stable upland crops production is cassava. In combination with either rice or corn and interplanted with legumes, the human nutritional needs can be met. But do we have the technology for sustained crop production for the future?

Systematic Crop Management

Stable farmers' pattern — Throughout Indonesia there is a generalized cropping pattern that prevails in upland areas. There are some variations but basically it consists of rice and corn planted about the same time at the beginning of the rainy season. After 2 months, cassava is interplanted in the combination. Depending upon the length of the rainy season and local conditions, other crops are planted in the standing cassava after harvest of the rice and corn. The pattern may be characterized as follows: C + ULR + Cv + legume - legume (McIntosh and Effendi 1977). In practically all areas of Indonesia the first three crops can be grown with varying degrees of success even in areas of Eastern Indonesia where there are only 3-4 wet months (>200 mm) and 8-9 dry months (<50 mm). The relative population of each crop in the pattern depends mostly upon soil fertility and rainfall. For good soils of volcanic origin on Java, upland rice and corn are more important than cassava. But for steep and eroded land on Java, cassava predominates just as it does on the less fertile soils of Southern Sumatra and the drier areas of East Java and Eastern Indonesia.

Improved stable patterns — In 1973, research was begun to evaluate the productive capacity of the red-yellow Podzolic soils of Lampung in Southern Sumatra. The area chosen had been settled for 20 years by people transmigrated from Java. It has been estimated that there are 15-20 million ha of land with this kind of soil that could be used for crop production and settlement that is not presently being used. The rainfall in the area exceeds 200 mm per month for 6 months and 150 mm for 9 months (Berlage 1949).

Background

Many of the transmigration settlements in Indonesia have not been as popular as hoped. At least there was very little spontaneous transmigration of people following the government-sponsored programs. It was obvious from inspection of many of the settlements in Lampung that there was little incentive for newcomers. First of all, inadequate infrastructure was discouraging. But most of all crop production decreased rapidly with time when compared to Java. The settlers were not free to engage in shifting cultivation like the indigenous people. Although enough food could be produced to meet family needs there was little to really stimulate enthusiasm. Fertilizers and insecticides were not available for upland crops. These were restricted, when available, for irrigated lowland rice. The farmers had little money for inputs. The local markets were not able to accommodate large increases in production anyway. To solve these problems three things would have to be done. First of all, the productive capacity of the soil over time would have to be evaluated. Secondly, agronomically and economically sound cropping patterns would have to be developed into a production program suitable for the area. Thirdly, all sectors of the local economy would have to develop to accommodate increased production.

Field Studies

A long-term study was started in October 1973 in Central Lampung to answer some of these questions. The plot area chosen had been used continuously for about 20 years. The land was poor and cassava growing in the fields was yellow and stunted. There were eight different soil fertility and management practices superimposed over three cropping patterns. The fertility treatments consisted of a check, full treatment with lime, residues, and fertilizers, and six combinations. The patterns consisted of a simplified farmer's pattern with the crops randomly planted; intercropping pattern with the crops in rows but with the same kinds and proportions of crops as for the check; and a sequence of crops growing alone. The cropping patterns and full fertilizer treatments are shown in Table 3.

The main objective of this experiment was to evaluate the productive capacity of these soils and determine the management practices necessary to promote economical crop production over time.

Crop Response

A partial summary of the first year's results is shown in Table 4. The effects of fertilizer application on crop production is striking for all crops. The value of mixed and intercropping is clear if we compare the net returns for these patterns with those from the sequential planting treatment. The difference is mostly due to cassava, which can be interplanted

Table 3. Cropping patterns and full fertilizer treatments for long-term cropping systems experiment, Bandarjaya, Lampung, 1973–78.

Main plot	Cropping patterns	Spacing[a]		Fertilizer (kg/ha) N	P_2O_5	K_2O
A. Mixed cropping (no rows)	Corn +	Uncertain		48	15	15
	Upland rice +	"		72	24	24
	Cassava +	"		20	20	20
	Peanut -	"		14	25	36
	Rice bean	"		14	25	36
			Total/yr	168	109	131
B. Intercropping (rows)	Corn +	150 × 20		48	15	15
	Upland rice +	25 × rows		72	24	24
	Cassava +	300 × 60		20	20	20
	Peanut -	30 × 10		14	25	36
	Rice bean	30 × 10		14	25	36
			Total/yr	168	109	131
C. Sequential planting (rows)	Upland rice -	25 × rows		90	30	30
	Corn -	100 × 20		90	25	25
	Rice bean	40 × 20		20	45	50
			Total/yr	200	100	105

[a]The populations of corn, rice, peanut, rice bean, and cassava, in mixed cropping and intercropping were 53, 80, 71, 71, and 44.4% of that in sequential planting or solid planting, respectively. Sorghum was included the first year but was eliminated later and some modifications were made in planting and harvesting dates and spacing.

Table 4. Average yield of crops and approximate net returns for check and full treatment plots. Cropping Systems Research, Bandarjaya, Central Lampung, 1973–74.[a]

Fertility treatment	Dry grain (kg/ha) Corn	Upland rice	Peanut	Rice bean	Cassava fresh root (t/ha)	Approximate net return (Rp/ha[b])
		(A) Mixed Cropping				
No lime + no NPK + no mulch	467	690	161	55	12.7	65000
Lime + NPK + mulch	1165	1358	356	248	28.3	132000
		(B) Intercropping				
No lime + no NPK + no mulch	455	769	222	93	14.6	91000
Lime + NPK + mulch	1350	2724	567	627	23.2	265000
		(C) Sequential Planting				
No lime + no NPK + no mulch	606	850	-	153	-	(-6000)
Lime + NPK + mulch	2935	3536	-	723	-	74000

[a]Yields subsequently have varied due to pests and management but have remained basically the same.
[b]U.S. $1.00 = ca. Rp 415.

with little effort or cost and which grows during the turn-around time between other crops in the sequence. It is high yielding and stable even under conditions of low soil fertility.

Calories

The full impact of the yields from these plots may be illustrated by summarizing the total calories produced and comparing the production to rice. Table 5 shows the comparison from the intercropping pattern. The full-treatment plots produced calories equivalent to 18.3 t/ha of padi rice and protein equivalent to 11.3 t/ha of padi. The amounts of fertilizer used (168 kg N + 109 kg P_2O_5 + 131 kg K_2O/ha) were less than the amounts commonly used for lowland rice on Java on some of the best rice land in the world. These yields were produced without irrigation on lands that had been classified by some

Table 5. Calories and protein produced per hectare from year-round cropping patterns with no and full fertilizer treatments. Cropping Systems Research, Bandarjaya, Central Lampung, 1973-74.

Cropping pattern	No treatment			Full treatment		
	Yield (*kg/ha*)	Calories (*KCal/ha*)	Protein (*kg/ha*)	Yield (*kg/ha*)	Calories (*KCal/ha*)	Protein (*kg/ha*)
Corn +	455	1615	42	1350	4792	124
Rice +	769	1840	52	2724	6521	185
Cassava +	14600	17520	102	23200	27840	162
Peanut -	222	1003	51	567	2563	145
Rice bean	93	308	23	627	2075	157
Total		22286	276		43791	773
Gabah[a] equivalent (*kg/ha/year*)		9325	4060		18323	11371

[a]Gabah ×0.665 = milled rice. Average value of 6.8% protein used for conversion from protein to gabah.

as alang-alang-infested waste lands. Results of the cropping pattern and soil fertility trial have been replicated in other places. Data in Table 6 show the consistent productivity of the basic pattern and profitableness of cassava in another area in Southern Sumatra. Similar results have been found in three other locations. There are two questions that arise. Were these unusually fertile red-yellow Podzolic soils and can the production be sustained over time?

Present and Future Soil Fertility

If we compare the analysis of this soil (Table 8) with that of the most common soil type in Central Lampung (Table 2), we can see that the results are comparable. Test values for exchangeable cations and organic matter in the soil from the plot area are lower, which indicates the land had really been opened and used for a considerable length of time. This becomes clearer if we compare the test results with results in Table 5 from the cassava plantations. In the latter case the soils appear to be newly opened from alang-alang and still high in organic matter and exchangeable bases. We conclude the soil from the plot area was unique in that it was extremely low in fertility rather than the other way around.

Furthermore, we feel the fertility of the soil can not only be maintained but improved. There are two reasons to believe this. The soil is responsive to fertilizer and good crop management as indicated by the striking response to fertilizer the first crop year after 20 years of subsistence farming. Soil test data in Table 8 show that after 5 years of continuous cropping with five crops per year (including cassava), the level of fertility increased with respect to phosphorus and calcium where fertilizers and lime were used. Without fertilizer, not only were the crop yields low but the soil lost fertility.

Of special interest to us at this symposium is the fact that nothing mysterious seems to have happened from continuous cropping of cassava in rows in exactly the same place in each plot for 5 years. There was some movement and mixing of soil during land preparation each year. But the practice of mulching the cassava with straw residues from the rice and legumes contributed to the increase in pH and buildup of calcium in the cassava rows. It is also interesting that the level of magnesium seems to have decreased in the fertilized plots. The relatively large yields removed from these plots in comparison to those from the (0) fertilizer plots would account for this. Another interesting result from the analysis is that the extractable aluminum by both measurements decreased in the fertilized and limed plots. It appears to have decreased in the cassava rows also. No doubt this is due to effects of liming and mulching of cassava with the crop residues.

Sustained Production

We hope to continue some treatments in the long-term fertility plots for several more years. Studies need to be started in other places with different soil and climatic conditions. We simply cannot predetermine all the factors that affect crop production. The striking response to fertilizer does not occur on all soils. Work in Central Java on latosols with much higher inherent fertility than those we have discussed in this paper do not respond to fertilizer treatments so strikingly. Soils with higher clay contents and capacities for fixing P and K require larger amounts of nutrients for comparable yield increases.

Data in Table 7 show that yields from the no treatment plots have, in general, decreased. Although the effects are less consistent, there tends to be a trend for total crop production to increase with mulch. The effects of mulch on the appearance of the crops in the field were obvious. The use of residues from the previous crops or from green manure from other fields should be strongly encouraged.

Table 6. Calories and protein produced per hectare and costs and returns from year-round cropping patterns. Cropping Systems Research, Bandar Agung, Central Lampung, 1976–77.

Cropping pattern	Yield (*kg/ha*)	Calories (*KCal/ha*)	Protein (*kg/ha*)	Gross return (*Rp/ha*)	Material costs (*Rp/ha*)	Labour costs (*Rp/ha*)	Net returns (*Rp/ha*)
Corn +	1977	7018	182	88965	54375	75600	77241
Rice +	1689	4043	115	118251			
Cassava +	21125	25350	148	126749	17625	6300[a]	102824
Corn –	1739	6173	160	86925	22289	28500	36136
Cowpea	328	1122	75	39396	11403	27600	393
Total		43706	680				216594
Gabah equivalent (*kg/ha/year*)		18258	10003				

[a]Labour costs for cassava would be increased by Rp 415 11300/ha if one-third of costs for land preparation and weeding for the first three crops were charged to cassava.

[b]U.S. $1.00 = ca. Rp 415.

Table 7. Comparisons of crop yields and net returns for three management practices in long-term cropping systems study from 1973–78. Cropping Systems Research, Bandarjaya, Central Lampung.[a]

Fertility	Dry grain (kg/ha)				Cassava wet root (t/ha)	Net returns (Rp/ha)
	Corn	Upland rice	Peanut	Rice bean		
No lime + no NPK + no mulch						
1973–74	455	769	222	93	14.6	91000
74–75	206	862	467	50	6.1	–
75–76[b]	223	653	229	–	6.0	21667
76–77	46	538	–	7	3.7[c]	–
77–78	130	153	224	–	3.9	27137
Lime + NPK + no mulch						
1973–74	1353	1608	431	545	22.2	–
74–75	1904	3114	740	380	20.6	
75–76	1983	1893	348	–	19.9	212784
76–77	1837	1450	–	39	14.2[c]	–
77–78	2065	2056	582	–[d]	21.0	344765
Lime + NPK + mulch						
1973–74	1350	2724	567	627	23.2	265000
74–75	2436	3222	763	492	20.1	–
75–76	2213	1820	490	–	36.8	397344
76–77	1896	1490	–	44	15.9[c]	–
77–78	2261	2146	584	–[d]	22.7	369540

[a]Taken from Laporan Kemajuan Penelitian, Seri Pola Bertanam (No. 4, 5, and 6) from 1974–77.
[b]Exceptionally dry year — almost no rain in May, June, and July.
[c]First planting of cassava failed because of bad cuttings and had to be replanted late.
[d]Good crop but not yet harvested in September 1978.

Table 8. Soil test results from long-term research plots after continuous cropping (5 crops per year) for 5 years and adjacent field. Cropping Systems Research, Adijaya, Central Lampung, 1973-78.

Test[a]	No treatment		Full treatment		Check
	Cassava row	Between rows	Cassava row	Between rows	Adjacent field
pH H_2O	5.2	5.2	6.5	5.9	6.0
pH KCl	4.1	4.1	5.5	4.9	4.8
Extr. Al - M.E. (1N KCl)	0.21	0.23	nil	0.04	nil
Exch. Bases - M.E.					
Ca	0.98	1.00	3.8	2.7	2.8
Mg	0.51	0.45	0.3	0.3	0.4
K	0.10	0.10	0.1	0.1	0.1
Na	-	-	-	-	-
Sum of bases - M.E.	1.6	1.6	4.2	3.1	3.3
CEC - M.E.	5.6	5.4	6.4	6.3	6.6
% Base Sat.	29	30	66	49	50
Organic Matter					
C - %	0.96	0.94	1.15	1.13	1.23
N - %	0.08	0.08	0.09	0.10	0.10
C/N	12.0	11.8	12.8	11.3	12.3
$Bray_1$ - PPM	2.3	2.2	28.	27	2.6
$Bray_2$ - PPM	4.6	4.6	50	45	4.2
Extr. Nutrients - PPM (1N NH_4O AC at pH 4.8)					
P	1	1	3	2	1
K	23	17	52	47	21
Ca	138	126	700	450	379
Mg	41	38	28	30	53
Mn	10	10	10	10	6
Fe	5	6	2	3	4
Al	85	84	43	53	43

[a]Average results of tests of three samples from each of the three replications from the plots. There were four replications for the check samples.

Implications

(1) Continuous cropping of cassava should always be accompanied by other crops to help protect the soil from the sun, rain, and leaching and provide mulch. Rice is one of the best crops for this purpose.

(2) Fertilizer and lime applied to these intercrop combinations will increase crop yields and residue protection. The residue must be returned to the soil either directly or as stable manure.

(3) With some variation, the pattern C + ULR + cassava + legume-legume can be used for most upland crops situations. If the management practices suggested are used, the numbers of crops and productivity will be dependent mostly upon rainfall and its distribution.

(4) The productivity of tropical upland soils with cassava as one crop in the cropping pattern can be maintained and even improved with the management practices suggested.

Agroeconomic Considerations in Cassava Intercropping Research

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Many cropping systems programs do not have agricultural economists as part of their core staff. As a result, if cropping pattern experiments are to be analyzed and interpreted from an economic viewpoint, it is often necessary for the biological scientists to undertake these analyses — in a similar manner as they are responsible for their statistical analysis. In other situations where newly trained agricultural economists are members of cropping systems programs, or where they are new members of teams, it is useful, as a point of departure for the biological scientists to have some notion of what to expect from this particular member of their team.

Within cropping systems programs, agricultural economists should be expected to play major roles in:

(*a*) helping to define the environment (biophysical, technological, socioeconomic) for which new innovations will be designed;

(*b*) contributing to the design, analysis, and interpretation of experiments conducted with the view to increasing agricultural productivity in selected target areas;

(*c*) formulating production recommendations; and

(*d*) evaluating post release, the impact of new innovations emerging from the cropping systems research.

The contributions of this paper are thus as follows. Initially, a framework in which cassava-based cropping systems research may be set is presented. The purpose of the approach is to increase the probability of relevant technical innovations being developed for specific target groups of cassava farmers. Following this, economic considerations related to crops grown in intercropping patterns are reviewed and the use of budgeting techniques to evaluate cassava-based intercropping patterns discussed. Finally, the environment in which proposed innovations should be evaluated, it is argued, should be derived from farm focus, as opposed to research station studies. The evaluation should include both pre-release and postadoption studies of technology and should be structured in a manner to provide a feedback to contribute to the future orientation and priorities in research programs.

A Model for Cassava Intercropping Research

One possible framework for structuring a problem-oriented research program focusing on cassava-based cropping systems is shown in Fig. 1. The crop, the farmer, and his environment are focal points in the approach. The farmer is included in the scheme in the sense that he contributes, implicitly at least, to the identification of priority areas for biotechnical research and explicitly to the evaluation of the relevance of innovations evolving from the research. By implication, farmer and farm-focused research are stressed when identifying problem areas and potentials for research, and in the adaptive and evaluation phases of the research process (Dillon et al. 1978).

However, although the existing farming system, and the focus on adaptive research with a short-term payoff, are important when attempting to solve the real-world production problems faced by farmers, it is critical that the associated "investment" type research necessary to support the applied research is not ignored in the drive for a short-term payoff from the applied research.[1] Often, while the major-

[1]The desirable balance between adaptive and investment research, of course, cannot be generalized. Cassava represents an example of a crop where little investment research has been undertaken when compared with other major staples (e.g., rice, maize, wheat, sorghum, potatoes), and where the potential payoff from breeding and associated support research appears to be enormous. Indeed, in the author's view, a number of the high- and stable-yielding varieties of cassava developed by Hahn and his colleagues at IITA represent as significant a technological development for the African continent at least, as the more widely known and acclaimed modern varieties of rices and wheats.

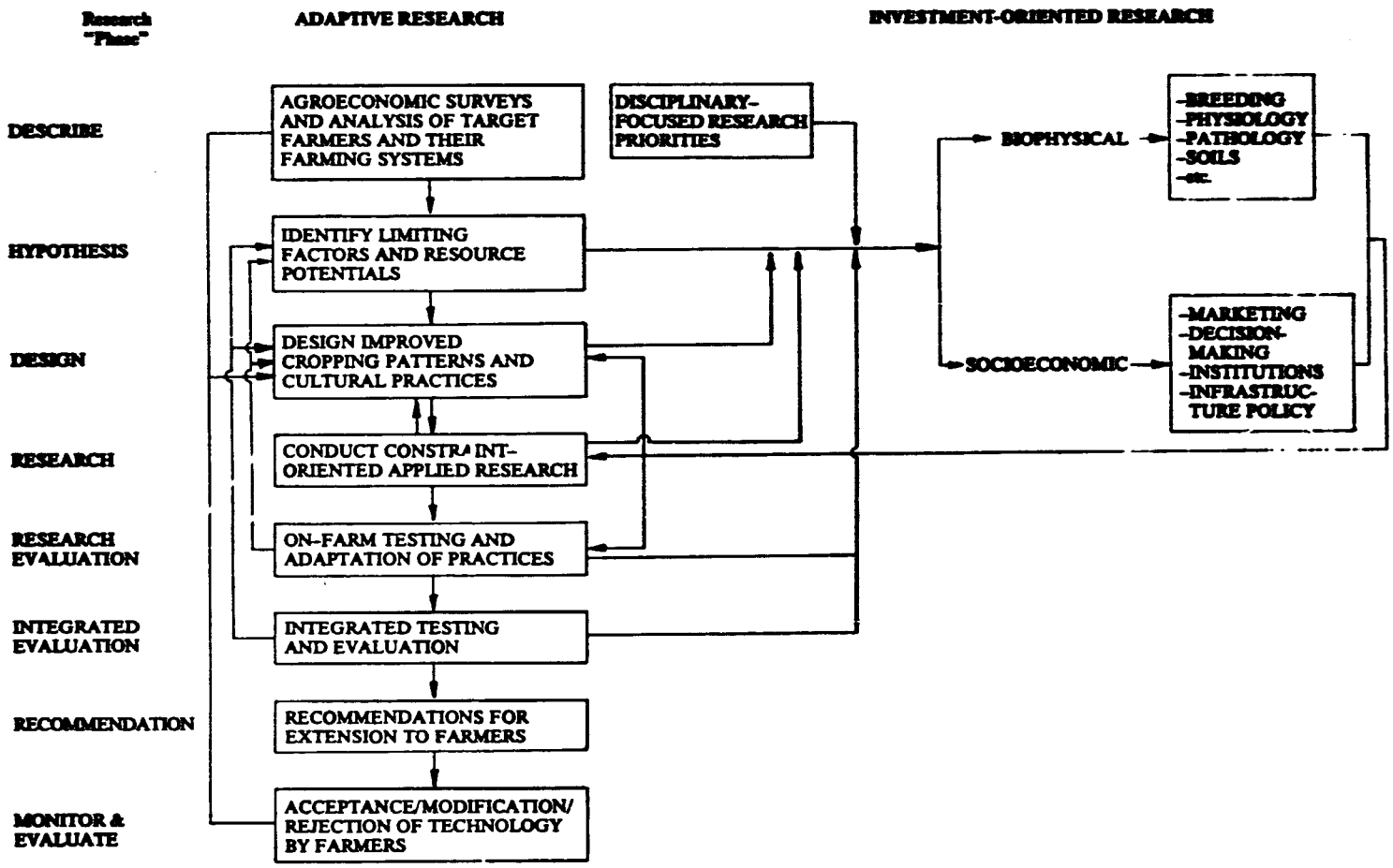

Fig. 1. Conceptual outline of a farmer-focused cropping systems research and application program.

ity of the adaptive research and evaluation will be conducted by multidisciplinary agronomically focused programs, the more "pure" research may more efficiently be conducted within disciplinary-oriented research programs.

In Fig. 1, the focus is on research designed to ameliorate biotechnical factors that limit the productivity of cassava-based cropping systems. Yet many constraints to increasing the supply of food crops are not biological or farm-based in nature. For example, problems or limitations in processing the cassava or related crops, transporting them to markets, procuring inputs when required, and crop and input prices, may be dominant constraints — and more difficult to change — than the biological ones (Flinn 1976).[2] Thus, an effective program in cassava-based cropping systems must be designed with an awareness of the implications of these constraints on the feasible set of new innovations emerging from the research program.

Agroeconomic Studies of Cassava-Based Cropping Systems

Often, scientists, extension workers, marketing and consumer groups, and planners do not provide the directors and administrators of agricultural research projects with the necessary information to enable them to make the best decisions as to priorities in agricultural research. This problem tends to be more acute in the developing than the so-called developed world, and for cassava-related research in particular. There are several reasons for this. First, in many instances where the farm family provides the majority of the labour, where land is not freely sold, and where the bulk of the crop produced is for family sustenance, the market prices for these items that planners and entrepreneurs gain access to, need not reflect their true values to the farmer. As a result, the "demand-induced" concept with prices influencing priorities for agricultural research as demonstrated by Hayami and Ruttan (1971) may not be terribly effective in such cases.[3] Secondly, low resource farmers may not recognize or relate the yield-limiting factors in cassava production to the real causal agents, nor, even if they do, are they often in the position to make researchers aware of the factors that effectively limit the yield of crops. Thirdly, in many cases, the priorities, methods of production, and the environment in which the small farmer operates are not well appreciated or related to by researchers. As a result, researchers tend to have an imperfect understanding of the real constraints and the interaction of these constraints at the farm level, and may have difficulty translating the real production problems faced by farmers into research projects with design criteria for fabricating new technologies that are appropriate, given the conditions of low resource farmers.

Given the above problems of identifying research projects with the highest expected payoff to farmers, farm-focused agroeconomic studies provide a basis to either confirm, modify, or establish the scientist's impressions of priorities in cassava-related research (including design criteria), and provide background information for site selection for field trials and for farmer evaluation of technology.[4] Four types of studies are particularly useful as sources of information for the design of research programs in those instances where farming systems are imperfectly understood or where there is a communications gap between the researcher and the farmer (Table 1).

Initial descriptions of cassava production, processing, consumption, and marketing may be obtained through single visit enumeration of informants and by focusing on cassava-related aspects of the farming systems. These surveys, referred to as baseline surveys in this paper, often combine broad cross-sectional surveys of a large number of farmers with more in-depth surveys of key informants, and enable the researchers to identify at least quantitatively[5]:

(*a*) by whom and how the cassava crop is grown, in which cropping patterns and soil types is it an important component;

(*b*) what are the major factors (biophysical and agroeconomic) influencing the crop's production;

(*c*) for what purposes does the farmer produce various cultivars of cassava;

(*d*) how, and which components of the crop are consumed, processed, and marketed, and at what prices;

[2]Economists working in cropping systems research tend to focus their research on the supply side of the equation. However, often the reason for the failure of a new crop or variety is simply that the farmer cannot sell it (or the increased output) at a remunerative price. The author is convinced that economists associated with cropping systems programs should be more concerned with estimating, ex-ante, the demand, at the farm level for the varieties or crops it is proposed to introduce.

[3]Ruttan (1978, p. 356) in his later writings also seems to be dubious as to the possibility of atomistic market forces inducing desired changes for the less advantaged.

[4]The methodologies and problems involved in conducting different types of agroeconomic surveys of low resource farmers have been widely discussed (e.g., Collinson 1972; Kearl 1976; Binswanger and Jodha 1976).

[5]Categories of information that are regarded as valuable from baseline surveys are provided by Banta (1977), Collinson (1978), and Norman and Palmer-Jones (1977).

Table 1. Typologies of agroeconomic surveys for production-oriented research in cassava.[a]

Type of survey	Characteristics	Typical visiting frequency	Examples
Baseline studies	Broad overview of cassava-based production systems	Single	Ezeilo et al. 1975
Bioeconomic studies of yield-limiting factors	Identify factors that reduce on-farm yields of cassava and quantify their importance	Few visits, based on physiological development of the crop	Pinstrup-Andersen et al. (1975)
Intensive ("cost-route") farm management surveys	Detailed description and analysis of cassava production and use within a whole farm context	Multiple, frequent visits	Lagemann (1976)
Adoption and evaluation surveys	Evaluate the farmer's reaction and attitudes to new packages, evaluate factors limiting packages' adoption	Single	Okali and Borti Doku (1978)

[a]Excluding marketing and policy-oriented studies, see Johnson (1963) and Jones (1959) in this regard. The survey, of course, should not be the first activity in the process. A review, analysis, and interpretation of relevant background information available for the region are vital to help guide the field work and focus the investigation.

(*e*) what are the farm resources and infrastructural support available that will influence the farmer's capacity and desire to adopt new innovations.

Ideally, the baseline studies should focus on cassava from a wide range of viewpoints; to be most effective, and to increase the probability of the inferences drawn from the work being credible to others requires that the studies be collaborative; for example, with a core staff of an agronomist and a farm management economist and where necessary, drawing on the expertise of pathologists, entomologists, etc.

A merit of single-visit, baseline surveys is that they can be completed quickly and provide rapid feedback to scientists on a range of problems and potentials related to cassava research. The procedure also serves as a basis to (Price 1977, p. 3):

(*a*) identify practices currently used by farmers that can be further and rapidly exploited by applying existing scientific knowhow;

(*b*) determine the benefits that farmers receive from present practices so that by comparison, the likely acceptability of new patterns can be assessed; and

(*c*) obtain a measure of present conditions in target areas so that the impact of the cropping systems research can be eventually evaluated.

Although baseline surveys provide a broad overview of cassava within existing farming systems, and provide in most cases qualitative data on factors limiting production, they do not normally enable the relative magnitude and importance of these factors to be precisely quantified. A more intensive approach using multiple visits to selected respondents is usually required to quantify these relationships at the field or farm level. Pinstrup-Andersen and Diaz (1975) and Pinstrup-Andersen et al. (1976) provide excellent examples of how repeat observations on farmers' crops (timed to coincide with the major physiological stages of its development) when plots are scored for pest, environmental, and management parameters, enable the impact of various yield-limiting factors on yields to be quantified. The basis of the approach adopted by Pinstrup-Andersen requires that observations are taken from a large number of farmers' fields; due to differences between fields in relation to the incidence of pests and diseases, climate, soil characteristics, crop management and yield, the impact of each of these factors on productivity is assessed.

If the contribution of the various yield-limiting factors are to be quantified, it is necessary that considerable differences exist between observed plots in the incidence of factors that influence yields. The required variability between plots is not always found. For example, some cassava diseases may be endemic over very large areas (e.g., CMD in West Africa), or there may be a high degree of similarity in some aspects of crop management (e.g., minimal or no use of fertilizer).[5] In this instance, an alternative approach, one adopted by the "Constraints Program" Network of the International Rice Research Institute may be considered.

The purpose of the Constraints Program was to develop a procedure to measure the contribution of biological and socioeconomic factors that result in farmers' yields of rice being lower than potentially achievable on their fields (De Datta et al. 1978; IRRI 1977a). Briefly, the approach used a combination of field experiments located on farmers' fields and farm surveys. The field experiments were used to estimate potential farm yield, actual farm yield, and the contribution of the various management factors to this yield gap. The agroeconomic farm surveys were designed to provide insights to explain *why* the levels of inputs necessary for higher rice yields were not being applied by farmers. Although the procedure was developed for rice, the principles and logic of the approach suggest it could be adapted to evaluate the on-farm yield potential of cassava-based intercropping systems, and the contribution of important management factors to the gap that exists between actual production and potential production.[7]

A feature of plot-focused field investigations of cropping patterns is that they tend to be more successful in quantifying the impact of various management and biophysical factors on yields than explaining why farmers apply some inputs at what appear to be suboptimal ways or levels. This limitation is partly because the decision-making framework of the farmer is imperfectly incorporated in the analysis at the field level, and partly because the analysis of a field fails to consider the allocation of resources between competing uses at the farm level.

Intensive, often referred to as "cost-route" studies, of cassava-based farming systems have been conducted and provide extremely detailed information on the production and role of cassava within a whole farm framework (e.g. Lagemann 1976). A feature of the cost route approach is that through frequent visits to a select group of farmers, an extremely detailed picture of cassava production sys-

[5]Baseline surveys will provide the researcher with evidence of the variability in the levels of pest incidences and management factors (and the level of confounding that exist between variables) and as a result an indication of the likely success if this approach is adopted.

[7]Some interesting statistical challenges may emerge in the analysis of the yield components of the cassava and the companion crop. Pearce and Gilliver (forthcoming) are developing statistical procedures related to the intercrop situation.

tems within an integrated farm framework may be developed. These studies are demanding on personnel, expensive and time consuming, and specific findings of the research are unlikely to be available for at least 2 years after the project is initiated. By that time, scientists and administrators will have already made their minds up as to what are research priorities, so such studies tend to be more noted for their interest as opposed to effectiveness in short-run research decision-making. However, the long-term payoffs from such studies in fostering collaborative research between scientists, in their training as to the realities of farm families and their farming systems are substantial.

Economic Analysis of Cassava-Based Intercrops

Competition and the Principle of Marginality

When two or more crops are grown on the same piece of land, with a given level of inputs and their growth cycles overlap, their production will be related in one of three basic ways (Fig. 2). The two crops may be *competitive*, wherein the output of one crop can only be increased at the expense of the other; or *complementary*, wherein an increase in the output of one crop will also bring about an increase in th production of the other; or *supplementary*, wherein the output of one crop tends to be independent of the output of the other.[a]

Within many "agronomically realistic" cassava-based intercropping systems it appears that the yields of the two crops tend to be biologically independent over normal ranges of plant populations. IITA (1976), for example, cites examples of cassava/maize intercrops where supplementarity existed in production. This particular relationship is most likely in those cases where the maximum demands on the environment by the two crops occur at different times. However, in most instances, increasing the output of one component crop, at the limit, is only achieved at the expense of the other. That is, the crops are competitive in the production system, which seems to be the situation, for example, when cassava is light stressed by the companion crop during the early stages of its growth. CIAT (1976, p. B-66), for example, reported a

[a]Heady (1952) provides an extensive presentation of production relationships.

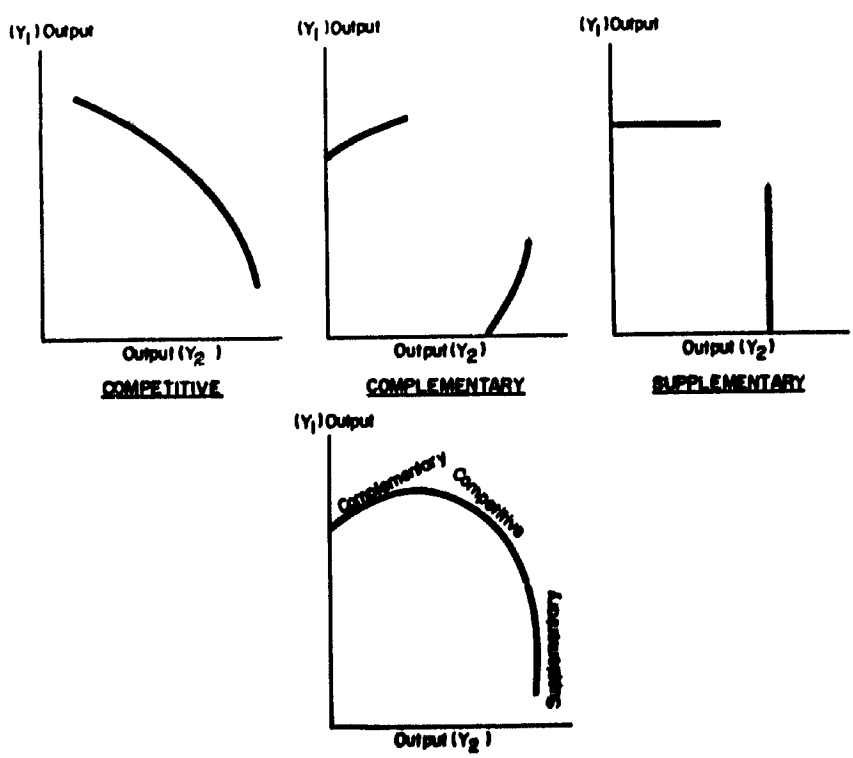

Fig. 2. Production possibilities for two crops, Y_1 and Y_2, in an intercrop.

competitive relationship for a series of cassava/bean intercrop.

Even if there tends to be a degree of biological independence between cassava and the alternative crop grown in the mixture under normal management practices, the farmer is still faced with the question of deciding:

(*a*) which crop is it "best" to grow in association with the cassava;

(*b*) what are the "best" populations of cassava and the companion crop to grow;

(*c*) what are the "best" combinations of other inputs (e.g. labour, fertilizer, insecticide) to apply to the intercrop?

The low resource farmer will tend to make these production decisions jointly and intuitively. However, the three have been separately identified for discussion purposes because although the farmer determines the cropping pattern and density of the component crops, to a large extent, the benefits from other inputs applied to the intercrop (e.g., fertilizer, weeding) are internally allocated to the component crops, not by the farmer, per se.

The "best" combination of crops to grow and inputs to use will depend on the objective(s) the farmer seeks to achieve by growing the crops, the resources available and the constraints that limit his choices and freedom in meeting his production objectives. In production, there are gains (the output produced) and losses (the inputs used to produce the crops), the net gain from the intercrop being the differences between gains and losses. Normally, the "best" combination of inputs is that which maximizes net gain, appreciating the limitations imposed on the farmer's freedom of choice. To estimate a meaningful net gain requires that both output (gains) and inputs (losses) are measured in the same units.

The unit of measure used to assess the productivity of a cropping system must satisfy several criteria (Hildebrand 1976, p. 349):

(*a*) it must be common to all products and inputs and provide a means of comparing different cropping systems;

(*b*) it must be relatively easy to measure;

(*c*) it must be capable of reflecting quality differences between the products; and

(*d*) the unit of measurement must be meaningful to the farmer in such a way that it helps him allocate his resources between competing uses.

In addition to the criteria prepared by Hildebrand:

(*e*) the unit of measurement must be meaningful to the researcher so he can compare new innovations with existing ones.

For convenience, indices of productivity may be classified as physical measures and economic measures.[9] The most commonly used physical units of productivity are energy, protein, and dry matter. These indices are extremely useful when measuring the gross physical output of a production process. However, problems arise when measures of net gains are required in these units as it is difficult to measure many inputs in the same physical units. Thus, while physical indices enable the gross output of intercropping systems to be compared over space and time, they are less useful when measuring net outputs. The most robust of the physical measures — for the low resource farm situation in particular — is energy, as both the food output of a cropping system and the major input under the farmer's control, i.e., his labour, can be reasonably measured in energy terms. As a result, the productivity of various agricultural systems have been compared in these terms (e.g., Makhiyani 1975).

However, the only index that meets all five criteria is the economic indicator of price or value, as reflected in the market price of the goods produced, and inputs or services used in production. For this reason, the measurement of gains and losses of cropping patterns used in this paper are in economic terms.

One weakness of the market price criteria, as previously mentioned, is that they may not always reflect the true values to the decision-maker of products and scarce resources. In these instances, opportunity costs or values should be used (this point will be revisited). What may be regarded as a further weakness of market prices is that prices differ between locations and change over time, thus making comparisons over space and time of cropping systems more involved.[10] Although this is true, it is also a strength of the market price criteria in the sense that it enables the economic combinations of inputs used and crops produced to be tailored to specific and changing economic conditions.

The theory that provides the basis for identifying the economically optimal combination of crops to grow and inputs to use is presented in several excellent texts (e.g., Dillon 1977; Heady 1952; Heady and Dillon 1961). These texts focus on the situation where crops are grown as sole crops, and where the manager can control the inputs allocated to the various production processes. However, the conditions for allocating resources in an intercrop where the farmer has little control of the allocation of inputs between crop components are not explicitly covered in these texts.

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[9]Excluding physical indicators such as land equivalent ratio, multiple cropping index, etc.

[10]Economists have means of adjusting values to remove time and space effects (e.g., Thomsen and Foote 1952).

Identifying the economically efficient combination of resources to use in an intercrop is conceptually straightforward; the decision-maker should keep using additional units of a productive input as long as the use of the added input earns or saves more money than it costs. That is, for the intercrop, it pays to add inputs so long as

$$\Sigma p_y \Delta Y_y > p_x \Delta X \quad \ldots\ldots 1$$

where ΔY_y is the increment in output of the yth crop component of the intercrop brought about by an increase in input use of ΔX; p_y is the field price per unit of crop Y_y; and p_x is the field price of the input X.

Because agricultural production is usually subject to diminishing returns to variable inputs (i.e., for additional and similar increases in X, smaller and smaller, and eventually negative increments in Y occur), the inequality in equation 1 will continually diminish until:

$$\Sigma p_y \Delta Y_y = p_x \Delta X \quad \ldots\ldots 2$$

and if excessive quantities of inputs are used,

$$\Sigma p_y \Delta Y_y < p_x \Delta X \quad \ldots\ldots 3$$

which implies that the added cost of the input exceeds the added value of output.

Equation 2, which identifies the economical level of an input to use, can be rearranged as:

$$\Sigma p_y \frac{\Delta Y_y}{\Delta X} = p_x \quad \ldots\ldots 4$$

where $\frac{\Delta Y}{\Delta X}$ is referred to as the "marginal product" of X. When the marginal product of an input as multiplied by the product price (i.e., the left-hand side of the equation), the term is referred to as the "marginal value product."

If there are many variable inputs in the production process, denote the ith input by X_i; equation 4 is then generalized to:

$$\Sigma p_y \frac{\partial Y_y}{\partial X_i} = p_{x_i} \quad \ldots\ldots 5$$

From the above, it is apparent that the optimal combination of inputs to use in an intercrop will depend on:

(*a*) the prices of inputs and products; and

(*b*) the biological relationships that prevail between the output of the crop components of the intercrop and the inputs applied to the cropping pattern.

The algebraic function used to describe the relationship between inputs used and the resulting physical crop production are referred to as "response" or "production" functions and may be empirically approximated from experimental and farm-based data (Dillon 1977, chap. 5).

In those situations where estimates of the underlying production function exist along with prices, the optimal levels of inputs to use in the intercrop can be quantitatively derived. To restate the necessary condition, it is beneficial to increase the levels of inputs to a production process until the value of their marginal product to the intercrop equals their prices.[11] The conditions, referred to as the "equimarginal principle," provide the underpinning to guide decision-makers on the optimal level of inputs to use and crop densities to establish,[12] and a procedure to assess whether farmers are using inputs at economically optimal levels (e.g., Mandac 1978; Sahota 1968; Shapiro 1976; Welsch 1965).

Although the production function approach provides the conceptual underpinning for efficient resource allocation, the author is unaware of examples of its successful empirical application to cassava-based cropping systems. Difficulties encountered when applying production function analysis to this rather complicated type of production process include the following:

(*a*) Normally, there are many products of value produced in the intercrop that may be harvested over an extended time period. For cassava, there may be roots, leaves, and stems. It is difficult to estimate production functions (and their interrelationships) for each of these products and crops;

(*b*) Some of the costs and benefits (e.g., soil depletion and conservation aspects) of alternative management strategies cannot be easily included in the analysis;

(*c*) Experiments designed to provide the necessary data to generate the response relationships are extremely expensive and time consuming to conduct (even if there are no statistical problems in estimating the response functions);

(*d*) The complexity of the experiments normally will require that they be conducted under experimental conditions, under the control of a researcher, not a farmer. Thus, the results obtained and inferences drawn are unlikely to be applicable to the farm situation; and

(*e*) Farmers are operating in an uncertain environment. Their preferred use of inputs will usually be less than identified as desirable in a riskless situation.

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[11] Unlike the sole crop situation, the marginal value product of an input in an intercrop situation is the sum of the marginal products of the component crops relative to that input.

[12] For an extensive and current bibliography of the application of these principles to resource allocation in agriculture, see Dillon (1977).

Budgeting

Although the concept of marginality provides the intuitive logic for designing what are hoped to be efficient combinations of input levels to apply and crop combinations to grow in the cropping pattern, researchers tend to rank the attractiveness of a discrete number of patterns and associated cultural techniques using the more direct budgeting technique. In this way, the net benefits of alternative technologies are ranked in relation to a number of choice criteria, where the appropriate criterion is that which maximizes the productivity of the system in relation to the most limiting factor(s) in the production process. The most commonly used enumerator is economic benefit, while commonly used denominators are land, labour, capital and, in some areas, water.

A procedure for evaluating the benefits of cassava-based intercropping systems is shown in Table 2.[13] In the format provided, the choice criterion is return per unit of land. The direct benefits from a cropping pattern will normally include the value of the primary components harvested, and probably a number of secondary products. The cassava yield used in the analysis, incidentally, should be that component of the total yield the farmer would be expected to harvest, not the total physiological production of roots as often reported in experimental work.

In most low resource farmer situations, labour costs dominate in terms of money costs and opportunity costs. Correctly estimating the opportunity cost of family (and exchange) labour is difficult. For family labour, the opportunity cost usually used for budgeting purposes is the wage that the person could earn in off-farm employment, the value of time if spent on another farm activity, and the value that the worker places on leisure. The last three values are difficult to measure in a partial context. As a rule of thumb, Perrin et al. (1976) assumed the opportunity cost of labour was 125% of the going agricultural wage in seasons when farmers were expected to be very busy, and between 50 and 75% of that rate in slack seasons. Of course, the opportunity cost of different members of the farm household may vary considerably, depending on the work alternatives available to them.

The budget in Table 2 generates net benefits per unit of land. Often this is not the most limiting factor in the production process. As a result, returns are normally computed per unit of land, labour, and capital. The outline in Table 3 provides a means of evaluating and comparing intercropping patterns in a nontime-discounted situation, in terms of various scarce resources, both as total inputs, and the return to selected resources during the period of greatest expected scarcity. These ratios enable the suitability of selected cropping patterns and management techniques to be evaluated and ranked under wide variations in factor supplies, and the most appropriate cropping patterns identified for specific situations.

The "timeless" procedure outlined above becomes limited when the elapsed time from planting to harvest is other than short term, or when different cropping patterns or management practices have input costs and revenues occurring at different points in time. Both these situations are typical of cassava-based cropping patterns, and when comparing cropping patterns that include cassava with ones that do not. Thus, it is appropriate to discount gains and cost to a common point in time to enable alternative cropping patterns to be compared on the same basis.[14]

There has been considerable discussion but little agreement in the literature as to what are appropriate discount rates to apply to the small farm situation (e.g., Lim 1975; O'Mara 1971). Each individual's discount rate will vary according to his time preference for consumption, his opportunity cost of capital, and his level of risk aversion; also, the appropriate discount rate may vary over time and for different decisions. These factors are difficult to quantify, but as a general guide it is likely that:

(*a*) poor farmers have higher discount rates than rich farmers;

(*b*) farmers with profitable investment alternatives, or stringent necessities, have higher discount rates than others; and

(*c*) farmers who live in a natural environment that imposes high risks on them will have greater discount rates than others.

Perrin et al. (1976, p. 33) used a 40% discount rate in their analysis of (maize-based) cropping systems; the components were 20% riskless time rate of discount, and a risk premium of a further 20%. This (or most any other) discount rate can only be justified on intuitive grounds; many would claim the 40% is low and that the riskless time rate of discount to use for the low resource farmer should be closer to 50 or 100%. Further, although the riskless time rate of discount (often equated with the cost of borrowing capital) faced by different groups of farmers may be relatively easily estimated, the "risk premiums" may differ markedly between investment alternatives (i.e., cropping patterns) and farmers. However, the point is that the appropriate discount

[13]This budget presentation draws heavily on the concepts excellently presented by Andersen (1976) and by Perrin et al. (1976) and adopts their terminology in an effort to highlight the differences between market prices and opportunity prices.

[14]See Chisholm and Dillon (1966) for a detailed treatment of discounting procedures.

Table 2. Structure of budget to assess the benefits of alternative cassava-based cropping systems.

A. Benefits	Unit	Harvested primary		Components secondary		Total
Crop 1: Cassava (for example)		*Roots*		*Leaves*		
1. Anticipated market or opportunity price (recognizing quality)	$/kg					
2. Harvest costs of labour[a]	$/kg					
3. Transport costs	$/kg					
4. Marketing costs	$/kg					
5. Other postharvest costs (specify)	$/kg					
6. Hired labour[b]	$/kg					
7. Family labour	$/kg					
8. *Net unit value of cassava*	$/kg	1-(2 to 7)		1-(2 to 7)		
9. Average field yield of cassava	tonnes/ha					
10. Harvester's/owner's share	kg/tonne					
11. Transport and storage losses	kg/tonne					
12. *Net field harvest to cultivator*	tonnes/ha	9-(10+11)		9-(10+11)		
13. *Total value of net harvest, cassava*	$/ha	12*8	+	12*8	=	A
Crop 2: Maize (for example) *(Repeat elements 1 to 12)*		Grain		Nil		
13. Total value of net harvest, maize	$/ha	12'*8'	+	Nil	=	B
14. *Total field value of cropping pattern*						A+B

B. Costs that vary between technologies[c]

Activity	Unit	Field costs ($/ha)[d] Net money Price	Net money Cost		Net opportunity Price	Net opportunity Cost	Total
Land preparation							
Family labour	man-d/ha				-	-	-
Hired labour	$/ha	-	-				-
Equipment use	$/ha	-	-	or	-	-	-
Planting							
Cassava sticks	$/ha				-	-	-
Maize seed	$/ha	-	-				-
Family labour	man-d/ha				-	-	-
Hired labour	$/ha	-	-				-
Pesticide (specify)	$/ha	-	-				-
Other (specify)	$/ha						
(Repeat the above for other field activities, e.g. weeding, cultivation, thinning, fertilizer, plant protection.)							
15. *Total variable cost of cropping pattern*	$/ha		____		+ ____	=	C
16. *Net benefit of pattern*	$/ha						GM

[a]Harvest and related cost usually related to harvest volume, and may vary by cropping pattern.

[b]The real cost of hired labour will often include a wage cost and an imputed cost representing the value of meals provided to the labourer by the farmer.

[c]The dash (-) indicates whether the field cost will more likely be a money or an opportunity cost.

[d]Net field costs are market price plus credit/interest charges, transport storage, costs, etc. The net field cost may be budgeted as follows:

Item	Unit	Price/kg
1. Market price of input	$/kg	
2. Less price discounts	$/kg	
3. Transport charges	$/kg	
4. Credit/interest	$/kg	
5. Storage	$/kg	
6. Other	$/kg	
Net unit price/cost	$/kg	1-2+3+4+5+6

Table 3. Estimating returns to factors of production.[a]

Factor	Specific return	Method of calculation
Land	$/ha	As per Table 3 (GM)
	$/$ land	(GM)/land rent
Labour	$/man-day	(GM + total labour cost)/total man-day
	$/family labour man-day	(GM + family labour cost)/family labour
	$/man-day of peak lot[b]	(GM + labour cost in nonpeak period)/ total man-days in period
Cash	$/$ cost	(GM + variable costs)/variable costs
	$/$ money cost	(GM + money costs)/money costs
	$/$, cost constraint[c]	(GM/total cost) cost in period

[a]After Norman and Palmer-Jones (1976, p. 252).
[b]Period when labour limits output.
[c]Cash constraint by supply and demand.

rate for low resource farmers is certainly higher than the 5–10% often used in budget analysis.

The example in Table 4 illustrates the impact of different discount rates on the present net benefit of two hypothetical cropping patterns. The first cropping pattern may be based on a three-crop sequence (e.g., maize–legume–maize), the second on a maize–cassava intercrop The differing occurrences of revenues and costs reflect different time sequences of activities. In the example, cropping pattern B has a higher net benefit than cropping pattern A up to a discount rate of about 40%; at discount rates higher than this, pattern A has the higher net present value.

Normally, a number of choice criteria (as listed in Table 3, which should be discounted to present values) are used to evaluate the potential of new cropping patterns. In addition to these, Banta (1978) argues that for a cropping pattern to have a clear advantage over existing systems it should:

(*a*) have a (discounted) net benefit at least 30% higher than the present pattern;

(*b*) the return per unit of labour must exceed its opportunity cost; and

(*c*) the (discounted) net benefit of the pattern should be sufficient to pay the cash costs of another cycle of that pattern.

Perrin et al. (1976, p. 19) also argue that before a new technology can be judged superior to existing ones it should also have:

(*d*) a marginal rate of return on capital, in relation to the current practice, of at least 40%.[15]

Variability of Net Benefits

Average yields (adjusted for harvest and storage reductions) are normally used to evaluate the ben-

[15]The marginal rate of return on capital is

$$\frac{\text{(net benefits of new technology — net benefit of old technology)}}{\text{(variable costs of new technology — variable costs of old technology}} \times \frac{100}{1}$$

or

$$\frac{\text{incremental benefits}}{\text{incremental costs}} \times \frac{100}{1}$$

Table 4. Discounted values (*$/ha*) of two hypothetical cropping patterns.

Time period (*months*)	Pattern A Benefits	Pattern A Costs	Pattern A Net benefit	Pattern B Benefits	Pattern B Costs	Pattern B Net benefit
Stream of benefits and costs						
1-3		120	-120		150	-150
4-6	300	150	150	300	50	250
7-9	350		350			
10-12		90	-90			
13-15	300	30	270	500		00
Discounted present value of benefits and costs						
Discount rate						
0	950	390	560	800	200	600
20	809	378	431	663	188	475
40	697	308	389	558	178	380
60	606	284	322	475	168	307

efits of alternative intercropping systems, thereby ignoring the yield variability of the practice resulting from differences in weather year to year, differences in response over space (sites), and differences due to farmer management. The most rudimentary way of accounting for the adverse effect of uncertain yields, as mentioned, is to add a risk premium to the cost of capital used in the budget analysis to ensure a conservative estimate of benefits. This approach is not selective when examining the riskiness of economic returns between cropping patterns.

The usual way that output variability of cropping practices is compared is in terms of their means, and some measures of dispersion of the means. From these statistics, it is possible to calculate (among others):

(*a*) the minimum level of net benefits for guaranteed levels of probability;

(*b*) the probability of achieving minimum defined levels of net benefits;

(*c*) the probability of losses of given magnitudes, for each cropping pattern being evaluated. If the distributions can be reasonably approximated by normal distributions then the above estimates can be derived directly using standard probability tables. If the distributions of net benefits are skewed, which seems to be the more common case (Day 1965; Roumasset 1976) then it may be easiest to plot out the frequency distributions of the observations and to derive the probabilities from these figures.

Table 5 provides an example of an analysis of the net benefits of three hypothetical cropping patterns in terms of the variability criteria. Cropping pattern A for example, may be the farmer's current practice, with B and C two proposed patterns. Both B and C appear attractive when compared to A from a net benefit viewpoint, with C being superior to B. However, the variability of expected returns of C is higher than B, and although there is a higher probability of larger gains with C, there is also a higher probability of loss. On this basis, if the farmer is risk adverse, he may prefer pattern B to C, although it has a lower expected net benefit. The problem is, it is not clear what are individual tradeoffs between higher expected gains with the probability of being worse off on some occasions, and lower expected gains with less chance of an adverse outcome.

Indeed, Dillon (1977, p. 103) points out that although the above approaches have intuitive appeal for appraising risky outcomes and ranking alternatives, they are somewhat arbitrary and "without logical foundation in decision making." The decision theoretic approach based on the maximization of expected utility provides the most rigorous basis for risky choice (Anderson et al. 1977). This approach, however, has not been widely applied to the evaluation of cropping innovations in developing countries partly because of difficulty and stability in estimation and a lack of understanding of the utility functions of low resource, transitional farmers.

A more general appraisal of the attractiveness of a technology vis-a-vis others that does not require a knowledge of the farmer's utility function is possible using the rules of stochastic dominance (Andersen 1974), wherein cropping patterns are identified that have a greater probability of a higher net benefit at all levels of net benefit than alternative patterns. The first-order cumulative probabilities for the three hypothetical cropping patterns illustrated in Table 5 are shown in Fig. 3. Pattern B is "risk efficient" when compared to pattern A, because its cumulative probability distribution is always to the right of A. Thus, pattern B is always better than A, and would be preferred by decision-makers who prefer a higher net benefit to less. Pattern C, although having a higher mean net benefit to A and B, in some situations, will have lower net benefits (i.e., the curves cross over). Thus, although unqualified statements about the relative merits of C versus A or B should not be made, the probability of C being superior to the former patterns (i.e., 91% and 80% of time) can be identified, and statements made on this basis. In most situations, and as demonstrated in Fig. 3, stochastic dominance if strictly applied is

Table 5. Comparison of hypothetical cropping patterns based on means and measures of variability.[a]

		Cropping pattern		
	Units	A	B	C
Mean net benefit	$/ha	80	120	150
Standard deviation[a]		10	24	60
Coefficient of variation	%	12	20	40
Min. benefits with probability of 90%	$/ha	57	88	70
Min. benefits with probability of 80%	$/ha	71	99	98
Min. benefits with probability of 70%	$/ha	75	107	118
Probability of at least $80/ha	%	50	93	86

[a]Assuming 15 degrees of freedom for *t* distribution.

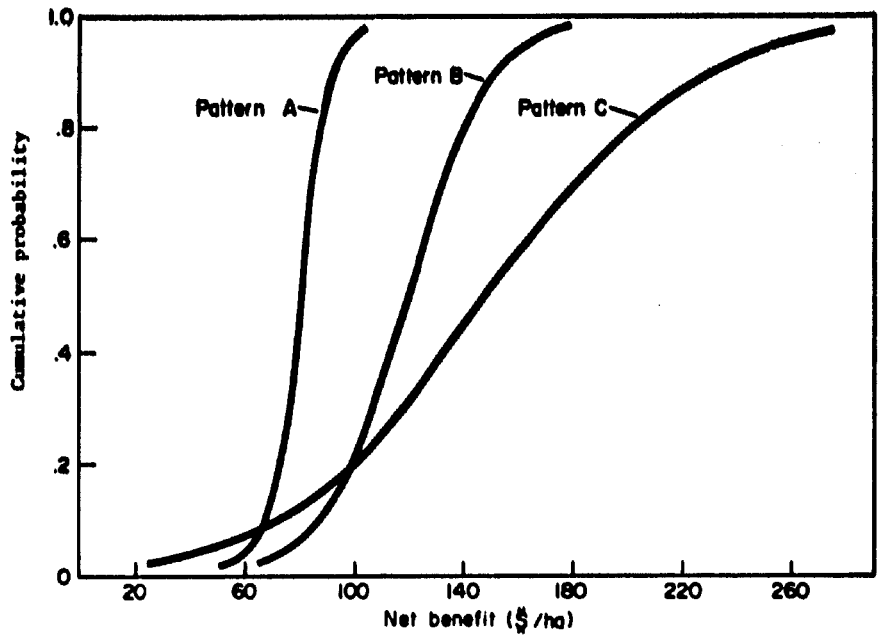

Fig. 3. Illustration of the principle of stochastic dominance.

not a discriminating criterion, since the cumulative distributions of the alternative cropping patterns may cross more than once.

"Minimum return analysis" provides a working approximation to the concept of stochastic dominance (Perrin et al. 1976). The procedure compares the worst 25% of the net benefit of each proposed practice (and the average of the worst 25%) with the worst 25% of the outcomes from the current practice (and the mean of this quartile). If the proposed practice is worse than the current practice on either count, then its relevance and the reason for this poor performance should be examined.

Whole Farm Analysis of Cropping Alternatives

Budgeting procedures, supplemented by returns to the scarcest resources and by measures of variability, in the majority of cases provide the end point for the economic analysis and comparisons of new innovations within cropping systems-oriented programs. The procedures have the strength of being relatively simple and are usually sufficient to identify new cropping patterns and management techniques that have a real chance of being adopted.

However, the users of budget analysis also recognize that the approach is partial and does not consider the relevance of innovations within a whole farm framework. To this extent, budgeting in the manner presented suffers from the following limitations:

(*a*) the correct evaluation of opportunity prices for resources that have distorted market prices — often land, labour, and capital — is difficult;

(*b*) the comparison of two (or more) alternative cropping patterns does not identify the most appropriate way for resources to be allocated between these and other uses; and

(*c*) it is difficult to judge whether the input requirements for the technology are managerially feasible, given the farmer's resource base and the alternative uses to which the family commit these resources.

One way of internalizing many of these questions is to analyze the proposed and existing production opportunities at the same time in a simulated whole farm family framework. These models are designed to reflect the resource base of the farmer, his objectives, and his committment of resources and produce to the needs of the family, the farm, nonfarm activities, and the market. Generally speaking, there are two types of models designed to simulate the family and farm.[16] There are those models that are essentially designed to evaluate the feasibility of selected

[16]Vincent (1977) discusses the application of mathematical models to simulate small farmer decision-making.

new practices (e.g., Zuckerman 1973) and those that are designed to select a combination of practices that will optimize some suitably chosen (and constrained) objective function.

Linear programing is the most widely used optimizing technique in the latter regard and provides a conceptually straightforward approach for the whole farm analysis of currently used and proposed cropping systems. The direct benefits of each activity included in the programing model are derived using budgeting techniques in a manner described in the previous section. As a result, average values are used in most linear programing models when estimating the benefits of each production process. However, with ingenuity, the basic model can be modified to take account of stochastic elements, most easily in the benefit function.[17] Arifin (1978), Barlow (1977), Benito (1976), Heady and Agrawal (1970), McCarl (1978), Schluter (1974), and Thodey and Rapeepum (1974), among others, provide examples of the application of linear programing and its extension to the low resource, multiple cropping-based farm.

Farm Level Evaluation of Technology

The framework for cassava intercropping research presented earlier in the paper recommended that improved production practices should be identified from on-farm evaluation of promising cropping patterns and cultural practices. Normally, the on-farm evaluation will include a sequence of trials, the farmer's testing of the technology, and an evaluation of the technology after it has been recommended to farmers.

Zandstra (1978) discusses the logic and conduct of on-farm trials and refers to the extremes of on-farm testing as "research managed" trials and "cropping pattern" trials. Typical experimental designs, with small plots, are used for research-managed trials that are usually designed to evaluate a wide range of management alternatives. As a next step in the assessment, farmer field trials may be conducted using the farmer's land and labour but the management input (and risks) borne still by the researcher. The number of alternatives considered in these trials should be few because it is necessary to obtain:

(*a*) an idea of the variation of treatment outputs that require emphasis on replication over the environment being studied;

(*b*) an impression of the desirable characteristics, limitations, and difficulties experienced by the farmer when implementing the proposed technique; and

(*c*) the farmer's impression of the technologies, which is difficult for him to do adequately if there are a large number of treatments.

The results of the farmer field trials should be carefully evaluated for economic and management relevance before the best alternatives are chosen to go forward for farmer field testing in cropping pattern trials. This evaluation in part will be a comparative one between the farmer's current cropping patterns and practices and new ones designed by the collaborating researchers. Thus, whether the results are included in budget analysis alone, or extended to a whole farm evaluation, they need to be examined for their relevance in the reality of a farm-managed situation as opposed to the somewhat stage-managed trial conditions. Thus, the analyst is faced with the challenge of deciding in particular:

(*a*) how much should yields be discounted to reflect that they are still "experimental" yields and not really "farmers'" yields;

(*b*) what should the labour coefficients be for the various production practices, as labour estimates derived from experiments normally overestimate what would be the farmer's practice;

(*c*) what will likely be the level of use of other inputs (e.g., fertilizer, insecticides); and

(*d*) what will be the equipment used, and its performance were the practice applied by farmers.

Obviously, no hard and fast adjustment rules exist for these points. Sensible adjustment of these figures requires that the research is familiar with farmer practices, conditions, and performance rates, and understands how and why farmers have adapted other recommendations to suit their own conditions.

Finally, the best alternatives identified through the analysis of the field trials should be tested in cropping pattern trials using the farmer's resources and management, with the cropping pattern under test competing with other activities for the farmer's resources. The cropping pattern trials are normally field size, with one pattern per collaborator. As with the farmer field trials, replication of the cropping patterns over the region of interest is important to enable the yield variability of the practice to be estimated.

To assess their suitability as improved methods of crop production, the cropping patterns should be evaluated in terms of:

(*a*) their technical feasibility — if it failed at this late stage of the screening process, why?

(*b*) profitability and dependability when expressed in terms of the most limiting resources;

[17] It is beyond the scope of this paper to discuss the weaknesses, merits, and extensions of linear programing models. In this regard, the interested reader is referred to Hardaker (1975).

(c) the compatibility of the innovation with the farmer's overall farming system;
(d) social acceptability; and
(e) whether the innovation is realistic given the institutional and infrastructural realities in the target area.

Any alternative that is positive in relation to the above five criteria should have a reasonable chance of being adopted by farmers if extended to them. Flinn and Lagemann (1976) provide an example of the evaluation of a proposed technical innovation based on the above criteria. Their study also demonstrates the value of the appraisal being a joint one between the various scientists involved in the research project and the farmer.[18]

Often the researchers who designed the technology and the extension workers who have the responsibility of disseminating it come from different agencies of government or different departments within agencies. The collaborative design, conduct, and evaluation of the farmer field trials and cropping pattern trials provides an excellent focus for these two groups to work together and to jointly contribute to the formulation of the extension recommendations for the new technology.

During the extension of new innovations, an impression of farmer acceptance of the new technology is of value to help assess the success of the technology; who and why certain farmers and not others have adopted it; and how and why farmers have adapted recommendations to suit their individual conditions. The inferences drawn from such evaluation studies can contribute to the identification of future research objectives and designs, the modification of extension recommendations related to the practice, and the effect of institutional backup to the technology. Okali and Bortei Doku (1978) provide an example of an early evaluation of a cassava-based intercropping system, and demonstrate the importance of on-farm and off-farm factors that influence the farmer's adoption of the recommendation.

Summary

Research aimed at developing improved cassava-based cropping systems should be based on an understanding of why specific cassava-based cropping patterns prevail. This implies a knowledge of the reasons why farmers manage their crops in the way they do, and an appreciation of the agronomic, economic, and social advantages and disadvantages of the cropping systems it is hoped to change. Such information is best gained through the researcher having first-hand contact with the farmer and his environment. Farm-focused studies designed to generate this information should be collaborative between, for example, an agronomist, farm management economist, and pest management scientist if they are to most effectively influence research requirements and design.

The normal bioeconomic relationship that prevails in cassava-based intercrops is one of competition. That is, after some point, the yield of one crop in the mixture can only be increased at the expense of the other. The combination of inputs that will result in net benefits being maximized for the cropping pattern is when inputs are used to the point where the value of the increment in output of the intercrop is equated with the per unit value of the input.

The most usual and practical way of evaluating the relevance of proposed cropping patterns and cultural techniques is through budget analysis focusing on the return to the farmer's most limiting resources, and the variability of these returns. Often the market prices for some of the most important inputs for the low resource farmer — particularly family labour, capital, and land — poorly reflect their scarcity value to the farmer, which implies that these inputs should be valued at their opportunity costs. When resources and time permit, the alternatives may be evaluated within a whole-farm framework, which to some extent reduces the researcher's need to estimate opportunity values as they are internally generated.

The evaluation of new innovations should be derived from results that resemble farm conditions as closely as possible. Such conditions are best achieved by conducting the cropping systems research on farmer's fields. This component of technology development and assessment will ideally involve a range of activities from research-managed trials through to the joint evaluation of proposed extension recommendations by farmers, scientists, and extension workers. Postadoption studies provide links to the research and planning process to enable their activities to be more efficiently directed to the real constraints to production faced by farmers.

[18]Often, farmers, either through courtesy or self-consciousness, are not as openly critical to the scientists of an innovation as they might be. The real test of the innovation, of course, is whether the farmer adopts it on a continuing basis after the researcher ceases to work on his farm.

Acknowledgments

With the usual caveats, the author is grateful to Sisira Jayasuriya, R. W. Herdt, and Joyotee Smith for their comments on an earlier draft of this paper.

Agronomic Implications of Cassava–Legume Intercropping Systems

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Cassava has slow initial growth and usually covers ground only 3 months after planting. During this initial phase, light and other resources are poorly utilized by cassava in monoculture. Hence, intercropping a fast ground covering, short stature, and short cycle crop such as beans could improve the cropping system's total per hectare and per year productivity.

Considering the nutritional aspects, the cassava-bean association is of particular interest as it produces energy and protein at the same time. Besides the dietary advantage, several agronomic advantages are also likely to result from cassava–bean intercropping. The rapid ground covering characteristics of bush beans provide an early green cover to cassava that may prevent both erosion and excessive loss of soil moisture. At the same time, where beans occupy the space between cassava, none is left for weeds, i.e., the system is likely to have weed-suppressing characteristics. Finally, with few exceptions, beans and cassava suffer from different insect pests and diseases. Therefore in an intercropped stand, a single pathogen or insect pest does not find the uniform substrate that a monoculture provides that enables the pest to multiply and acquire epidemic dimensions. As a result, generally lower pest damage is likely to occur in the mixed stand.

Considering these advantages, the number of Colombian farmers who grow cassava and beans together is surprisingly small. As a mean of five zones of the Colombian territory, only 5% of cassava growers use beans as associated crop (Diaz and Pinstrup-Andersen 1977). This may be explained by the limitation in temperature ranges where the two crops grow well, cassava needing a level of 18 °C or above and bush beans 20 °C or below for good productivity. Also, beans lack the adaptation to acid, infertile soil conditions that cassava possesses. Most likely, cassava–grain legume intercropping systems could acquire a much broader application if grain legumes with an adaptation range similar to that of cassava were used.

In this paper, I wish to explore agronomic possibilities and limitations of cassava–grain legume intercropping, including the use of legume species other than field beans and to point out lines of research that we feel have to be carried out to fill the present gap of knowledge.

Planting Time — Seasonal Effects

In many parts of the tropics, cassava planting is not limited to a single date, plantings being usually carried out whenever moisture conditions allow.

According to Teixeira (1949), traditional planting time for cassava in Campinas (Brazil) is October. However, good yields were also obtained from May plantings. In a communication by Albuquerque et al. (1974), results from 3 years of planting date trials conducted in Paraná State (Brazil) are reported. The author states that cassava planting should be avoided from October to January, but for the rest of the year, no limitations as to planting date were found.

In Colombia, cassava is planted and harvested throughout the year (Vega et al. 1968). The bimodal rainfall distribution prevailing in vast areas of this country allows for two major planting seasons, the first being April to June and the second September to November. Yield trials conducted on the Colombian North Coast and in the Eastern Plains showed no significant differences in fresh root yield between May and September plantings, although dry matter yields tended to be slightly higher with September-planted cassava (Kawano, personal communication).

The observations suggest that in tropical Latin America cassava does not encounter fundamental planting date limitations during a major part of the year.

An entirely different situation is that of field beans. Without irrigation, bean yields are not only strongly influenced directly by the moisture regime but along with this by a complex of insect pests and

diseases being either suppressed or favoured by certain precipitation levels. This results in characteristic seasonal yielding patterns.

Such a yielding pattern of monocropped field beans was observed in Popayán, 160 km south of CIAT, in one year, but it was the opposite in the following year (Fig. 1 and 2)(CIAT 1975, 1976), suggesting that there is no consistency of seasonal yield trends in field beans.

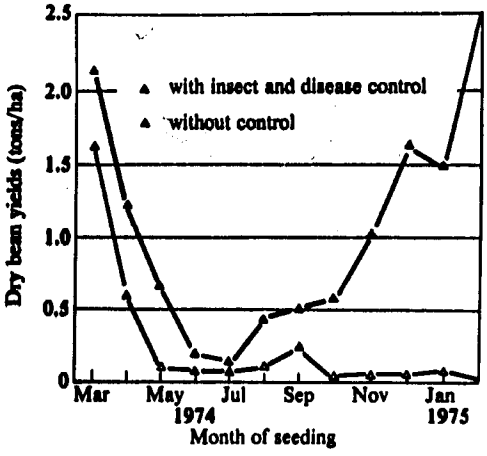

Fig. 1. Effect of month of seeding on yields of bean variety ICA Tui grown with or without control of insects and diseases, Popayan, 1974-75. Source: CIAT Annual Report on bean production systems, 1975.

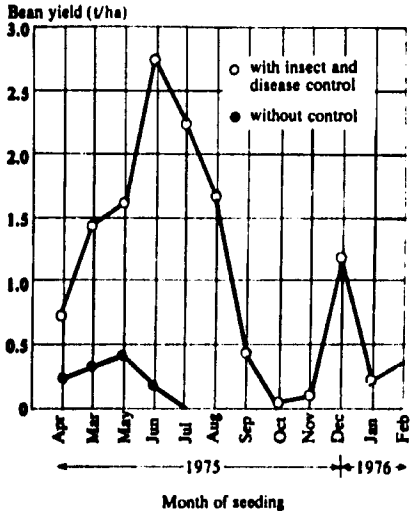

Fig. 2. Effect of month of seeding on yield of Guali beans grown with and without control of insects and diseases, Popayan, 1975-76. Source: CIAT Annual Report on bean production systems, 1976.

In cassava-based intercropping systems, it may therefore be necessary to adjust the cassava planting date to the period optimal for field beans in case beans are used as an associated crop. This appears feasible given the planting date flexibility of cassava. However, cassava-legume intercropping could be made a much more versatile option and would fit better into more complex cropping systems if the legume associated with cassava had a flexibility similar to cassava regarding its planting date.

More flexibility appears to be given with peanuts (*Arachis hypogaea*), for example. In a peanut cultivation manual for Colombia, the authors mention two possible planting periods, March–April and September–October. Furthermore, they report the most commonly grown peanut cultivars to have a temperature adaptation of 24–29 °C mean temperature and good drought tolerance. All these characteristics together give ample scope for dates of associated planting.

Cowpeas (*Vigna unguiculata*), grown as monocrop in two seasons in Nigeria (IITA, 1975), showed little response of yield to planting seasons, yields being 1678 kg/ha in the first and 1311 kg/ha in the second season (mean of seven varieties). This indicates that cowpeas, too, may have a low planting date sensitivity, although seasonal yield losses are known to occur due to unfulfilled daylength requirements, for example, in the case of specific cultivars.

It may be concluded that the more tolerant a grain legume is of the local stress complex, the smaller will be its yield fluctuation at different planting dates and consequently its flexibility will increase with respect to planting season. Combining largely planting-date independent cassava with a grain legume of similar characteristics appears to be a desirable agronomic practice that would allow this intercropping system to fit into complex crop sequences.

Planting Time — Relative Planting Date

Our data have indicated that simultaneous planting of cassava and beans gives satisfactory results under the CIAT experimental farm conditions when a particular genotype of cassava and field beans was used (Thung and Cock 1979). However, one might suspect that in different environments, i.e., at different temperature, precipitation, and soil fertility levels, or using other genotypes of cassava or other grain legume species, the developmental pattern of the individual crop is changed, which in turn changes development and growth of one component relative to the other. In general, plant growth in a cassava-legume intercropping system is considered optimum when the cassava canopy stays slightly on top of the associated crop. Although small periods

of competition for light are unlikely to affect cassava yields, a prolonged shading by the legume may reduce cassava yields considerably (Table I) (Cock, personal communication). On the other hand, grain legume yield is seriously affected when the legume is planted too late, being shaded by cassava (Thung and Cock 1979).

Measuring the canopy levels of three legume species, cowpea, mungbean (*Vigna radiata*), and peanut, relative to cassava when legumes were planted 15 days before cassava, simultaneously, or 15 days after cassava, it was observed that the optimum relative planting date was highly dependent on the growth habit of the legume species (Fig. 3).

Table 1. Effects of early shading on cassava fresh root yield. A shade intensity of 50% was applied in each treatment.

Shading period (*weeks after planting*)	Relative yield, %
Unshaded control	100a[a]
0–3	98a
3–6	96a
6–9	98a
9–12	98a
0–12	76b

[a]Figures with the same letter are not significantly different at the 5% protection level, using Duncan's multiple range test.

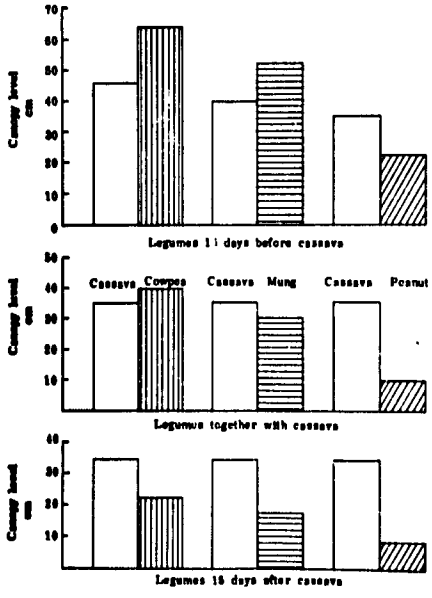

Fig. 3. Canopy height levels of cassava and three grain legume species at 50 days after cassava planting. Three relative legume planting dates. Source: Cassava cultural practices program, CIAT, 1978.

These observations were made at CIAT on fertile soil, with 24 °C mean temperature. At CIAT-Quilichao, a station not far away from the headquarters with similar mean temperature but highly infertile soil, cowpea growth was more depressed than that of cassava and hence a simultaneous planting with cassava was best.

These observations demonstrate that the relative planting date in cassava–grain legume associations may have to vary from the general rule of simultaneous planting, depending on cassava genotype, legume species, and environment.

Determination of the correct relative planting date, however, is critical as it influences greatly the initial competition situation and consequently yield of the associated crops. Further investigation in this area should therefore provide data to handle this aspect with the greatest possible precision for different genotypes, species, and environments.

Spacing

In row-planted crops the term "spacing" comprises both the plant population or density aspect and the planting pattern as distances between rows and intrarow plant spacing determine both the number of plants per unit area and the spacial arrangement. In traditional intercropping systems, farmers tend to decrease plant densities below the monocropping level they are used to. This is justified when limitations in soil moisture or nutrients do not support higher stand densities, but it makes traditional intercropping an extensive system with low productivity. On the other hand, ample information exists on the influence of planting density on yield of intercropped food plants, indicating that when resources are not so limiting, the closer the population densities of the associated crops get to their respective monoculture levels, the greater are total yields due to an optimal utilization of the resources complex (CIAT 1974, 1975; Desir and Pinchinat 1976). In the cited references, grain legumes and maize planted in intercropping at the same high density as in monoculture had the greatest yield.

Although cassava was not used in these trials, we now have strong indications that cassava, too, needs to be planted at about monocrop densities in intercropping systems to obtain maximum total production. Good yields and highest land equivalent ratios have been obtained in cassava–bean intercropping trials with both beans and cassava at their optimum monoculture plant populations (CIAT 1977).

Turning to the spacial arrangement aspect of spacing, it should be noted that currently the most widely used planting pattern for cassava monocropping, 1 × 1 m, is likely not to be the optimum in an intercropping system as equally spaced cassava produces complete ground coverage earlier than other arrangements and thus shades any underseeded crop earlier than when other spacial arrangements were used. In particular, grain legumes associated with cassava would conveniently be row-planted between cassava, and both the planting and harvesting operation would be greatly facilitated in case a space wider than 1 m between cassava rows was provided.

Trials conducted at CIAT (CIAT 1977; Cock et al. 1978) have shown that there is no significant variation in yield when the spacial arrangement of cassava plants is altered from 1 × 1 m spacing to 2 × 0.5 m, or any other possible combination in between if the same plant population is maintained. Thus, it appears that cassava is very flexible regarding its yield response to spacial arrangement; different planting patterns may be used in intercropping systems without sacrificing major portions of root yield when the total plant population is maintained (Fig. 4).

An interesting alternative has been recently proposed by Brazilian scientists (Furtado et al. 1978). They suggest planting one double row of cassava, leaving a between-double rows space for intercropping while taking advantage of the two-sided border effect for cassava (Fig. 5). In view of our results from planting pattern experiments, this system should be perfectly feasible; in Brazil it has been reported to give cassava yields equal to or slightly greater than traditional planting systems (Mattos, personal communication).

In the grain legume area, data are extremely scarce on the yield response to planting patterns, specifically in intercropping systems. Data from an intercropping trial with beans and maize, conducted at CIAT, show that bean yields were not significantly affected, planting two single bean rows on each side of maize plants in one treatment, and one double bean row on one side of the maize in another treatment, with planting densities being kept at the same level (Fig. 6) (CIAT 1976). It may be assumed that beans and bean-like grain legumes are, like cassava, not very sensitive to changes in their spacial arrangement. Consequently, planting patterns may be arranged according to plant architectures in each specific combination and in agreement with practical convenience.

Practical convenience in some cases may even include attempts to partly mechanize the intercropping system. Since machinery already exists for planting and harvesting both cassava and grain legumes, it would probably only take some adaptive development of implements for this purpose. The

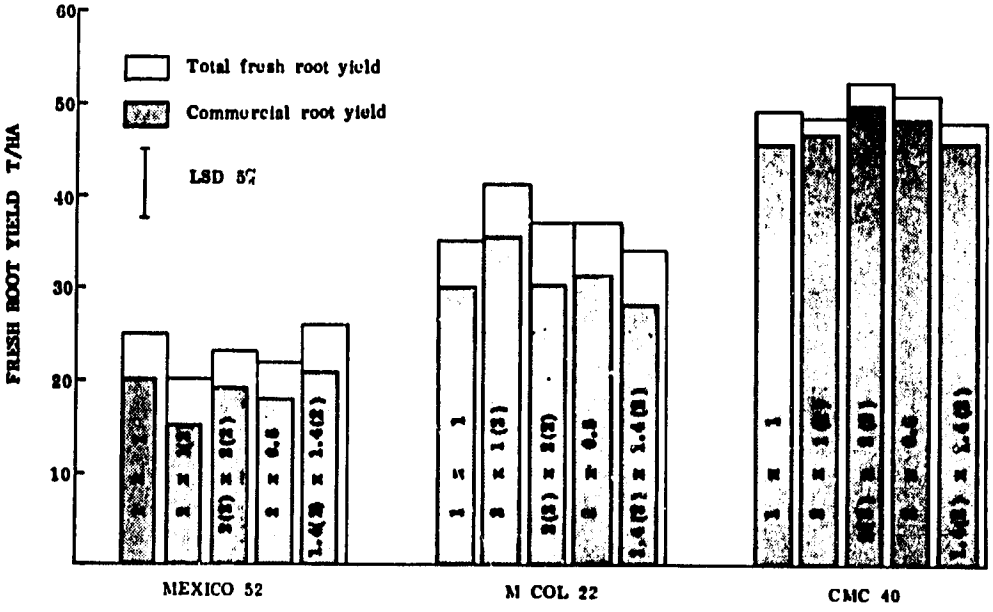

Fig. 4. Effects of planting patterns on total and commercial root yields of three cassava varieties at a standard density of 10 000 plants/ha, at CIAT, 1977. First figures in columns are distances (meters) between ridges, second figures are distances within ridges. Figures in parentheses are number of plants per site. Source: Cock et al. (1978).

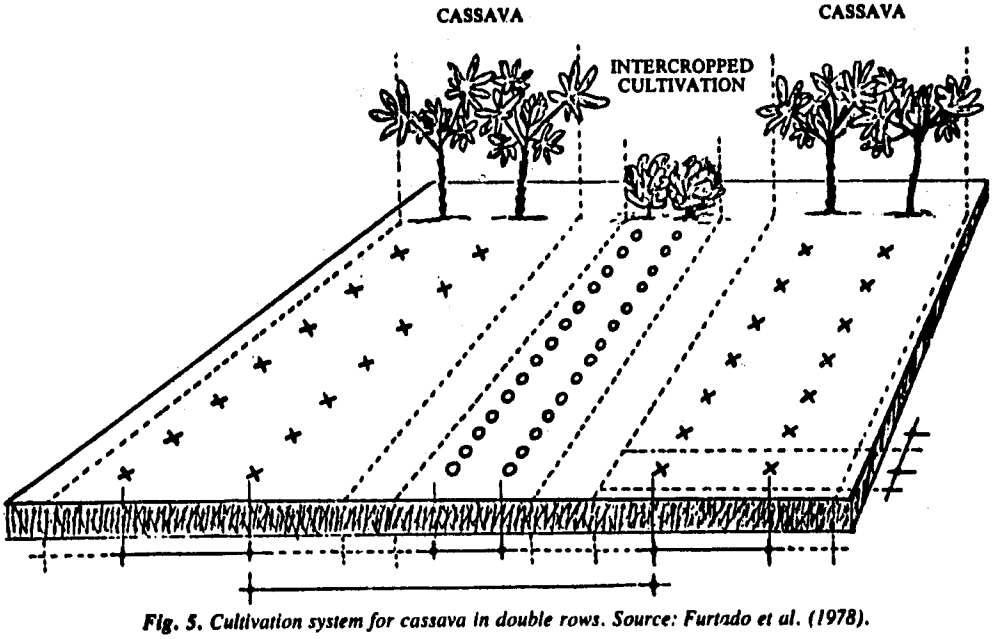

Fig. 5. Cultivation system for cassava in double rows. Source: Furtado et al. (1978).

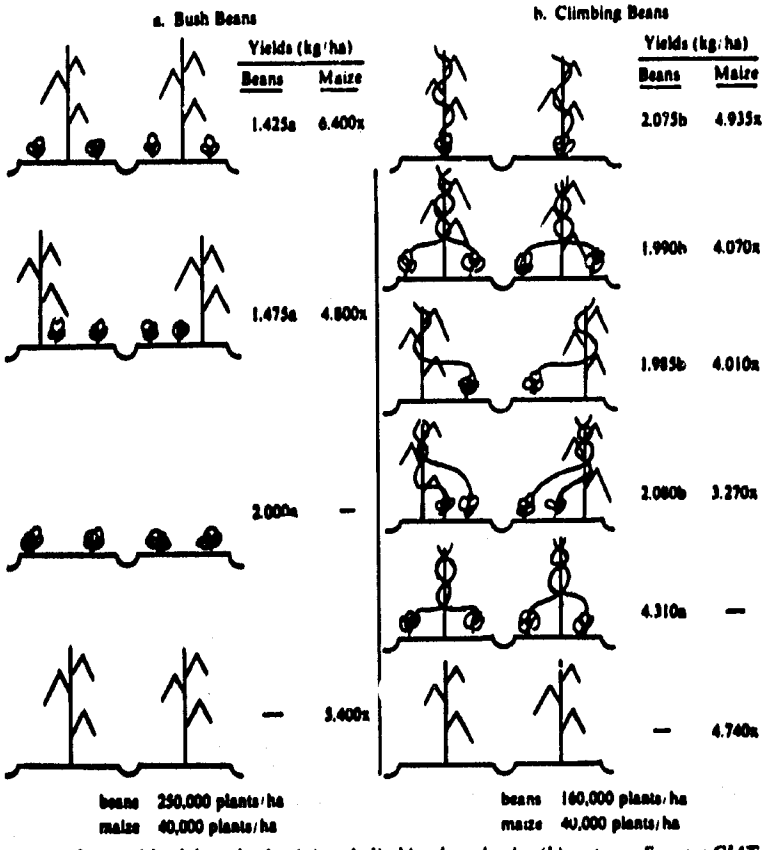

Fig. 6. Comparison of several bush bean/maize (a) and climbing bean/maize (b) systems. Source: CIAT annual report on bean production systems, 1976.

spacial arrangements that would facilitate mechanical planting and harvesting need to be established for each crop combination and type of machinery but the inherent flexibility of the cassava–legume intercropping system appears not to impose major limitations.

In regard to mechanizing the intercropping system, we wish to make clear that our efforts to improve intercropping technology, although primarily directed at the small farmer who produces food without purchased inputs, are essentially scale-neutral and applicable to the big farm operation and the small holding alike.

Crop–Soil Interactions

Cassava has been shown to give reasonable yields with a moderate fertilizer input even on highly acid, infertile soils (CIAT 1975; Cock and Howeler 1979). This tolerance of poor soil conditions is an advantage that places cassava high on the list of food production potential in those parts of Latin America where ultisols and oxisols occupy several million hectares. *Phaseolus* beans as the best studied intercropping partner for cassava do not share this important feature. Without high applications of lime and phosphorus, *Phaseolus* beans grown on acid, infertile soils, usually fail to produce grain at all (CIAT 1974). A successful cassava–legume production system for the acid infertile soils would therefore need to make use of other, more tolerant species. In trials conducted during 1972 at Carimagua, which is located on an infertile oxisol in the Eastern plains of Colombia, several cowpea varieties reached more than 90% of maximum yield at only 0.5 t/ha of lime (Fig. 7) (CIAT 1974). Another poor soil tolerant species that most likely would fit well into a cassava-based intercropping system is peanut. Good performance in monoculture on an oxisol at "La Libertad," Eastern Plains of Colombia, has been demonstrated by Instituto Colombiano Agropecuario (ICA). When 2 metric tonnes (t)/ha of lime were applied to a soil of low pH and P, and high in Al and Fe, up to 2.8 t/ha of unshelled peanuts were harvested (Varela, personal communication).

In Peru, both cowpeas and peanuts were intercropped with cassava during several years of multiple cropping research on acid, infertile soil. The complex relay-intercropping system tested involved

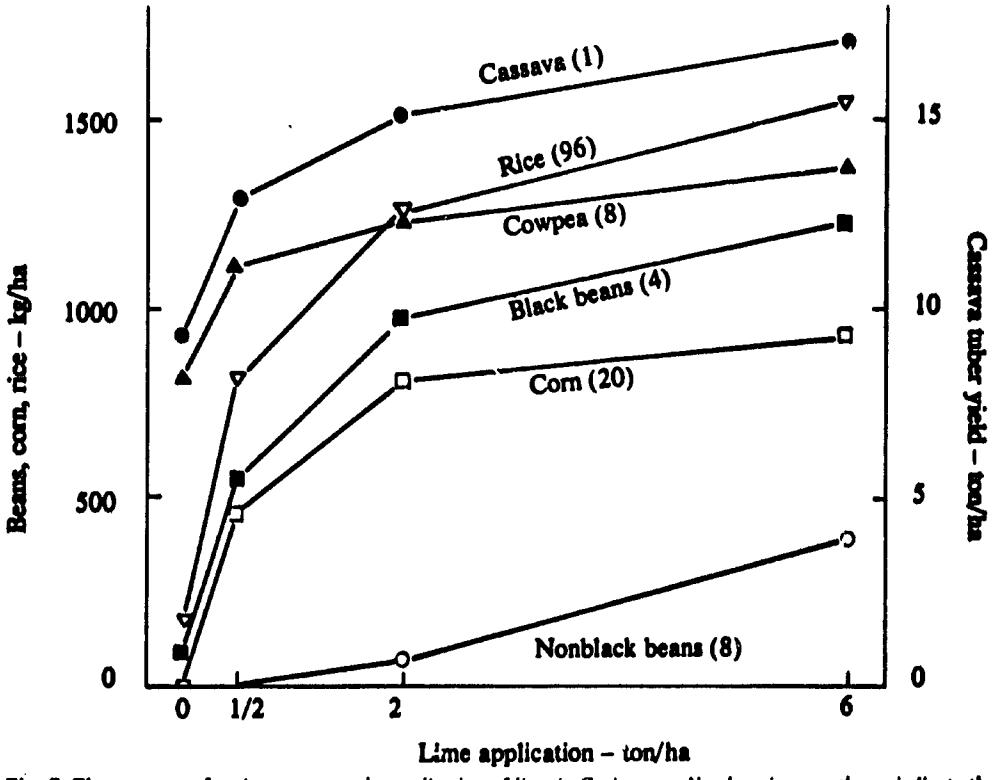

Fig. 7. The response of various crops to the application of lime in Carimagua. Numbers in parentheses indicate the number of cultivars tested. Source: Cock and Howeler (1979).

corn, rice, cassava, peanuts, and cowpeas (Fig. 8) (Wade and Sanchez 1976).

Yield of unshelled peanuts, which were planted early during cassava growth, was satisfactory, even when associated with closely spaced cassava (13 300 plants/ha, 1-m row system, Table 2). Cowpeas yielded low even when wide spacing was used between cassava rows (2-m and 3-m rows) as they were planted when cassava was older and consequently must have suffered serious competition. Despite adequate fertilization and optimal spacing in the 1-m row system, cassava yields were always below 18 t/ha in the intercropping systems, but besides reportedly bad weather conditions affecting this trial the inherent production potential of the variety used

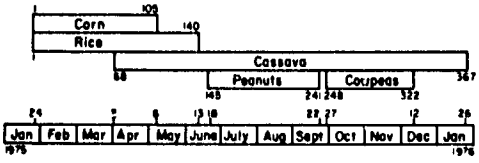

Fig. 8. Representation of the intercropped system in the N-row spacing experiment. Numbers at the corner of the boxes reflect the numbers of days from the start of the experiment, when a crop was planted or harvested. Source: Wade and Sanchez (1976).

may have been low as indicated by monocrop yields (Table 2).

It is interesting to note the negative yield response of cassava to N in the 1-m row plots, highest yields being obtained with 0 N. Apparently, residual N from the maize and rice crop plus fixed N from the legumes was sufficient and optimal for root yield formation.

We believe that due to the complex situation in the described system, the cassava–legume association could not express its full potential.

Concentrating on the cassava–legume system, a trial is being grown at CIAT-Quilichao, a station close to the Palmira headquarters with highly acid, infertile soil conditions. On a soil with pH 4.3, available P 2.5 ppm (Bray II), and 85% Al saturation of the base complex (Al = 4.2 meq/100 g soil) and with a fertilization of 0.5 t/ha lime and 100, 105, 35, 3, and 1 kg/ha of N, P_2O_5, K_2O, Zn, and B, cowpeas and peanuts in association with cassava produced grain yields of 1.9 t/ha and 1.5 t/ha, respectively, while the growth of a mungbean variety was severely disturbed by these extreme soil conditions and yield was less than 400 kg/ha.

The fertilizer levels used in this trial are tailored basically to the needs of cassava, the nutrient requirements of which on this type of soil are relatively

Table 2. Performance of intercropped systems as affected by row spacing of the tall crops and nitrogen rates. Monoculture comparisons are also shown. Yurimaguas, 1975. Source: Wade and Sánchez (1976).

Cropping system	Total N applied (*kg/ha*)	Grain or tuber yields (*t/ha*)				
		Rice	Corn	Cassava	Peanuts	Cowpeas
Intercropped, 1-m rows of tall crops	0	1.70	0.72	17.85	2.04	-
	45	1.78	0.83	7.91	2.43	-
	90	1.43	1.52	17.26	1.79	-
	180	1.39	1.14	15.12	1.75	-
	Mean	1.57	1.05	14.53	2.00	-
Intercropped, 2-m rows of tall crops	0	2.28	0.14	3.78	2.49	0.24
	45	2.01	0.51	7.96	2.62	0.24
	90	2.21	0.61	6.04	2.88	0.16
	180	2.37	0.61	6.62	2.95	0.31
	Mean	2.22	0.47	6.10	2.74	0.24
Intercropped, 3-m rows of tall crops	0	2.41	0.24	2.77	3.47	0.21
	45	2.20	0.31	5.89	2.85	0.33
	90	2.10	0.46	6.34	2.64	0.27
	180	2.12	0.58	7.50	2.56	0.43
	Mean	2.21	0.40	5.63	2.88	0.31
Monocultures, 0.75-m rows of tall crops	0	2.20	0.95	20.44[a]	3.94[b]	0.49[b]
	45	2.38	1.19	22.87	3.05	0.47
	90	2.39	1.73	17.36	3.13	0.51
	180	2.36	2.36	21.50	2.86	0.49
	Mean	2.33	1.56	20.54	3.25	0.49
	$LSD_{.05}$	0.68	0.36	6.88	0.95	0.11
	CV (%)	19.5	26.4	34.9	20.9	24.2

[a]Only half the rate was applied to monoculture cassava.
[b]Residual effect from rice monoculture application.

well studied (CIAT 1976). However, from the scarce nutrient requirement data of monocropped legumes grown under similar soil conditions, we feel entitled to assume that the modest quantity of lime applied in this trial, which we know satisfies most of cassava's requirements, will also be sufficient for acid soil-tolerant legumes. Small amounts of N appear to be optimal both for cassava root production and grain legume productivity under these soil conditions. On the other hand the somewhat higher P level that cassava needs to give an acceptable root yield, is also essential for good legume growth as initial P availability is one of the factors determining the establishment of symbiosis with *Rhizobia*. This indicates that cassava and acid soil-tolerant legume species like cowpeas have important parts of their nutrient requirements in common. We feel, therefore, that a cassava-legume intercropping system for acid, infertile soils is feasible but more has to be learned about suitability of species and cultivars for these conditions and their nutritional requirements under intercropping conditions.

Because the soils we focus on are poor in major potential and actual cassava-growing areas, an important aspect of research would be to explore the contributions that intercropped grain legume species could make to improve soil fertility. *Phaseolus* beans, besides being no choice for acid, infertile soils, have only an intermediate N-fixing capacity.

On the other hand, cowpeas, being well adapted to poor soils, have also outstanding N-fixing capacity (Table 3) (CIAT 1976). As a well-grown, high-yielding cassava crop extracts considerable amounts of nutrients, it would be of great interest to know whether an intercropped legume could return some of these through N fixation and organic matter addition to the soil.

Long-term research in this area is needed to increase our knowledge on nutrient dynamics in cassava-based intercropping systems, specifically on poor soils.

Pest Control in the Intercropping System

Analyzing the pest situation of a cassava-legume intercropping system, one realizes that most of the insect pests and some of the diseases are crop specific whereas weeds are a common problem of both components.

Although still lacking data on disease incidence in associated cassava-legume versus monocrop stands, we have some knowledge on the insect and weed problem. Departing from this first information, interesting clues on the economic-biological justification of intercropping and possible motivation of farmers to adopt this system have been obtained.

Periodical counts of the nymphal population of *Empoasca kraemeri* in bean monoculture and a bean-maize association showed that in the association, population peaks were reduced considerably and the fluctuations in the population were smoothed throughout the period of observation, suggesting that insect damage in the associated system should have been smaller as compared to bean monoculture (Fig. 9).

In a weed control systems trial, introducing beans as an intercrop with cassava reduced weed growth drastically, whereas with frequent weeding, no big difference in weed growth was observed between cassava monocrop and the cassava-bean association. More specifically, at the early growth stages, the intercropping system without any additional inputs was as efficient in reducing weed infestation as was a preemergent herbicide mix in cassava monoculture (Fig. 10). Small farmers surely have noted this beneficial effect of intercropping and for many of them this alone may be a strong argument to follow the system of cultural control, given the numerous hazards of applying purchased inputs.

Furthermore, in fields infested with weeds or with uncontrolled insect populations, yields of grain legumes obtained with intercropping will not differ

Table 3. Parameters of nitrogen fixation in some grain legumes. Source: CIAT Annual Report on bean production systems, 1976.

Species	Nodule dry weight (*mg/plant*)	Specific nodule activity (*μmol/g nod wt/h*)	Acetylene reduction (*μmol/plant/h*)	Nitrogen fixed (*kg/ha/yr*)
Phaseolus vulgaris (P590)	167-300	228	20-30	82
P. vulgaris, 20 cultivars	259-665	124-270	18.5-38.8	50-60
Glycine max	133	35-176	4-29	57-94
Arachis hypogea	80	135	27	35
Vigna unguiculata	210-413	80-288	42	95
Pisum sativum	2-150	60-228	4-16	25

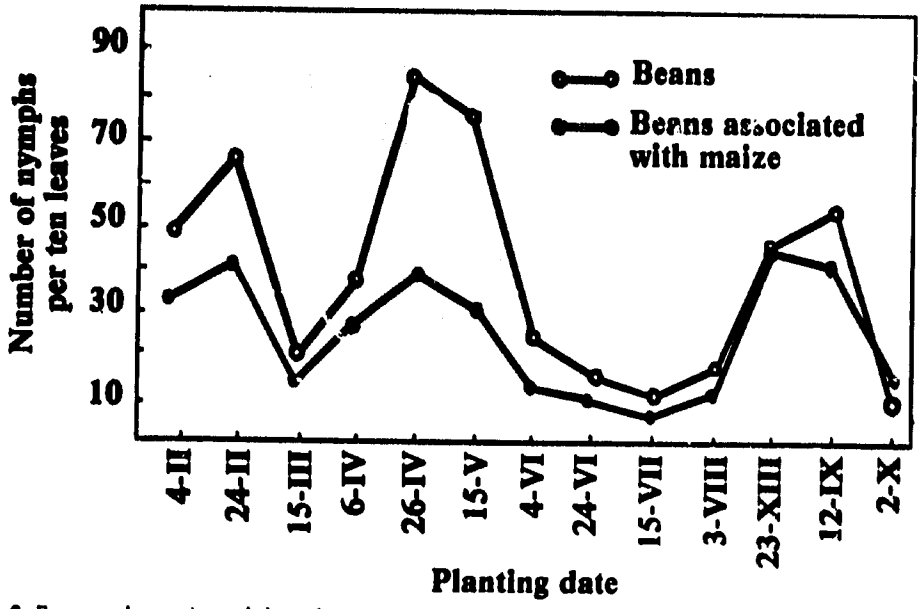

Fig. 9. Empoasca kraemeri nymphal populations on beans monoculture and beans associated with maize. Source: CIAT Annual Report on bean production systems, 1974.

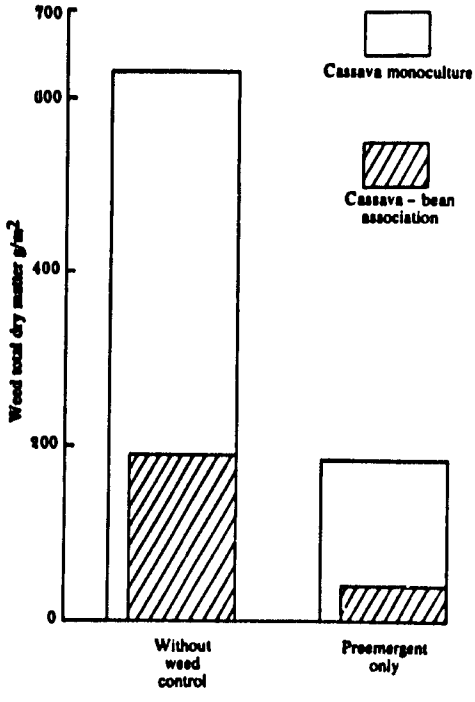

Fig. 10. Weed total dry matter in cassava monoculture and a cassava-bean association. Two weed control systems, 45 days after planting. Source: Cassava cultural practices program CIAT, 1978.

greatly from those achieved in monoculture, as under these circumstances, the presence of cassava is only one of many factors tending to decrease yields of the legume and therefore it does not make a big difference for the return from the grain legume if cassava is present or not (Thung, personal communication) However, in terms of total yield of the system, there is of course a big difference between the two alternatives.

In the weed control trial already mentioned, fresh root yields of cassava showed a spectacular 44% increase at the no input level (zero weed control) when cassava was planted together with beans instead of monoculture planting. On the other hand, with intensive weed control, differences between fresh root yields from intercropped and monoculture plots were small (Fig. 11).

This demonstrates that without purchased inputs, intercropping cassava with grain legumes gives a tremendous increase in total yield that the farmer would never achieve by monocropping any of the two components with the same input level. In our opinion, this constitutes another strong argument in favour of the intercropping practice of which the farmer is very likely to be aware.

Conclusions

Up to the present, intercropping has been considered an important means developed by the "primitive" farmer to stabilize yields and reduce risk in a no-input situation. By following this system he was

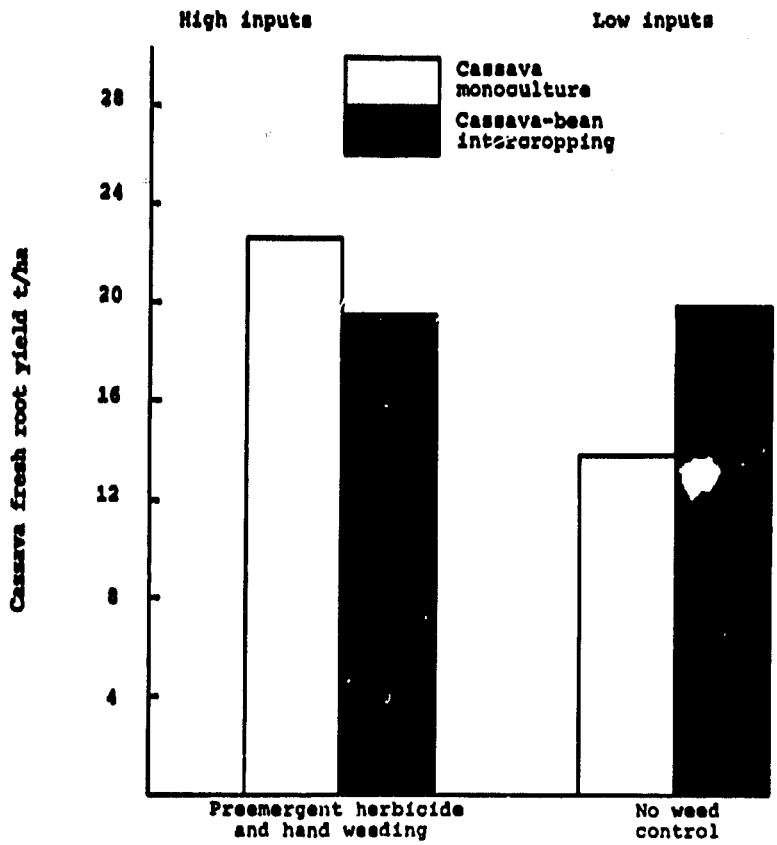

Fig. 11. The effect of different input on yield in cassava monoculture and cassava/bean association. Source: Cassava cultural practices program, CIAT, 1978.

able to counterbalance successfully the high pressure from weeds, insect pests, diseases, and other yield constraints that may have evolved together with the crops in their native environment. Although biologically sound, total productivity of the system was low due to wide spacing, infertile soil, minimal fertilizer application or weed control, and water stress (Jennings and Cock 1977).

Intensification of the system by use of modern inputs including high-yielding varieties is not readily achieved since the new improved varieties were designed to express their yield potential only in dense single-crop stands. In this regard, cassava represents a unique exception and opportunity as those genotypes selected for high-yielding ability in monoculture at the same time appear to have characteristics favourable for intercropping, namely an acceptable level of initial vegetative vigour, late branching, and no excessively broad canopy (Thung and Cock 1979).

The research progress we hope to make in the future will focus on the agronomic implications of the system. Identification of grain legume species with good adaptation to poor soils has great priority.

Possible ranges of planting dates throughout the year and optimum planting dates of one crop relative to the other need to be established for different species and environments. The complex of nutrient requirements for the most important species combinations and soil structure and fertility-conserving intercropping practices have to be found and tested.

Low-input pest management systems are a must if intensive cassava-grain legume intercropping is to become feasible for small farmers. Finally, approaches toward a part-mechanization of the system should be investigated aiming at the alleviation of short-term labour restraints that may occur at planting and harvest, even in rural areas with reasonable labour availability.

With these agronomic problems solved, we are confident that a low input requiring biologically and economically productive intercropping systems can be designed by which the dietary and economic situation of rural people may be improved.

Crop Protection Implications of Cassava Intercropping

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It has been cited repeatedly (Janzen 1973; Igbozwike 1971; and Holdridge 1959) that tropical agroecosystems with mixed stand populations are more stable than monocultures, although this belief can be refuted with several exceptions, notably sugar cane (Robinson 1976). Outbreaks of insect pests and/or plant pathogens constitute one of the most important factors contributing to the unbalance of a plant community in the tropics.

The search for integrated pest management methods has led to a series of entomological studies and theoretical discussions related to the influence of the composition of the plant community on the composition of the insect populations. Some of these studies have been recently conducted under tropical conditions (Risch 1977). However, this information is still not enough to provide a basis for designing new, more stable production systems for different tropical conditions.

Information on the influence of mixed plant populations on the plant pathogen community composition in the tropics is greatly lacking. Botanical epidemic development in most plant communities of mixed genotypes has been studied mostly in temperate regions with horticultural crops (Berger 1973, 1975) and more thoroughly discussed in cereals (Krantz 1968a, b, and 1974). Studies of botanical epidemic dynamics to interpret the host–pathogen–environment system in its tridimensional magnitude are recent in plant pathology. Because tropical ecosystems are generally more complex than temperate ecosystems and there are more plant diseases in the tropics than in temperate regions (Wellman 1969), the study of botanical epidemics in the tropics is complex and needs a more integrated systems approach (Robinson 1976).

Cassava, like other food crops, is intercropped by small farmers to minimize production risk involved in "reduced scale" agriculture. These close to subsistence food crops production systems are cultivated with the minimum of cash expenditure on pest and pathogen control. Intercropping, the burning of crop residues, shifting cultivation, rotation, and the cultivation of mixtures of varieties contribute to achieve a certain degree of sanitary stability. Severe parasite damage is in general terms rare in subsistence production systems. As the farm becomes larger and the resource base more diversified, the cassava-based production systems become more market-oriented and cassava monoculture becomes prevalent. The management of these market-oriented production systems implies the use of pesticides although cassava is still considered a safe crop as compared to other tropical crops.

Small-scale agriculture has not received attention from researchers until recently; consequently data on these mixed cropped production systems have just begun to accumulate.

Information about cassava diseases was generally lacking (CIAT 1970) but has improved notably in recent years (Lozano and Booth 1974). However, quantitatively epidemiological studies are few (Lozano and Sequeira 1974) and most of these evaluated the reaction of different cultivars to certain cassava pathogens (CIAT 1975).

Information about botanical epidemics on cassava intercropped with other crops was unavailable to the author and as a consequence, this paper is based largely on Central American data on plant pathogens attacking cassava cultivated in pure and mixed stands and on the possible influence of cassava on the disease development of other crops that are intercropped with cassava. Most of the information has been obtained during the last 4 years by my former graduate students, colleagues, and field assistants of CATIE.

Influence of Intercropping on Cassava Disease Development

Larios and Moreno (1976, 1977) conducted one of the most comprehensive studies on the influence of intercropped species on the development of cas-

sava diseases. In this work the incidence and severity of several cassava diseases were studied in different cropping systems (Fig. 1). Species, varieties of plant components, and planting distances in every cropping system are summarized in Table I. Incidence (%) is the number of infected units and severity is the affected area (%) estimated according to previously calculated scales. The concepts of incidence and severity have been previously discussed by James and Shih (1973). Disease development was evaluated approximately every 20 days from the same 16 cassava plants randomly selected from 90 m^2 plots.

Cassava Powdery Mildew (*Oidium manihotis* P. Henn)

O. manihotis attacks mainly the lower leaves of susceptible cassava cultivars and produces a typical yellowing on the attacked surface (Drumond 1946).

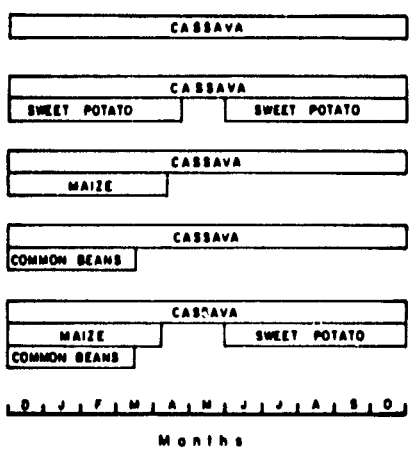

Fig. 1. *Cropping systems tested at Turrialba, Costa Rica, to determine the influence of intercropping on cassava diseases development (from Larios and Moreno 1976).*

Very susceptible cultivars display a necrotic reaction. In Turrialba, both incidence (I) and severity (S) of this disease were positively correlated to deviations (frequency and amplitude) below the average temperature (21.1 °C) and below average daily relative humidity (88.79%). Significant and negative correlations between I and S and both average daily precipitation and 24-h periods with more than 5 mm of rain, also were found. I and S decreased proportionally as the number of leaves per plant increased. As this disease attacks mainly the lower leaves, when more foliage is produced either the relative humidity reaches levels inappropriate for pathogen development or the intercepted amount of light increases to critical levels for both the pathogen and the persistence of lower leaves. Figure 2A–E shows that peaks in both I and S curves coincide with the "dry period" at Turrialba (February and March mainly) when water tension reaches negative values (Amézquita 1974). Immediately after this period, either the growth of the host surpasses the development of the pathogen or the microenvironmental conditions become inappropriate for the pathogen. Maxima values of leaf area index in Turrialba are normally reached during April–May, about 185 days after planting (Gallegos 1976).

The incidence and severity of *O. manihotis* attacks were higher when cassava was intercropped with maize, than in cropping patterns not including maize (Fig. 2, B and E).

Infection rates of severity reached 0.071 units per day in cassava intercropped with maize and 0.066 for cassava monoculture (Table 2). The other cropping patterns tested had lower infection rates. A similar situation is represented by values of maximum severity.

Sweet potato (*Ipomoea batatas* L.) intercropped between cassava plants at the end of the cassava growing period did not significantly modify the development of the epidemics (Fig. 2, D and E). The rate of decrease of disease of both I and S do not differ significantly.

Table 1. Species, varieties, planting distances, and density of plant components of five cropping systems including cassava, Turrialba, Costa Rica.

Species	Varieties	Planting distance (*m*)		Planting density, *plants/ha*
		Between rows	On the row	
Common beans (*Phaseolus vulgaris*)	CATIE-1	0.5	0.2	100000
Maize (*Zea mays*)	Tuxpeño	1.0	0.5	40000
Sweet potato (*Ipomoea batatas*)	C-15	0.5	0.4	50000
Cassava (*Manihot esculenta*)	Valenca	1.0	0.5	20000

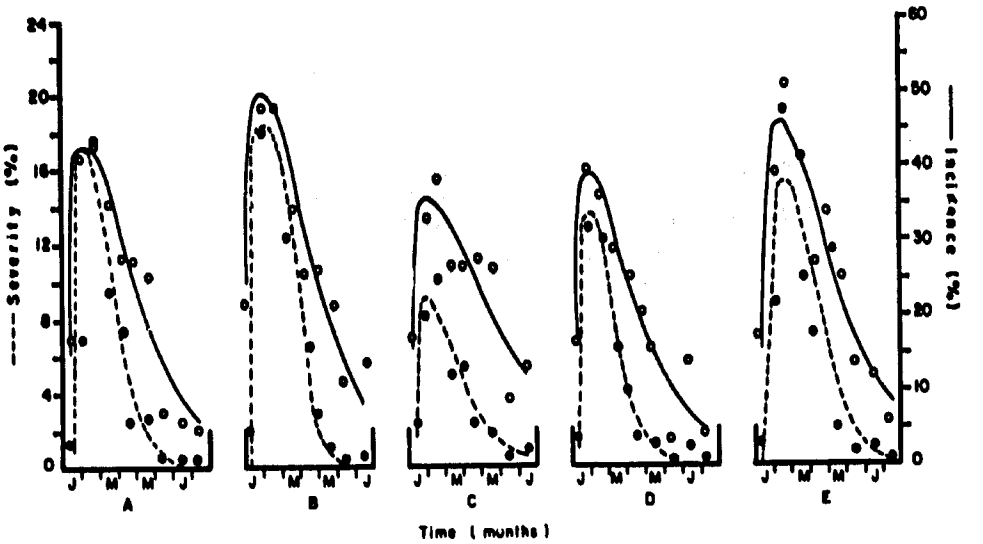

Fig. 2. Severity and incidence values of cassava powdery mildew (Oidium manihotis) in different cropping systems: A, cassava monoculture; B, cassava associated with maize; C, cassava associated with common bean; D, cassava associated with sweet potato; and E, cassava associated with maize, common bean, and sweet potato at the end of the cassava growing period (adapted from Larios and Moreno 1976).

Common beans (*Phaseolus vulgaris* L.) interplanted with cassava delayed the onset and development of both incidence and severity of *O. manihotis* infection (Fig. 2C). This is doubly important because *Isariopsis griseola* Sacc. infection was reduced on bean plants intercropped with cassava (Table 8). A possible simbiotic relation between these two plants components may be one of the reasons why this crop association is widely practiced by small farmers. Assuming that intercropping cassava and maize increases relative humidity in the interplanted spaces, a low infection level is expected since relative humidity is negatively correlated to I and S of powdery mildew. Perhaps infection occurred early in the growing season when maize plants were too small to modify the microclimate and subsequent development of the epidemic occurred by an esodemic type of process, according to the concept of Robinson (1973). Temperature could be higher due to reduced air movement and light could be significantly lower in cassava intercropped with maize than in cassava monoculture and this could cause higher powdery mildew levels in cassava intercropped with maize.

Cassava is relay-interplanted between maize stalks immediately after maize reaches physiological maturity to avoid high weed populations in the low humid tropics (Moreno and Hart 1978). This is one of the most widely cultivated cropping systems in areas of high rainfall and luxuriant weed growth. The relevance of *O. manihotis* in small cassava plants should be studied further in relation to this practice. Even though precipitation is abundant, cassava plants growing with low light intensity between maize stalks are heavily attacked by *O. manihotis* during the early stages of cassava develop-

Table 2. Infection rates (*r*) of cassava mildew (*Oidium manihotis*) in different cropping systems, Turrialba, Costa Rica (from Larios and Moreno 1976).

Cropping system	Infection rate[a]	Maximum severity, %
Cassava	0.066	17.65
Cassava + sweet potato[b]	0.055	12.50
Cassava + maize	0.071	27.34
Cassava + beans	0.038	10.20
Cassava + maize + beans	0.071	19.27

[a]Units per day (*r* of van der Plank (1963)).
[b]+ = cassava intercropped.

ment. The benefits derived from low weed infestation should be compared with the detrimental effect of high levels of powdery mildew.

No data are available on the effect of intercropping different cultivars of cassava and maize in different, spatial arrangements on the development of the cassava powdery mildew.

Cassava Scab (*Sphaceloma* sp.)

The symptomatology of this disease in Turrialba is characterized by scab lesions on the leaves, petioles, and young shoots. It is more similar to earlier descriptions of Bitancourt and Jenkins (1950) than to any other description. Elongation of internodes as reported frequently elsewhere was seldom observed under field conditions.

Opposite to powdery mildew the scab pathogen attacks mainly during the rainy season (Fig. 3, A through E). Maximum severity and incidence of the disease usually occur a few weeks after the onset of the rainy season. The disease is present until gradual defoliation of the cassava plant, starting about 200 days after planting, decreases both the amount of inoculum and susceptible tissue by reducing the number of leaves on the plant.

Accumulated precipitation and deviations of temperature (frequency and amplitude) above the mean (21.1 °C) were consistently and positively correlated with incidence and severity of the disease in all cropping systems studied.

Intercropping with maize (Fig. 3, B and E) delays the onset of the epidemic significantly compared with monoculture, intercropping with sweet potato, or common beans (Fig. 3, A, C, and D). These last three treatments had similar epidemic development curves for both incidence and severity. The two treatments involving maize showed the highest values for incidence and severity but this occurred late in the growing season. Maize plants delayed the onset of botanical epidemics but, once the maize plants reached physiological maturity and were doubled-over (about 135 days after planting), the epidemic spread rapidly. This may be influenced by mechanical damage to cassava in the process of bending the maize stalks, or by an increase in the number of propagules available for infection caused by field workers in contact simultaneously with infected and healthy tissue or both. The influence of field workers on the spread of plant pathogens has been previously noted by Berger (1973). It has been previously studied that wounds favoured *Sphaceloma* infection (Larios 1976). After the doubling of the maize stalks there is a large amount of susceptible tissue available for infection. A similar case is discussed by Berger (1977) when disease severity was less in sprayed fields. However, when spray applications ceased, disease sometimes reached greater intensity in the previously sprayed fields than in the unsprayed areas because of the rapid disease progress following the loss of fungicide effectiveness. Table 3 shows the difference in infection rate of *Sphaceloma* sp. on cassava before and after doubling the maize stalks. The higher value for "*r*" for the cropping system including cassava, maize, and common beans as compared to the cropping systems of cassava monoculture and cassava associated with maize could also be a consequence of the field workers harvesting the bean plants and both damaging cassava foliage and possibly spreading inoculum.

It has been observed in Turrialba that cassava scab increases more rapidly if tall maize cultivars, after doubling, remain as high as the cassava canopy.

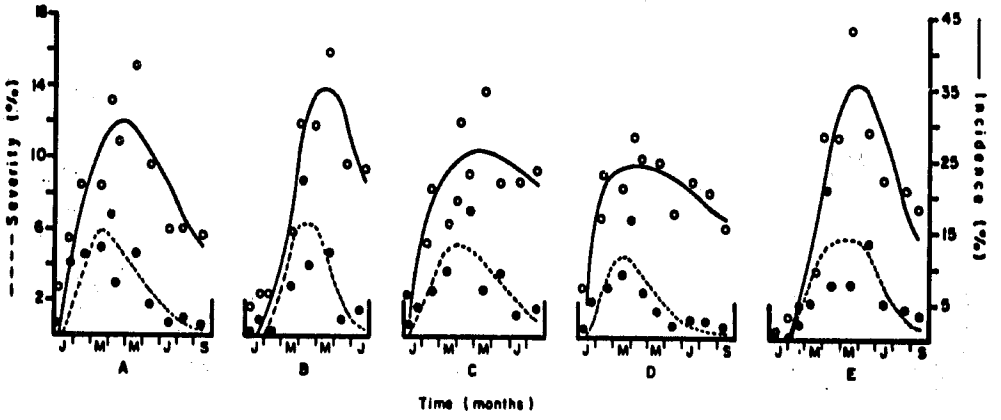

Fig. 3. Severity and incidence values of cassava scab (Sphaceloma sp.) in different cropping systems. A, cassava monoculture; B, cassava associated with maize; C, cassava associated with common beans; D, cassava associated with sweet potato; and E, cassava associated with maize, common bean, and sweet potato at the end of the cassava growing period (adapted from Larios and Moreno 1976).

Table 3. Infection rates of cassava scab (*Sphaceloma* sp.) in three cropping systems before and after intercropped maize was doubled, Turrialba, Costa Rica (from Larios and Moreno 1976).

Cropping systems	Infection rate (r)[a]	
	Before doubling	After doubling
Cassava	0.027	0.026
Cassava + maize[b]	0.027	0.035
Cassava + maize + beans	0.041	0.048

[a]Units per day (r of van der Plank (1963)).
[b]+ = cassava intercropped.

Wind movement of the hard dry maize foliage and cassava leaves probably abrade the cassava and produce more wounds that favour *Sphaceloma* sp. entry.

Cassava scab is more prevalent on the foliage exposed to the wind. In cassava monoculture the infection begins from the edge of the field facing the wind and spreads downwind in a decreasing gradient of severity. In cassava intercropped with maize this gradient disappears after the first two rows of maize if cassava and maize rows are perpendicular to the wind direction. Cassava scab spreads very slowly when planted with plantain (*Musa* sp. ABB cv. Pelipita) that is higher than cassava plants. If intercropping cassava with maize increases the amount of powdery mildew but delays the onset of a cassava scab epidemic, it seems logical to vary the maize density in the field by increasing it in the area facing the prevalent wind and decreasing it toward the centre of the field.

Severity of cassava scab generally is moderate in Turrialba as compared with other regions in Central America and elsewhere. It is not known if this apparent protection exerted by maize plants still holds under very heavy infections.

Cassava Rust *Uromyces manihotis*)

This disease affected cassava under dry and hot climatic conditions in Brazil (Normanha 1970) and in high altitude and cold areas in Colombia (Lozano and Booth 1974). In Turrialba, severity of rust infection was positively correlated with accumulated precipitation, daily average precipitation, relative humidity, and deviations (frequency and amplitude) of temperature below average. Incidence was not correlated with precipitation or relative humidity. Contrary to other cassava diseases, incidence and severity are not correlated. This disease, like several other rusts, apparently is not disseminated from infected to healthy host tissue under conditions of precipitation but either the size of the uredospore, the production of new uredospores, or the production of uredospores in existing lesions are favoured by available free water on the leaf surface.

Maximum intensity and severity of cassava rust are summarized for each cropping system studied in Table 4. Rust pustules were observed approximately 60 days after planting but the disease did not spread during the dry season. Cassava rust reached measurable levels only 157 days after planting. According to the maxima severity values, there was less rust in cassava cultivated in association with maize and with common beans. As maize was already doubled at this time, rust infection probably occurred early in the growing season when cassava was still associated with maize and the subsequent low incidence and severity was due to small amounts of primary rust inocula in the plots planted with maize intercropped in cassava. The relevance of a reduced amount of primary inoculum have been studied by Benson and Barker (1974), Summer and Littrell (1974), and Wiese and Ravenscroft (1975) among

Table 4. Maximum values of incidence and severity of cassava rust (*Uromyces manihotis*) in five different cropping systems, Turrialba, Costa Rica (adapted from Larios and Moreno 1977).

Cropping systems	Maximum values of	
	Incidence (%)	Severity (%)
Cassava	67.7	2.85
Cassava + sweet potato[a]	60.0	2.11
Cassava + maize	52.6	1.86
Cassava + beans	56.6	1.67
Cassava + maize + beans	47.2	1.17

[a]+ = cassava intercropped

Table 5. Average values of severity of cassava rust (*Uromyces manihotis*) by canopy strata in different cropping systems, Turrialba, Costa Rica (adapted from Larios and Moreno 1977).

Cropping systems	Average severity (%) by canopy strata		
	Low	Medium	High
Cassava	7.43	1.09	0.04
Cassava + sweet potato[a]	5.43	1.69	0.02
Cassava + maize	3.60[b]	1.40[b]	0.06[b]
Cassava + beans	4.76[b]	0.83[b]	0.01[b]
Cassava + maize + beans	4.20	0.55	0.04
Average	5.08	1.11	0.03

[a]+ = cassava intercropped
[b]One disease assessment only.

others. Maize acts as a barrier for bean rust spore dissemination (Mora and Moreno 1978) and probably *Ascophyta* spores (Moreno 1975 a, b). It is also possible that cassava plants competing with maize in association during 130 days, due to its reduced foliage might offer a smaller target leaf area for disseminating rust spores. Considering the length of time of the total growing season, there were no significant differences in cassava rust infection rates between the different cropping patterns tested.

Similarly to powdery mildew, rust is more severe in the lower part of the cassava canopy. Rust was more severe in the lower section of the canopy than in the upper, young, or middle leaf sections (Table 5).

Humidity, temperature, age of leaves, light, and probably other factors, acting alone or in combination, modify the microenvironmental conditions in different parts of the cassava canopy and significantly affect the host–pathogen interaction. This interaction should be studied for each host combination in tropical areas where either powdery mildew or rust limits cassava production. In the low humid tropics *Darlucca* spp. parasites rust uredospores earlier and with more intensity than in other tropical areas; this is particularly true in cassava plants growing under plantain (*Musa acuminata* × *Musa balbisiana*) or cacao (*Theobroma cacao*). This is an important biological control possibility worth exploring through more detailed studies.

Cercospora Leaf Spot (*Cercospora henningsii*) and *Cercospora caribaea*)

Both *C. henningsii* and *C. caribaea* are minor cassava pathogens in Turrialba. No statistical differences in either severity or incidence of the *Cercospora*-caused diseases were found between the different cropping systems tested (Table 6). No explanation is available for a more severe attack of *C. caribaea* on cassava plants intercropped with beans. A more detailed study should be conducted in areas where *Cercospora* leaf spot is more important.

Cassava Dieback (*Colletotrichum* sp.)

The intensity of damage (ID) of this disease was studied in cropping patterns 1, 2, and 5 of Fig. 1 under low and high management levels. To evaluate ID the following formula was used:

$$ID = \frac{\sum(IAP) + 4(IMS) + 2(ISS)}{SP}$$

where: IAP = infected apical apices; IMS = infected main shoots; SS = infected secondary shoots; SP = susceptible points.

The management levels differed by weeding frequency and fertilization (Table 7).

Dieback always caused more damage under low management, regardless of the cropping pattern (Fig. 4). According to Chevaugeon (1956), a potas-

Table 6. Average number of lesions per leaf lobule per plant of *Cercospora henningsii* and *C. caribaea* in different cropping systems, Turrialba, Costa Rica (adapted from Larios 1976).

Cropping systems	Avg no. of lesions/leaf lobule per plant	
	Cercospora henningsii	*Cercospora caribaea*
Cassava	0.28	0.39
Cassava + sweet potato[a]	0.32	0.40
Cassava + maize	0.30	0.31
Cassava + beans	0.25	0.69
Cassava + maize + beans	0.24	0.35

[a]+ = cassava intercropped.

Table 7. Differences in management of three cropping systems in which the damage caused by *Glomerella cingulata* was studied, Turrialba, Costa Rica (from Larios and Moreno 1977).

	Management level			
	Low		High	
Cropping system	No. weedings	Amt of fertilizer, *kg/ha*	No. weedings	Amt of fertilizer, *kg/ha*
Cassava	1	300[b]-100[c]	2	300[b]-400[c]
Cassava + sweet potato[a]	1	300-100	2	300-500
Cassava + maize + sweet potato	1	300-100	2	300-500

[a]+ = cassava intercropped.
[b]15-30-8 ($N-P_2O_5-K_2O$) at planting.
[c]20-10-6-5 ($N-P_2O_5-K_2O-S$) applied 30 days after planting.

sium deficiency may initiate dieback and *Gloeosporium manihotis* could subsequently grow in the affected tissue. The experimental area was low in potassium (Mojica 1975). If low soil potassium is associated with dieback damage, higher infection levels would be expected when cassava is intercropped with sweet potatoes and maize, which compete for available potassium. There is an unproven possibility that a better soil nutrient balance occurs when more diversified root systems are extracting nutrients simultaneously.

Influence of Cassava on the Disease Development of the Intercropped Plant

Common Bean Angular Leaf Spot (*Isariopsis griseola* Sacc.)

Common beans and cassava are commonly intercropped by small farmers (Moreno and Hart 1978).

Snap beans produced as a cash crop in areas close to a market utilize some fungicides, notably dithiocarbamates, especially during the rainy season. Cas-

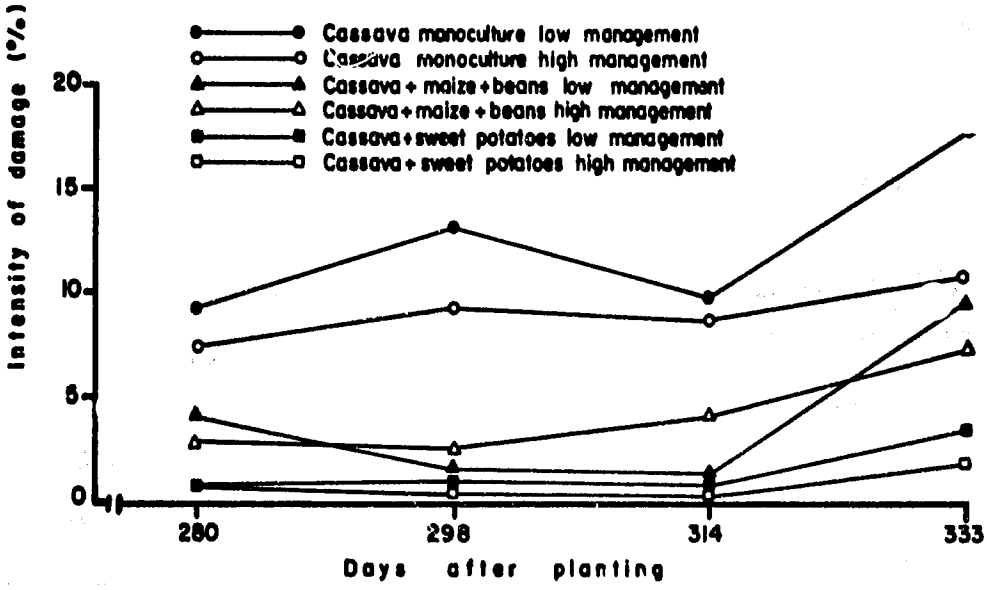

Fig. 4. Intensity of damage of cassava dieback disease (Colletotrichum sp.) under low and high level of inputs in different cropping systems, Turrialba, Costa Rica, 1977.

Table 8. Severity of angular leaf spot of beans (*Isariopsis griseola* Sacc.) in different cropping systems, Turrialba, Costa Rica (from Moreno 1977).

Cropping systems	Severity at different stages of development		
	Before anthesis	Anthesis	Green pod
Beans	10.23[b]	14.37	19.56
Beans + maize[a]	10.31	17.77	21.33
Beans + cassava	10.81	13.61	18.88
Beans ± sweet potato	10.26	13.13	18.89
Beans + maize ± sweet potato	10.46	16.11	21.03
Beans + maize + cassava	10.26	16.40	21.44

[a]+ = association of crops; ± crop intercropped 30 days later.
[b]Data obtained through a modification of the McKinney index and transformed with $(x + 0.5)^{1/2}$.

sava benefits from this fungicide spray and fields intercropped with cassava and a cash crop frequently appear free of diseases. However, in certain areas no fungicides are used in bean production and the associated crops are also healthy.

The importance of some common bean diseases when intercropped and in monoculture were studied by Moreno (1977) and Mora and Moreno (1978). The severity of angular leaf spot of common beans 20 days before anthesis, during anthesis, and at the green pod stage of development for different cropping systems are summarized in Table 8.

Bean plants growing between rows of either cassava or sweet potato were not as affected by *I. griseola* as were beans grown in monoculture and beans grown in cropping patterns including maize. Angular leaf spot severity increased more before and during anthesis in treatments including maize among their plant components. Between the anthesis and the green pod stage of development, angular leaf spot severity increased in the same proportion in every cropping system tested. Consequently the differences in severity registered between cropping systems at the final assessment of angular leaf spot is a result of a delay in the onset of the epidemic rather than in the further development of the disease. The specific role of cassava in the protection of plants from *I. griseola* infection is not well understood but perhaps could be explained by an umbrella-like effect that diminishes the impact of rain drops splashing propagules. Splashing water is an important factor in the dissemination of *I. griseola* (Cardona and Walker 1956). Maize plants apparently do not protect bean plants from splashed propagules of *I. griseola*, either because the infection occurs early in the growing season when maize plants are not fully developed or because the microclimatic conditions prevailing in the interspace of cassava–beans is less favourable for the fungus than the microclimatic conditions of the maize–beans interspaces. It has been previously demonstrated that once synematas of *I. griseola* are formed, sporulation is more abundant during dark periods (Silvera 1967). Higher percentages of conidia germination occurred under diffuse light conditions (Llanos 1957). Maize plants could be providing a more adequate microenvironment for *I. griseola* germination, penetration into the host, and further dissemination than cassava plants do.

Common Bean Rust (*Uromyces phaseoli* var. *tipica*)

Bean rust severity was studied in the same cropping systems as angular leaf spot but in different

Table 9. Severity of bean rust (*Uromyces phaseoli*) in different cropping systems, Turrialba, Costa Rica (Moreno 1977, unpublished reports).

Cropping systems	Severity at different stages of development		
	Before anthesis	Anthesis	Green pod
Beans	5.39[b]	15.11	17.16
Beans + maize[a]	3.04	10.07	14.01
Beans + cassava	3.39	16.67	20.41
Beans ± sweet potato	3.14	16.66	18.79
Beans + maize ± sweet potato	0.71	11.04	15.67
Beans + maize + cassava	0.71	11.00	13.37

[a]+ = association of crops; ± crop intercropped 30 days later.
[b]Data obtained through a modification of the McKinney index and transformed with $(x + 0.5)^{1/2}$.

plots. Before anthesis, bean rust was present only in beans grown in monoculture (Table 9). Traces of rust infection were recorded in beans associated with cassava, maize, and sweet potato. Rust was not detected in the association of crops involving three components. During anthesis, beans grown with cassava and sweet potatoes were slightly more affected than the beans grown in monoculture. Lowest severity values were registered in cropping patterns involving maize. During the green pod stage of development, beans associated with cassava and with sweet potatoes had the highest severity. Cassava and sweet potatoes probably provided an adequate microenvironment for bean rust development. A reduced number of available infection sites for *U. phaseoli* due to higher severity of *I. griseola* on bean leaves could also account for less severity in beans associated with maize.

Cowpea Mosaic Virus (CPMV) and Cowpea Chlorotic Mosaic Virus (CCMV)

CPMV and CCMV are major cowpea pathogens in Central America and elsewhere (Fulton et al. 1975). In Turrialba, both viruses are transmitted by beetles of the family Chrysomelidae, notably *Cerotoma ruficornis, Diabrotica balteata,* and *D. adelpha* among others (Valverde et al. 1978). Dissemination of the pathogen in cowpea monoculture has been frequently faster than among cowpea intercropped with maize (Gonzalez et al. 1975, 1976) but data are inconclusive and variables such as adjacent plot composition, unknown wild hosts of the virus, orientation of plots, weather conditions during the growing season, percentage of seed transmission, and several others are affecting the results in an undetermined manner.

An experiment was conducted to determine the incidence (number of infected plants) in different

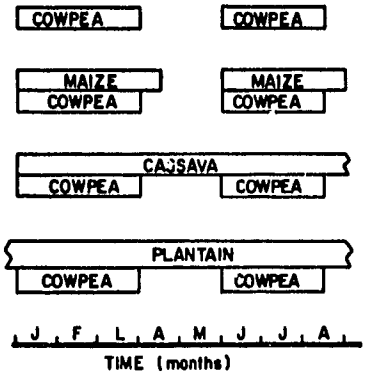

Fig. 5. Cropping systems studied to determine the influence of cassava on the development of cowpea diseases.

cropping systems (Fig. 5). Results for the first planting season show no difference between the number of cowpea plants infected by both viruses (CPMV and CCMV) in cowpea monoculture, in association with maize, or in association with cassava. However, the number of cowpea plants infected growing in intercrop with plantain was lower than the rest of the treatments. The number of infected plants tended to stabilize approximately 60 days after planting in cowpea intercropped between plantain (Table 10).

There was a positive and significant correlation between the activity of the vectors (*D. balteata* and *C. ruficornis*) in the tested plots and percentage of virus infection in the cowpea plants. A negative correlation was found between activity of the beetles and both radiation and precipitation during the two growing seasons. Fig. 6–9 represent the activity of the main vectors in plots with different cropping systems as determined by the number of beetles captured daily in yellow-pan traps and the relations between activity of the insects, precipitation, and

Table 10. Percentage of plants infected with cowpea mosaic virus (CPMV) and cowpea chlorotic mosaic virus (CCMV) in different cropping systems during the first planting season at Turrialba, Costa Rica (from Araujo and Moreno 1978).

	Cropping systems			
Days after planting	Cowpea monoculture	Cowpea + maize	Cowpea + cassava	Cowpea + plantain
24	8.41	8.99	5.85	5.27
31	12.25	13.30	11.62	10.54
38	12.65	13.83	13.14	11.65
45	14.14	16.17	15.72	15.07
52	18.97	21.09	19.66	17.65
59	26.93	24.87	26.94	21.89
66	29.20	25.49	21.47	23.12
73	29.94	26.59	33.87	23.94
80	31.80	33.36	34.98	25.88
87	31.80	33.36	34.98	25.88

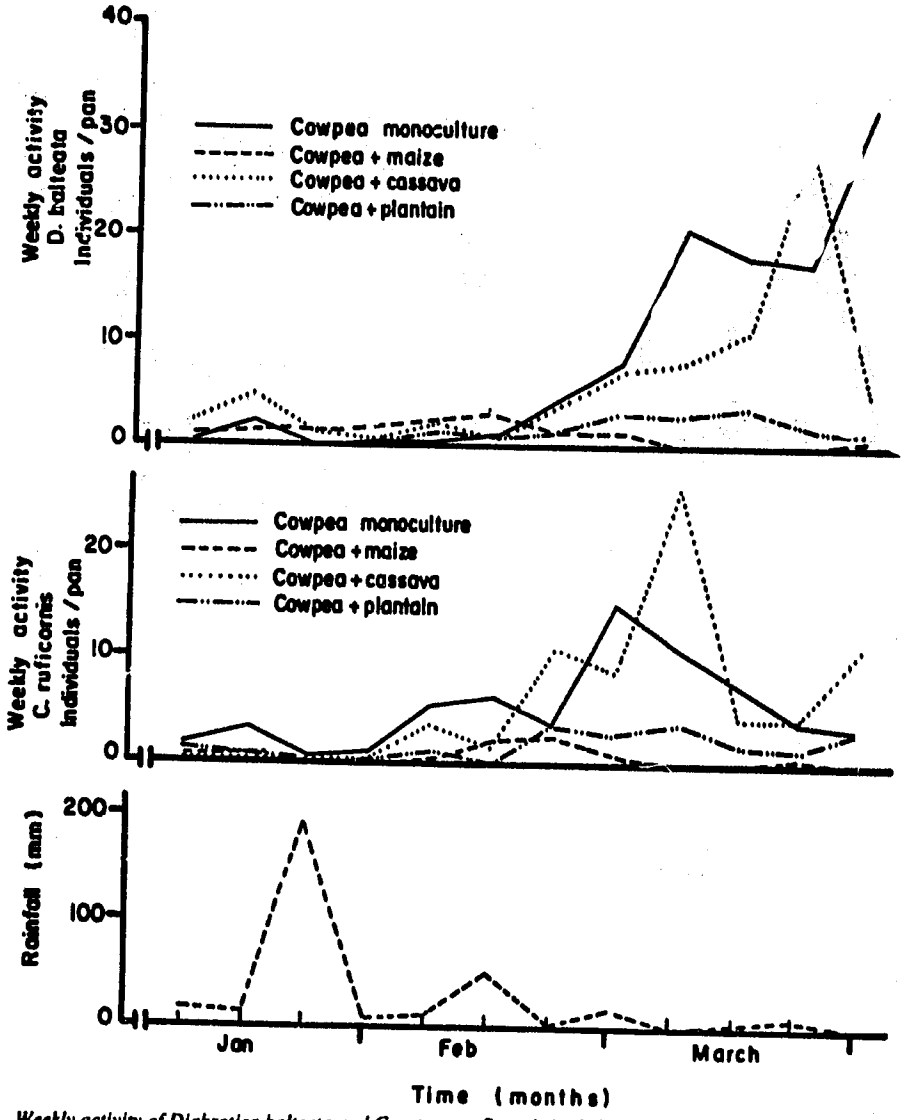

Fig. 6. Weekly activity of Diabrotica balteata and Cerotoma ruficornis in different cropping systems and rainfall registered during the first planting season at Turrialba, Costa Rica, 1977 (from Araujo and Moreno 1978).

radiation in two growing seasons. Risch (personal communication) demonstrated that some beetles reduce their activity proportionally under low light intensity. Cowpea was intercropped between cassava stalks and plantain again during the second part of the growing season (Fig. 5). There was a significant reduction in infected cowpea plants cultivated during the second planting season under cassava and under plantain (Table 11).

Fig. 10 represents the radiation registered at the height of the cowpea plants in the different cropping systems during two planting periods. The reduction in virus infection did not result in a better cropping system as the cowpea yields were reduced about 60% when cultivated under plantain or cassava. Higher yields have been obtained when cowpeas are interplanted later in the growing season when cassava has lost most of its foliage (Moreno and Hart 1978). More information is needed about the light intensity that allows an equilibrium between the level that reduces vector activity but still allows for an acceptable yield. Research on growing cowpea

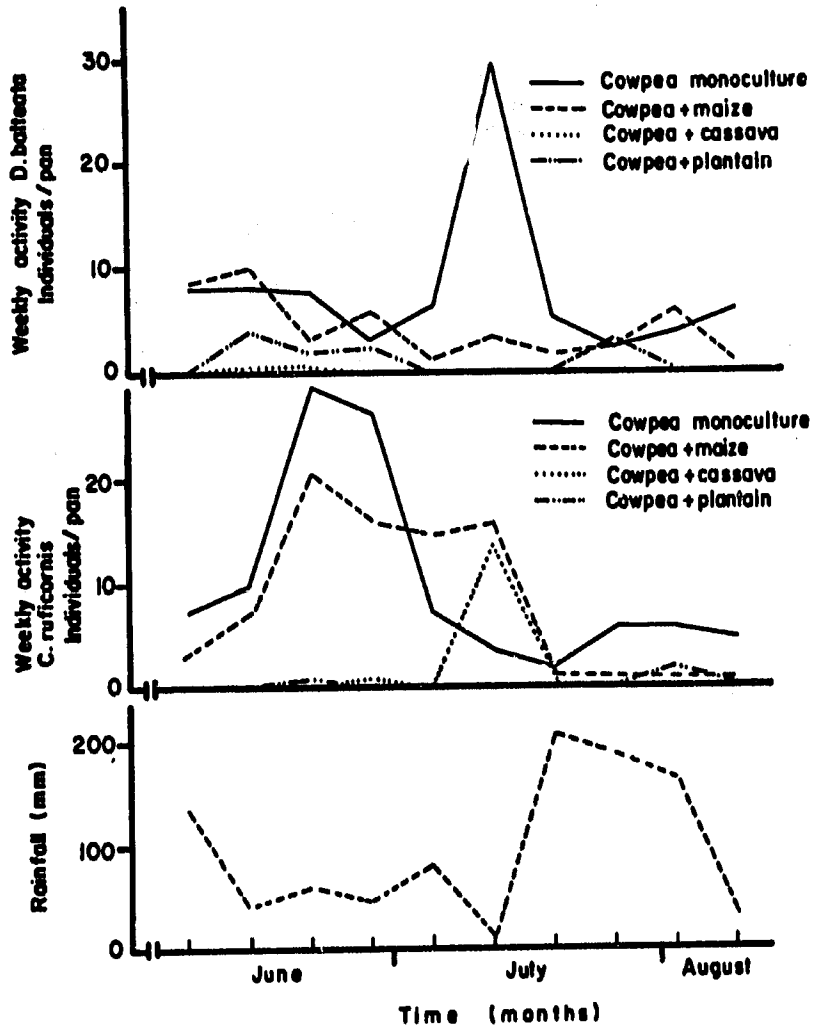

Fig. 7. Weekly activity of Diabrotica balteata and Cerotoma ruficornis in different cropping systems and rainfall registered during the second planting season at Turrialba, Costa Rica, 1977 (from Araujo and Moreno 1978).

Table 11. Percentage of plants infected with cowpea mosaic virus (CPMV) and cowpea chlorotic mosaic virus (CCMV) in different cropping systems, Turrialba, Costa Rica (from Araujo and Moreno 1978).

Days after planting	Cropping systems			
	Cowpea monoculture	Cowpea + maize	Cowpea + cassava	Cowpea + plantain
24	13.34	9.46	2.38	0.92
31	23.65	27.87	2.94	1.77
38	68.57	28.41	4.44	3.62
45	100.0	100.0	10.12	10.96
52	100.0	100.0	10.12	12.28
59	100.0	100.0	15.56	15.08
66	100.0	100.0	19.01	18.04

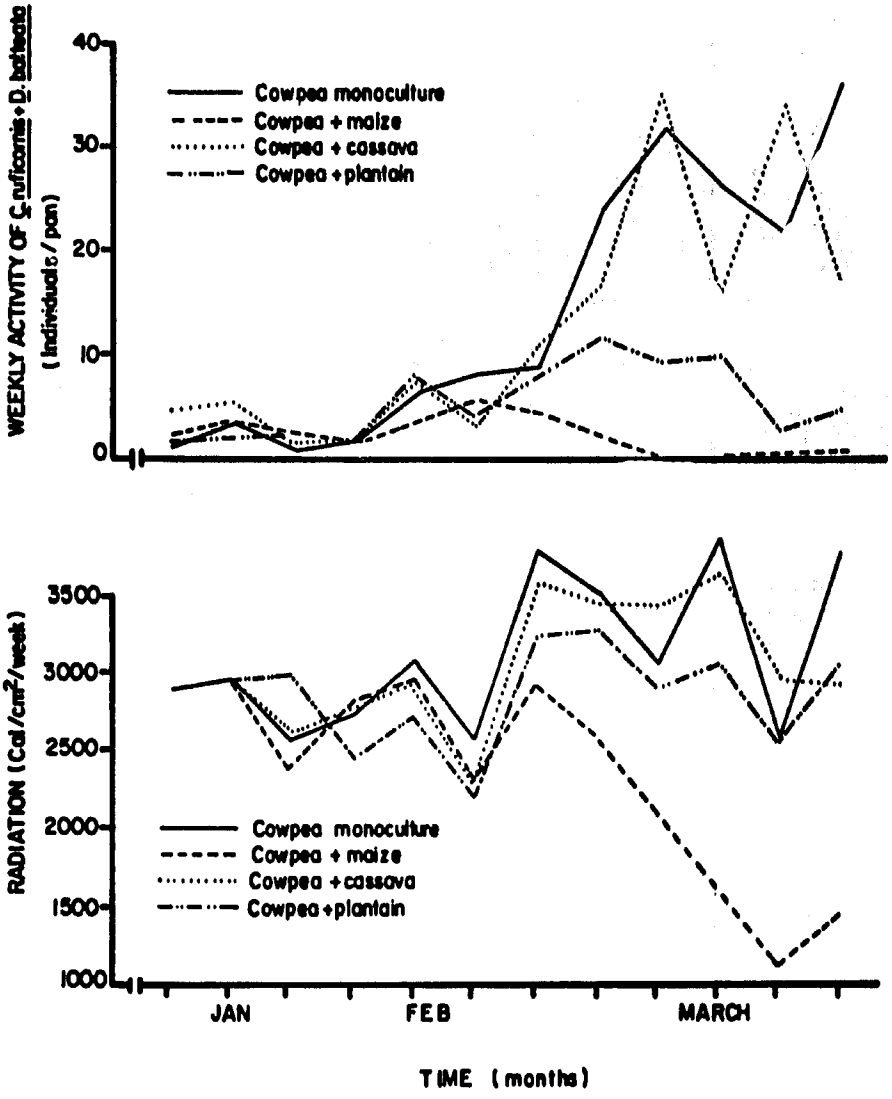

Fig. 8. Average weekly activity of Cerotoma ruficornis and Diabrotica balteata in different cropping systems and radiation registered at the canopy of cowpea plants during the first planting season at Turrialba, Costa Rica, 1977 (from Araujo and Moreno 1978).

under different degrees of cassava defoliation is continuing.

Ascochyta and *Cercospora* Leaf Spot of Cowpea

Ascochyta phaseolorum and *Cercospora cruenta* are important pathogens of cowpea in Central America. *Ascochyta* leaf spot was less prevalent when cowpea was intercropped with maize (Moreno 1975 a, b). Incidence and severity in number of units per day of these two plant pathogens in different cropping patterns are summarized in Table 13. No significant differences exist between treatments in incidence of *Ascochyta* leaf spot of cowpea but plantain, cassava, and maize intercropped with cowpea reduced significantly the severity of the disease. No significant differences either for incidence or severity were found for *C. cruenta*.

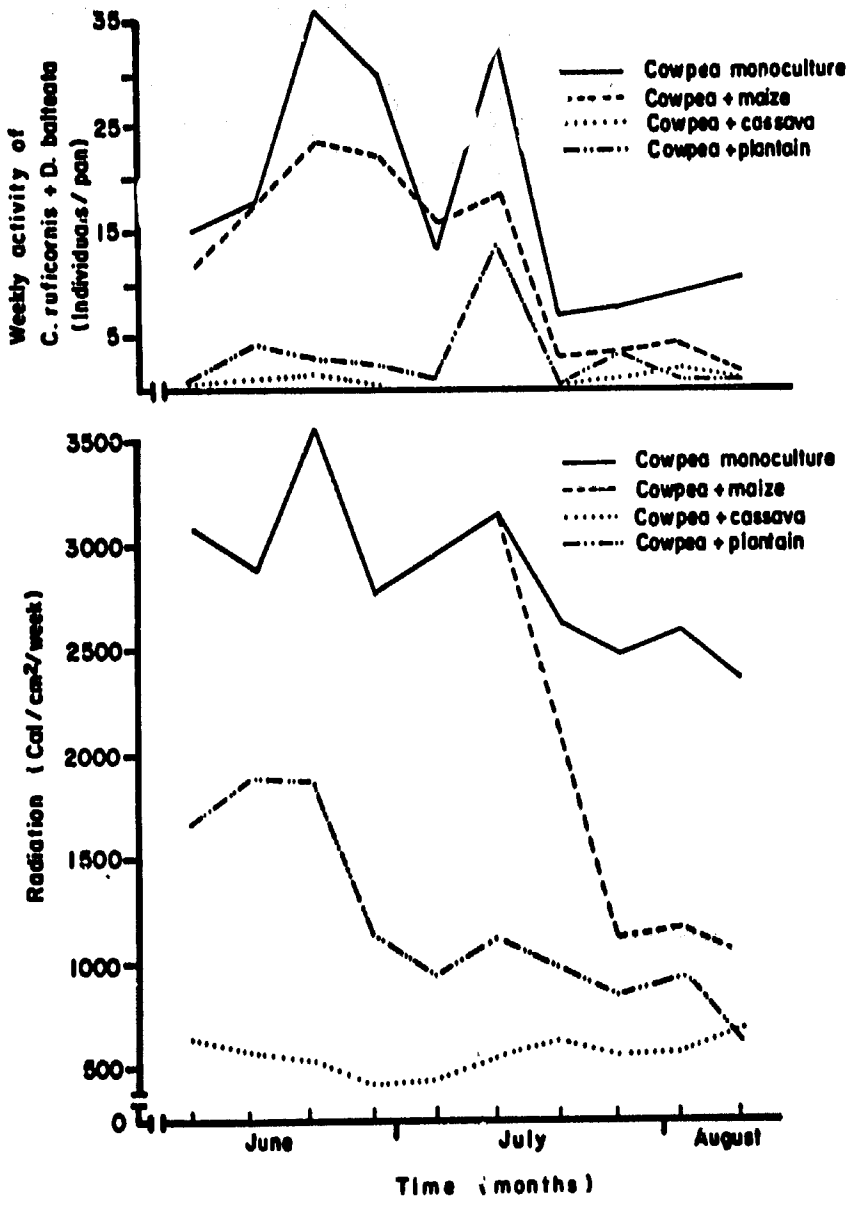

Fig. 9. Average weekly activity of Cerotoma ruficornis and Diabrotica balteata in different cropping systems and radiation registered at the canopy of cowpea plants during the second planting season at Turrialba, Costa Rica, 1977 (from Araujo and Moreno 1978).

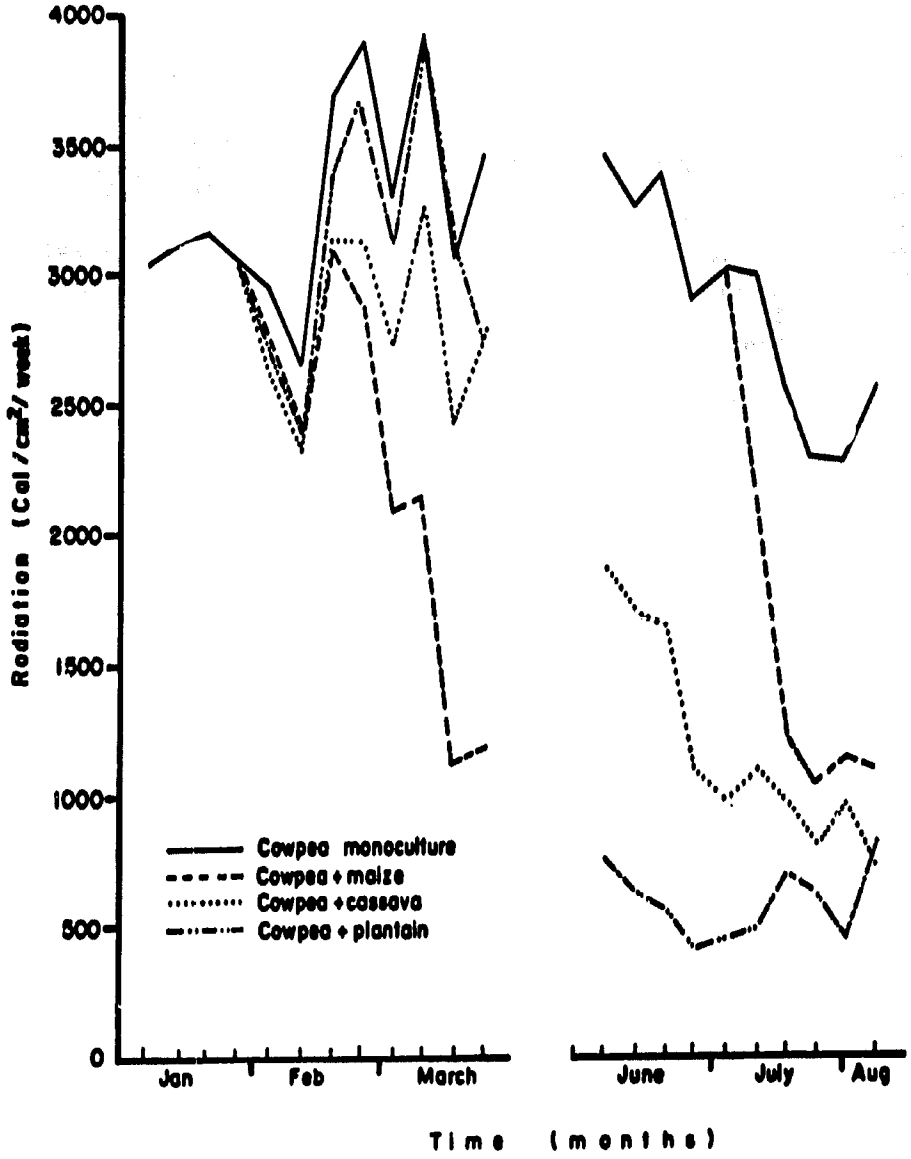

Fig. 10. Radiation registered at the height of the canopy of cowpea plants in different cropping systems and two planting seasons at Turrialba, Costa Rica, 1977 (from Araujo 1977).

Table 12. Time to the onset and final stage of an epidemic of *Erysiphe polygoni* D.C. in different cropping systems, Turrialba, Costa Rica (adapted from Araujo 1977).

Cropping systems	Days to the onset of the epidemic	Days to reach 100% incidence
Cowpea	46	72
Cowpea + maize[a]	57	72
Cowpea + cassava	58	85
Cowpea + plantain	38	76

[a] + = association of crops.

Table 13. Infection rates in number of units infected (incidence) and percentage of area affected (severity) of *Ascochyta phaseolorum* and *Cercospora cruenta* in different cropping systems, Turrialba, Costa Rica (adapted from Araujo 1977).

	Ascochyta phaseolorum		*Cercospora cruenta*	
Cropping systems	Incidence	Severity	Incidence	Severity
Cowpea	0.0603[b]	0.0499	0.0582	0.0776
Cowpea + maize[a]	0.0469	0.0183	0.0497	0.0737
Cowpea + cassava	0.0435	0.0238	0.0625	0.0732
Cowpea + plantain	0.0567	0.0294	0.0523	0.0629

[a]+ = association of crops.
[b]Units per day.

Cowpea Powdery Mildew (*Erysiphe polygoni* D.C.)

Cowpea powdery mildew is a disease with symptoms that are more prevalent at the end of the growing season when cowpea is approaching maturity. As chemical control is usually not economical, a delay in the onset of the epidemic by crop management could represent a significant increase in cowpea yield. A significant delay of the onset of the epidemic was achieved by interplanting cowpea with maize, cassava, and particularly plantain (Table 12). Intercropping with cassava delayed up to 85 days the time needed to reach a 100% incidence.

Discussion Summary

1. Most research work on cassava is carried out with the crop as a monoculture. However, in most parts of the world, cassava is grown as an intercrop on small low resource farms. This generalization appears to be valid whether the cassava is grown for home consumption, for sale as fresh roots, or for industrial uses.

2. Intercropping with cassava is practiced by farmers for a variety of reasons. Normally, little or no purchased inputs are used and at this low level of inputs, total biological yields are higher in mixed cropping than in monoculture, effectively increasing production per unit land area and cash investment. More efficient utilization of growth factors throughout the growing season is achieved, risk of losses to pests, especially weeds, is reduced compared with monoculture, risk of total crop loss is reduced, an assured supply of food is provided over time, labour requirements are spread over the year, erosion hazards are reduced, and market opportunities may be better exploited.

3. From the research standpoint a great deal more information is required from different agroclimatic regions regarding relationships between severity and duration of drought stress and crop productivity. Such physiological studies are necessary to help devise crop mixes utilizing cassava that will optimize yield potentials in drought-prone areas. More effective means of evaluating drought stress would make this task easier.

4. A further issue in relation to intercropping with cassava is that of the market prospects for individual components of the crop mix. In the last 5 years, cassava has benefited from a great deal of attention from research workers and in some areas its production has increased considerably. This has in some circumstances led to overproduction resulting in a sharp fall in prices received by producers. With additional management knowledge and germ plasm becoming available for cassava, prospects for further increases in production are considerable. To date, new cassava technology has hardly affected production in multiple cropping systems, although a considerable latent potential for change in this area exists. Attention needs to be given to ensuring that any additional cassava produced can be marketed at prices attractive to producers.

5. The question of root characteristics is of importance when cassava is grown with other crops. At low planting densities, such as are associated with multiple or intercropping practices, cassava tends to produce large roots that may be low in both dry matter and starch content. Starch manufacturers tend to offer lower prices for large roots, assuming reduced starch content. In the multiple cropping context, therefore, care must be exercised that the roots produced conform with local market requirements. This can be controlled by varieties and planting practices recommended.

6. In areas of marginal soil fertility, yields of crops, including cassava, grown in a multiple cropping system usually respond to applications of lime, mulch, and inorganic fertilizers. Cassava also exhibits a large potassium demand. This means that care needs to be exercised when growing cassava on impoverished soils to prevent the soil potassium level falling below the critical level required by the other crops in the multiple cropping system or by the succeeding crops. Combinations of

crops with a heavy potassium demand (e.g., cassava and sweet potato) should not be grown together in the same multiple cropping system on soils low in potassium unless adequate provision is made for this in the fertilizer regime.

7. There is a serious risk of soil erosion when cassava is grown on sloping sites. This risk is reduced by growing cassava in association with other crops, particularly where debris from other crops such as rice and/or maize is used as mulch.

8. Grain legumes are among the crops most commonly grown in association with cassava. The time of planting of beans relative to the time of planting cassava has been shown by CIAT to be an important determinant of the yield of both crops. The branching habit of the cassava can also influence the bean yield. Research is required to determine whether these canopy effects can be modified by planting long vertically oriented cassava cuttings that will give rise to shoots that will not be smothered by the canopy of the associated crop. This may not be feasible in dry areas due to cutting dieback through desiccation.

9. Cassava also offers opportunities for intercropping at later growth stages when its ability to intercept light diminishes. Depending on variety and climatic factors, it may be possible to establish a second crop at this time. Unfortunately a second crop planted under these circumstances is subjected to the major soil disruption of cassava harvesting and this usually damages the associated crop. However, an early maturing intercrop planted at this late stage of cassava growth may mature to be harvested before, or simultaneously with, the cassava. The feasibility of this system has been demonstrated at CIAT with a climbing-type bean intercrop. To facilitate establishment of the intercrop, cassava foliage may be removed and utilized as human or animal food. This system is widely practiced in Indonesia.

10. The workshop provided limited information on the effects of the multiple cropping of cassava on pests and diseases of both cassava and intercrops. A working paper dealt with the situation in Latin America and evidence from IITA indicates that multiple cropping may reduce the spread of both bacterial blight and common mosaic, either as a result of the cassava being less densely planted or due to the associated crop forming a mechanical barrier. Further work is required in the field of intercrop disease dynamics information from South and Southeast Asia.

11. Stability is an important issue in evaluating the merits of intercropping. The subsistence farmer is concerned that yields do not fall below a certain level, whereas the commercial farmer is concerned with maximizing his net return. Thus, the appropriate measure and level of stability and performance may vary widely between different classes of agricultural producers.

12. Because of the difficulty in obtaining good time-series data in multiple cropping systems, emphasis needs to be given to developing analytical techniques for use of cross-sectional data embracing a wide range of variability and cropping patterns. Variance and coefficients of variation have been used in evaluating stability, but many current studies are only using means.

13. The relationships and causes of stability reduction as yields increase in multiple cropping systems are not clearly defined or understood. The whole subject of stability in relation to multiple cropping is one that appears to require a great deal more study.

14. Product quality and biological stability factors raise important questions in relation to methodologies for field testing new intercropping patterns with cassava. The gestation period for testing new cropping patterns appears to be in the range of 3–7 years with a minimum of 3 years being required on farmers' fields before extension recommendations can be made.

15. Differences between the experimental station and the small commercial farm raise an important issue with respect to the evaluation of the adoption potential

of new cropping patterns. In all on-farm research there is a need for the farmer to be involved in the design and planning of the research as well as in conducting and evaluating it. On his own, the farmer is constantly evaluating his cropping patterns, and this process should be monitored. A single final evaluation of a new pattern by researchers or the farmer could lead to false reasons why the pattern was accepted or rejected by failing to observe and record key decisions on difficulties encountered during the process of growing a cropping pattern.

16. In this sense, the selection of cooperating farmers is most important because each will be evaluating the cropping pattern based on a variety of noneconomic factors such as land tenure, farm size, land fragmentation, family labour available, traditional work allocation, availability of hired labour, age of family members, and tradition regarding a specific crop. In every community there is a gradient of farmer from poor to rich. It was suggested that intercropping research with cassava should be conducted mainly with the poorer third of the farmers. In any event, different cassava production technologies are likely to be appropriate for different groups of farmers and hence proposed innovations should be tested across farm types.

17. A counterargument to the above was that a good (profitable) pattern is usually quickly adopted by farmers who make final adjustments to the pattern to suit their own resources and particular environment. Although new patterns may require new skills, it was suggested that few instances are known where farmers had not adopted new technology because it was too hard to learn. It was accepted that there is a cost to learning new skills but it was argued that farmers are willing to accept lower yields temporarily until they master new technology and procedures.

18. The workshop discussions illustrated very clearly that current research evaluating the economic impact of intercropping with cassava leaves a great deal to be desired. Many current research programs do not measure or record cost-and-return data accurately. They fail to define at what point in the system price data are being recorded, and they often use national rather than on-farm costs and prices. The recording of inputs used and output of the production process itself is often faulty, leading to an overestimate of benefits and an underestimate of costs.

19. Procedures were discussed for evaluating the economic relevance of one cropping system over another. The attractiveness of a practice should be evaluated in terms of its return to the effective limiting resource (whether this be land, labour, or cash) and supplemented by an analysis of the variability of revenues of the alternative patterns.

20. An overall impression from the workshop deliberations is that intercropping with cassava is beginning to receive attention in both national and international research programs. Nevertheless, most of the work is recent, little of it having commenced prior to 1976. Experiments are often complex, difficult to design, and, of necessity, of several years' duration. Because of the large number of alternatives, research on intercropping should be oriented in directions with greatest immediate potential as related to land quality, favourable climatic conditions, and market structure in important cassava-producing regions. This approach requires careful analysis of existing farm conditions as a point of departure for proper research design. Hopefully, the workshop will serve to inspire further research and the development of adequate methodologies for evaluating results. This appears to have been one of the weakest aspects in almost all papers, requiring more attention in the future.

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