Management and Evaluation of INTERCROPPING SYSTEMS WITH CASSAVA

Dietrich Leihner

CIAT Centro Internacional de Agricultura Tropical

CIAT is a nonprofit organization devoted to the agricultural and economic development of the lowland tropics. The government of Colombia provides support as host country for CIAT and furnishes a 522-hectare site near Cali for CIAT's headquarters. In addition, The Colombian Foundation for Higher Education (FES) makes available to CIAT a 184-hectare substation in Quilichao and a 73-hectare substation near Popayán; the Colombian Rice Growers Federation (FEDEARROZ) also makes available to CIAT a 30-hectare farm—Santa Rosa substation—near Villavicencio. CIAT also comanages with the Colombian Agricultural Institute (ICA) the 22,000-hectare Carimagua Research Center in the Colombian Eastern Plains and carries out collaborative work on several of ICA's experimental stations in Colombia; similar work is done with national agricultural agencies in other Latin American countries. CIAT is financed by a number of donors represented in the Consultative Group for International Agricultural Research (CGIAR). During 1983 these CIAT donors are the governments of Australia, Belgium, Canada, France, the Federal Republic of Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States; the World Bank; the Inter-American Development Bank (BID); the European Economic Community (EEC); the International Fund for Agricultural Development (IFAD); the OPEC Fund for International Development; the Ford Foundation; and the Rockefeller Foundation. In addition, special project funds are supplied by various of the aforementioned donors plus the W. K. Kellogg Foundation, the German Agency for Technical Cooperation (GTZ), the International Fertilizer Development Center (IFDC), the United Nations Development Programme (UNDP), and the International Development Research Centre (IDRC).

Management and Evaluation of INTERCROPPING SYSTEMS WITH CASSAVA

Dietrich Leihner, Dr.agr.
Agronomist, Cassava Program

Centro Internacional de Agricultura Tropical
Cali, Colombia

Centro Internacional de Agricultura Tropical (CIAT)
Apartado 6713
Cali, Colombia

ISBN 84-89206-32-5
December 1983
Press run: 2000
Printed in Colombia
(Spanish version also available. Yuca en cultivos asociados: manejo y evaluación, 1982.)

Correct citation:
Leihner, Dietrich. 1983. Management and evaluation of intercropping systems with cassava. Centro Internacional de Agricultura Tropical, Cali, Colombia. 70 p.

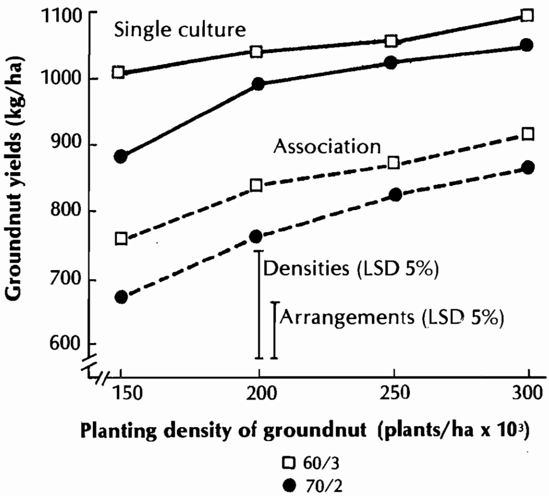
Cataloguing information:
1. Cassava — Plantings. 2. Cassava — Fertilization. 3. Cassava — Diseases and pests. 4. Cassava — Weed Control. 5. Legumes. 6. Intercropping systems. I. Centro Internacional de Agricultura Tropical. II. Title.

ERRATA

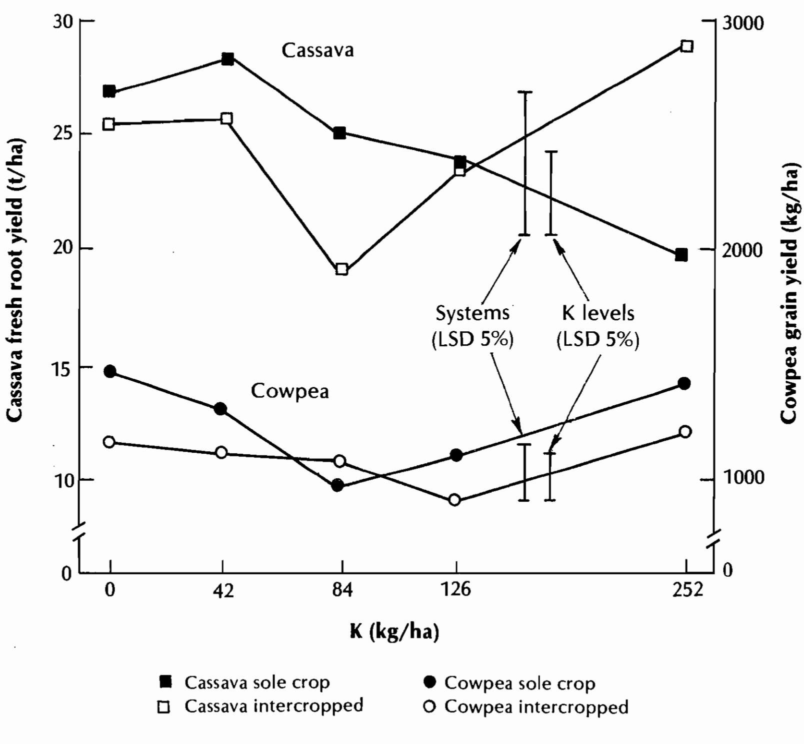
Management and Evaluation of Intercropping Systems with Cassava
(Leihner, 1983)

The identifying labels in two line graphs were reversed. Replace with the following figures:

p. 20 (Figure 11)



p. 25 (Figure 13)



Acknowledgments

I wish to thank Dr. John K. Lynam, economist of the CIAT Cassava Program, for his contribution of the chapter "Economic evaluation of intercropping systems." Futhermore, thanks are extended to my assistants, students, and co-workers for their valuable contributions. In particular, Ing. Agr. Diego Fonseca, Ing. Agr. M.S. Víctor Hugo Castellanos, and Dr. Bodo Hegewald, who have conducted their B.S. thesis, M.S. thesis, and postdoctoral research under my supervision, have contributed useful information to this text. The many comments and suggestions received by Drs. Anthony Bellotti, James H. Cock, Jeremy Davis, Reinhardt H. Howeler, and Carlos Lozano of CIAT; Raúl Moreno of the Centro Agronómico Tropical de Investigación y Enseñanza *(CATIE) in Turrialba, Costa Rica; and Roger Mead of Reading University, England, are acknowledged with gratefulness. Furthermore, thanks are due to Ing. Eduardo Granados M.S. for helping with the statistical analyses of data; Mary Luz de Isaza for typing the manuscript; and many others who in one way or the other have been of assistance.*

For the contribution of photographs, I wish to thank Drs. Kurt Georg Steiner, and Michael Thung and Mr. Diego Fonseca.

This publication is an abbreviated version of a habilitation thesis entitled "Cassava intercropping—management and evaluation of cassava intercropping systems" submitted by the author to the Faculty of Agronomy, University of Göttingen, Federal Republic of Germany.

Contents

Basic Aspects of Presently Practiced Intercropping Systems

Cassava (*Manihot esculenta* Crantz) is the fourth most important energy staple of the tropics, providing food and income for some 750 million people. This starchy root crop is of American origin, but today it is cultivated in tropical Africa, Asia, and America where 38, 36, and 26%, respectively, of the world production occurs. The total estimated world fresh-root production reached 122 million t in 1980. Cassava adapts to a wide range of ecological conditions and is known for its tolerance to low soil fertility, drought, and pests. This is why the crop continues to hold an important position in traditional tropical cropping systems, particularly in those of the small-farm and subsistence sectors. In these cropping systems, cassava is often found in mixed stands together with a variety of other food or cash crops. From personal experience, the traditional farmer adopts intercropping as a production system in order to reduce the risk of crop failure, obtain production at different times during the year, make the best use of the available land and labor resources, and provide the family with a balanced diet.

Recent estimates indicate that 40 and 50% (or more), respectively, of the cassava grown in America and Africa is intercropped, whereas in Asia, this percentage is likely to be lower. Each continent and region has developed its own characteristic crop combinations and sequences, the position of cassava often being at the end of relay intercropping systems. The greatest complexity of cassava intercropping systems is probably found in Africa, close to homestead gardens of rural farming families.

When small farmers adopt intercropping as the production system, a relatively small plot is sufficient to provide the family with the basic dietary elements. Cassava, sweet potato (*Ipomoea batatas*), yams (*Dioscorea* sp.), taro (*Colocasia esculenta*), and plantains (*Musa* sp.) are sources of carbohydrates and provide the primary caloric component; the intercrops, such as common beans (*Phaseolus vulgaris*), cowpeas (*Vigna unguiculata*), mungbeans (*Vigna radiata*), groundnuts (*Arachis hypogaea*), and pigeon peas (*Cajanus cajan*), will contribute the necessary protein. For example, 1 ha of cassava intercropped with black beans can produce 10 t/ha of fresh cassava roots (with 30% starch) and 600 kg/ha of beans (with 28% protein). This would provide the following amounts of food energy and protein:

$$10{,}000 \text{ kg/ha cassava}^1 = 13.44 \times 10^6 \text{ Kcal} = 56{,}270 \text{ MJ}$$
$$600 \text{ kg/ha beans} = 168 \text{ kg protein}$$

Assuming that the daily requirements of an adult person is 10.5 MJ (2500 Kcal) and 100 g of protein,[2] the above production of 1 ha would supply 5376 caloric rations and 1680 proteic rations; that is, 1680 complete rations and a surplus of 3696 caloric rations = 38,686 MJ (9.24×10^6 Kcal), without considering the protein content of cassava or the caloric value of beans. Thus, 1 ha supplies food for approximately five adults during 1 year, leaving a surplus of about 6 t of cassava for sale.

Although this is by no means a complete diet, and, furthermore, it is not likely that anyone would be able to subsist on this diet for a prolonged period of time, it is necessary to remember that in some areas of the world there are human beings with fewer calories and proteins to consume than this. The yields on which this calculation is based are those traditionally obtained with these crops in intercropping but with an improved technology and minimal inputs, they could easily be doubled (Fonseca, 1981).

Definitions

Multiple cropping—the production of two or more crops in the same field during the same year—is an effective way of intensifying agricultural production through the more efficient use of growth factors (light, water, nutrients), space, and time available for cultivation. Such use of growth factors, space, and time is possible in two different multiple-cropping patterns:

1. By **sequential cropping**—or producing two or more crops in single (or pure) stands, one after the other, on the same plot during the same year.
2. By **intercropping**—or growing two or more crop species at the same time in the same field.

Intercropping, the subject of this text, can be practiced in four different ways (Ruthenberg, 1971; Andrews and Kassam, 1976):

- **Mixed intercropping**—the simultaneous growing of two or more crop species in an irregular arrangement, i.e., without a well-defined planting pattern.

1. 10,000 kg of cassava contain 3000 kg of starch, the caloric value of which is 4480 Kcal/kg.
2. The normal daily protein requirement of an adult is presently estimated to be 60 g when 50% of the protein is of animal origin and the rest of vegetable origin. However, in the present case, only vegetable protein is provided. Therefore, a greater than normal requirement is assumed.

- **Row intercropping**—the simultaneous growing of two or more crop species in a well-defined row arrangement.
- **Strip intercropping**—the simultaneous growing of two or more crop species in strips wide enough to allow independent cultivation but, at the same time, sufficiently narrow to induce crop interactions.
- **Relay intercropping**—planting one or more crops within an established crop in a way that the final stage of the first crop coincides with the initial development of the other crop(s).

Biological Aspects

Intercropping of crop species with similar growth durations produces an advantage in the utilization of *space* only, whereas the association of crops with different growth durations results in a gain in total yield through better utilization of two dimensions, *space* and *time*. In both types of intercropping, however, the sum of interspecific competition is less than the sum of intraspecific competition of the same crops grown separately as sole crops. It is this lower sum that gives rise to a greater total yield of the intercropping system derived from either a greater yield per plant or a greater total plant population.

In intercrops of species with similar growth duration, the yield advantage is then derived from a lower "instantaneous" intercrop competition for space, both above and below ground. In intercrops of species with different growth durations, the yield advantage stems from low intercrop competition in space

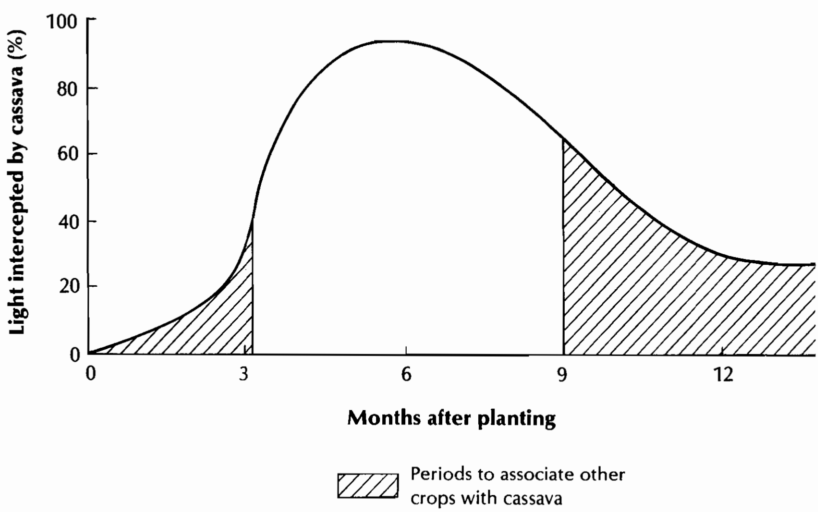


Figure 1. Interception of light by cassava during its vegetative cycle and possible periods for intercropping.

and time for the rapidly growing short-duration crop and from a lower intracrop competition in space and time for the slow-growing, long-duration component (Andrews and Kassam, 1976). A sole crop of cassava, which in this context may be considered a long-season crop, does not efficiently use the factors light, water, and nutrients during its early growth stages due to its slow initial development. Thus, a short-duration second crop may be interplanted to make more efficient use of these growth factors. Also, at the end of its growth cycle, cassava does not intercept all the incident light and probably also no longer absorbs the large quantities of nutrients and water that is needed during its most active development. Consequently, during this late stage of the growth cycle, cassava lends itself to intercropping (Figure 1).

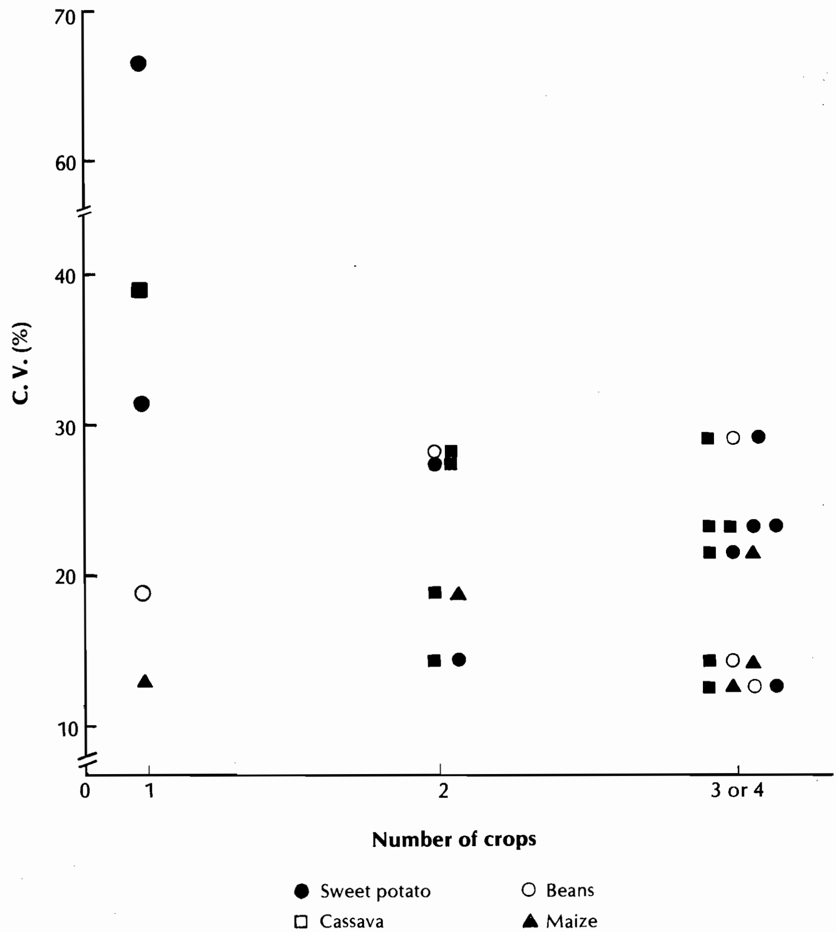


Figure 2. Coefficient of variability (C.V.) in biomass and yield of cassava, common bean, sweet potato, and maize in single culture and when intercropped in different combinations of these species.
Source: Adapted from Moreno and Hart, 1979.

Intercrops normally show less variability in total biomass and yield than do sole crops (Moreno and Hart, 1979); this applies both to total production and to individual yields of each component (Figure 2). Reasons for this greater stability, other than the compensatory effect among crops, may be found in the reduced incidence of diseases, insect pests, and weeds as a result of greater vegetative diversity and the better and earlier soil cover provided by the intercrop (CIAT, 1978; Leihner, 1979, 1980a; Moreno, 1979; and Moreno and Hart, 1979). For subsistence farmers, greater stability in the production of food crops in intercropping systems is particularly meaningful, since this characteristic of the production systems tends to better insure their sustenance and substantially reduce the risk of total crop loss.

Cassava Intercropping Systems Worldwide

Cassava has spread throughout the tropical world to such an extent that today more cassava is grown outside than within its areas of origin and domestication. Introduction into Africa occurred prior to 1558 by the Portuguese, via both the west and east coasts. Portuguese traders are also believed to have carried cassava to the Indian subcontinent in the early 18th century. At about the same time, it was introduced into Indonesia and the Philippines from Mexico, and, by the turn of the century, cassava was a well-known crop in southeast Asia (Cock, 1982.) Today, cassava is found in most of the lowland and intermediate elevation areas of the tropical world, but within these global limits it is grown in a wide range of differing climatic and soil conditions.

In Brazil, it can be found in the semiarid northeast with as little rain as 750 mm a year and mean maximum temperatures above 35°C, as well as in the Amazon rain forest with 2000 to 3000 mm annual rainfall. Cassava is one of the few crops that grows well on the acid, infertile soils of the Cerrado, where pH is as low as 4 and aluminum toxicity is high, but it is also found on fertile soils around São Paulo. In the Andean zones of Bolivia, Colombia, Ecuador, and Peru, it is grown up to elevations of 2000 m, with mean annual temperatures as low as 8°C. Cultivars and cultivation practices used by the farmers vary greatly from one region to the other; however, the ability of this species to grow under such contrasting conditions convincingly demonstrates its extremely wide adaptability.

Latin America

It is estimated that approximately 40% of cassava is intercropped in Latin America (Díaz and Pinstrup-Andersen, 1977). A very ancient crop association is that of cassava with maize (*Zea mays*), already practiced by the Mayas. Even today, prehistoric maize is found intercropped with cassava in remote parts of Guatemala where agriculture has remained traditional (Moreno and Hart, 1979). On the Colombian north coast, cassava is intercropped with maize by planting cassava in rows a little wider than normal (120 cm apart) and simultaneously interplanting maize at a low density (4000 hills/ha with

3–5 plants/hill). The production obtained in traditional cassava/maize intercrops was 600–800 kg/ha of maize and 10–15 t/ha of fresh cassava roots, with very little use of purchased chemical inputs (CIAT, 1980, p. 74–76).

The association of cassava with common beans or cowpeas is also very frequent. It is practiced all over the hemisphere, but is of particular importance in Central América, Colombia, and Brazil. The planting pattern of cassava is often not changed from the sole-crop arrangement, and beans are hill-interplanted in the same row after the first hand weeding (3–4 weeks after cassava planting). Thus, cassava yield is not affected (20–30 t/ha), but bean yields are very low (200 kg/ha) in farmers' fields in Colombia (CIAT, 1980, p. 74–76).

Other short-cycle crops associated with cassava in Latin America are upland rice (*Oryza sativa*), cotton (*Gossypium* sp.), and tobacco (*Nicotiana tabacum*) in Brazil, and pigeon pea and climbing beans (at the end of the cassava growth cycle) in Costa Rica and Colombia. Intercropping of cassava with other root and tuber crops, such as taro, yams, and sweet potato, is practiced in Nicaragua, while the triple association of cassava/maize/yams is typical in the Colombian northwest.

In addition, there are a great number of systems in which cassava is the short-season crop associated with perennial crops such as sugarcane (*Saccharum officinarum*) and cocoa (*Theobroma cacao*) in Costa Rica, oil palm (*Elaeis guineensis*) in Colombia, and coconut (*Cocos nucifera*) and rubber (*Hevea brasiliensis*) in Brazil. In these systems, cassava may be considered a secondary crop. Its productivity is normally low due to the reduced light incidence below the perennials when they have grown beyond their phase of initial development.

Africa

With the exception of several parts of the African continent in which agricultural production is characterized by large plantations of export crops, intercropping is very common in most of tropical Africa. Up to 50% or more of the cassava grown in Africa may be intercropped (S. Nyombe, personal communication, 1981). In Uganda, for example, 49% of the cassava is intercropped, whereas in Nigeria a lower portion of cassava (27%) is grown in intercropping systems (Okigbo and Greenland, 1976). Generally, cassava is grown in monoculture in fields far from the villages; near the homesteads, however, it is common to find very complex intercropping systems, which include a variety of annual food species, vegetables, and fruit trees.

The typical form of intercropping is relay intercropping, beginning with other crops and interplanting cassava when the earlier planted crops are fairly advanced in their crop cycle or are about to reach the end. There are typical sequences by regions such as:

- **Nigeria**—cowpea/amaranthus (as vegetable)/maize/cassava; taro/ maize/ cassava; taro/melon (*Cucumeropsis mannii*)/maize/okra (*Abelmoschus esculentus*)/cassava/cocoa.

- **Liberia**—upland rice/chili pepper (*Capsicum annuum*)/tomato (*Lycopersicon esculentum*)/common beans/maize/banana (*Musa* sp.)/cassava, all planted simultaneously.
- **Sierra Leone**—upland rice/maize/okra/chili pepper/cassava, in relay intercropping.
- **Zaire**—groundnut/cassava/sesame (*Sesamum indicum*)/watermelon (*Citrullus lanatus*)/sorghum (*Sorghum bicolor*)/hyptis (*Hyptis spicigera*)/ finger millet (*Eleusine coracana*).

In most of these sequences, cassava is grown as the last crop before changing the site. This is probably due to the fact that, in the still widely practiced system of shifting cultivation, soil fertility is exhausted after producing several crops on the same land, and only cassava with its ability to grow and produce on soils of low fertility yields reasonably well.

An analysis of cassava intercropping systems in Nigeria showed that 77% of cassava was planted on mounds prepared by hand and that mixed intercropping prevailed. Nevertheless, every single species had its specific position on top, on the sides, or at the bottom of the mound, cassava being frequently placed on the sides. Planting density was high (15,000 plants/ha); nevertheless, mean yields were never greater than 6 t/ha of fresh roots (Ezeilo, 1979).

Asia

There are no estimates regarding the percentage of intercropped casssava in Asia, but the proportion is certainly smaller than in Latin America and Africa. Nevertheless, intercropping cassava with a large number of other crop species, particularly in homestead gardens, is of great importance as a contribution to human nutrition in that part of the world, similar to Latin America and Africa.

Rice is the central element in most Asian cropping systems. In order to effectively produce this crop, irrigation systems were established which, according to the region, cover from 19 to 47% of the arable land (Harwood and Price, 1976). This could favor, but normally complicates, the growing of cassava together with other crops since paddy soils (rich in montmorillonite) are difficult to prepare under dry conditions for the nonirrigated crops.

Water regulation is essential for the production of wetland and dryland crops at the same time. It is achieved by making divisions between low and elevated parts in a field, as practiced in the "ditch and dike" system of Thailand or the "Sorjan" system of Indonesia (Suryatna, 1979). In these rainfed systems, rice is grown in low-lying strips, whereas the dryland crops are found on elevated beds of 4- to 8-m width. On these beds, cassava is normally on the borders, and toward the center there are usually one or several of the following crops: onion (*Allium cepa*), groundnut, soybean (*Glycine max*), chili pepper, maize, cucumber (*Cucumis sativa*), mungbean, and, sometimes, sweet potato.

The division between low-lying and elevated parts can be artificial or adjusted to natural topographic conditions. The latter is observed in southern India where irrigated rice predominates in the valleys, whereas cassava—frequently intercropped under coconut palms—is found in the transition zones between valleys and higher elevations.

In Indonesia, dryland cassava follows upland rice and maize as a third crop, the first two planted simultaneously and cassava intercropped 30 to 40 days later. Also common is relay cropping of cassava with groundnuts, cassava planted 30 days after the groundnuts. In Thailand, very little cassava is intercropped, but occasionally simultaneous association with maize is found. The planting pattern of cassava in this association is aproximately 1 x 1 m with both row and mixed intercropping being practiced.

The system of growing short-cycle annual crops together with a long-cycle relay crop (rice and maize with cassava) has an important implication where soil preparation is difficult and no motorized cultivation is available: with one single preparation it is feasible to produce two or three crops per year.

In India, Malaysia, the Philippines, and Thailand, more than in other Asian countries, cassava is also intercropped with perennials such as coconut, oil palm, rubber, mango (*Mangifera indica*), and banana. While in the previously described systems the productivity of cassava may be high, according to the intensity of management, yields are usually low when cassava grows intercropped under perennial species since its productivity is drastically reduced by shading (Mohan Kumar and Hrishi, 1979).

Improved Technology for Cassava Intercropping

As discussed in the preceding chapter, the productivity of cassava and its associated intercrops is low in the majority of traditional cropping systems. The most outstanding reasons for this low productivity are:

1. The association of species unsuitable for intercropping, due to incompatibility of plant type or growth cycle;
2. The coincidence of phases of maximum growth due to an inadequate relative planting date, resulting in excessive interspecific competition;
3. Selection of a planting density too much below or (in very few cases) too much above optimum, and inadequate planting patterns;
4. Low soil fertility and absent or deficient phytosanitary measures.

Several years of research efforts have been dedicated to the solution of these problems. As a result, it is now possible to describe the following elements that are desirable for an improved technology for cassava intercropping systems.

Plant Type Selection for Association

Cassava

In cassava, a wide range of growth habits exist with respect to branching and vigor (sometimes termed "leafiness"). Both characteristics may influence the quantity of light intercepted during early growth stages. Varieties with an erect growth habit (late branching) and medium vigor possibly cause less shade to an intercrop than those with early branching and high initial vigor. As seen in Table 1, the variety M Mex 59 with high initial vigor and early branching causes more reduction in the yield of intercropped beans than do five selected varieties with medium vigor and later branching. Furthermore,

Table 1. **Effect of casssava plant type (vigor and branching) on root yield in single culture and association, and on yield of intercropped common beans at CIAT-Palmira.**

Plant type and variety	Cassava yield		Bean yield	
	Sole crop[a] (t/ha)	Association[b] (t/ha)	Total (kg/ha)	Relative to sole crop[c] (%)
Vigorous, early branching				
M Mex 59	32.8	25.8	2077	89
Medium vigor, medium to late branching				
M Ecu 47	36.2	33.6	2747	117
M Ven 270	42.8	33.2	2455	105
M Col 1468	38.3	30.3	2361	101
M Pan 70	42.0	30.5	2313	99
M Ptr 26	40.2	28.4	2304	98
LSD 5%	NA[d]	9.1	254	11

a. Average of 4 years at CIAT.
b. Data for 1 year at CIAT.
c. Proportion of yield in single culture.
d. No statistical analysis available.
Source: Thung, 1978; Kawano, personal communication.

varieties with medium vigor and late branching more closely resemble the "ideal plant type for maximum yield" in single culture, described by Cock et al. (1979). The data presented in Table 1 show a numerical superiority in yield of this plant type, both in single culture and in association, although in this example the superiority was not statistically significant. On the other hand, bean yields were significantly more affected by the vigorous, early branching cassava than by the medium vigor, medium- to late-branching types.

It appears, then, that varieties with medium vigor and late branching (erect growth habit) are most suitable for intercropping since they impose relatively little competition on the intercrop initially and also have high yield potential. An exception is probably the cassava/maize association, where only the more vigorous cassava types compete favorably with the dominant crop, maize.

Grain legumes

When selecting a grain legume as an intercrop with cassava, an important characteristic is its earliness to flowering and maturity. With early maturity, the period of competition with cassava is reduced and excessive shading of the

Table 2. **Correlations between yields of cassava and associated legumes with varying number of days to physiological maturity.**

Species	Days to physiological maturity (no.)	Correlation of cassava/legume yields (r)
Bean	80	0.01
Cowpea	90	0.05
Peanut	106	−0.14
Soybean	125	−0.35*

* Significant at $P = 0.05$.

legume during pod-filling is avoided. When both crops are together in the field for a longer period of time, the interaction between them becomes more and more accentuated and yields are mutually affected. This was evident when the correlation coefficients of cassava yields were compared with those of four grain legumes. In associations of cassava with the early maturity legumes (common beans and cowpea), no correlation was observed between cassava and legume yields; however, an increasingly negative correlation was found when the legume growth cycle was greater than 100 days, indicating a higher degree of interaction between the associated species (Table 2).

The growth habit of the legume—erect or prostrate—does not appear to affect yields, as long as it is not a climbing type (for simultaneous planting). In a trial of cassava intercropped with nine varieties of cowpea, eight of these had an erect, semierect, or prostrate growth habit and reduced cassava yield from 6 to 24% compared to the sole-crop cassava. By contrast, one cowpea variety with a tendency toward a climbing growth habit reduced cassava yield by 32% (Hegewald and Leihner, 1980).

Nevertheless, climbing types of legumes—such as the common climbing bean (*Phaseolus vulgaris*), lima bean (*Phaseolus lunatus*), and velvet bean (*Mucuna deeringiana*)—can also be selected for association with cassava at the end of its growth cycle. The best adapted and most vigorous legume species and varieties may be chosen for this purpose since these crops must compete with an already established crop. Cassava, even when associated with the most vigorous climbing legumes, does not normally suffer a reduction in yield which, at this late stage of cassava development, is already mostly determined (CIAT, 1978, p. A66–A68; 1982).

Other crops

The great variety of other species intercropped with cassava has been described in the preceding section on worldwide systems. Several factors should be taken into account in the selection of these species for successful intercropping with cassava.

For simultaneous planting, the crop should have a growth cycle of preferably less than 100-days duration and an erect or prostrate growth habit. For planting near the end of the cassava growth cycle, the associated crop should not exceed 120 days to maturity when simultaneous harvesting of cassava and the intercrop is desired; for relay cropping into cassava, however, the growth duration of the intercrop is not important. Also, crops for interplanting into already established cassava should have either a bush or climbing growth habit, with shade tolerance being a particular desirable trait.

If the products from intercropping are destined for human or animal nutrition, protein sources, such as vegetable or grain legumes, should be selected as an intercrop rather than other carbohydrate sources, such as taro or sweet potato. On the other hand, if the products from intercropping are grown as cash crops for sale, any crop with acceptable profitability will serve as an intercrop.

It has already been mentioned that intercropping with perennials is also important. During the establishment phase of plantation crops, such as coconut, oil palm, or rubber, harvests of cassava can help to pay part of the establishment cost when there is still no production from the perennials. However, when the perennials grow and shade cassava, cassava ceases to produce profitable yields, and the intercropping system may no longer grant an economic advantage. As an exception, perennial fodder crops with a prostrate growth habit, such as *Stylosanthes guianensis,* can be intercropped with cassava for long periods of time with cassava benefiting from their nitrogen fixation (Nitis, 1977).

Relative Time of Planting

The relative time of planting—i.e., planting of the intercrop before, at the same time as, or after cassava—has both biological and practical implications. Cassava does not impose much competition at the beginning of its growth cycle, but it does not tolerate much competition either. As a result, cassava yields can be drastically reduced if the intercrop is planted earlier than cassava, imposing competition for light and other growth factors. On the other hand, if cassava is planted earlier than the intercrop, growth and yield of the intercrop can be affected by shading and competition for other growth factors.

Trials conducted with cassava and common beans have shown that greatest total yields were achieved when both crops were planted at the same time or with a difference in planting time of less than 1 week (Figure 3; Thung and Cock, 1979). This practice has been verified in many experiments, growing cassava in association with various grain legumes and maize. A practical implication of simultaneous planting is that it requires only one operation instead of two separate processes to establish the association. This facilitates a certain degree of mechanization in the establishment of inter-cropping systems if already-existing machinery is adapted for this purpose.

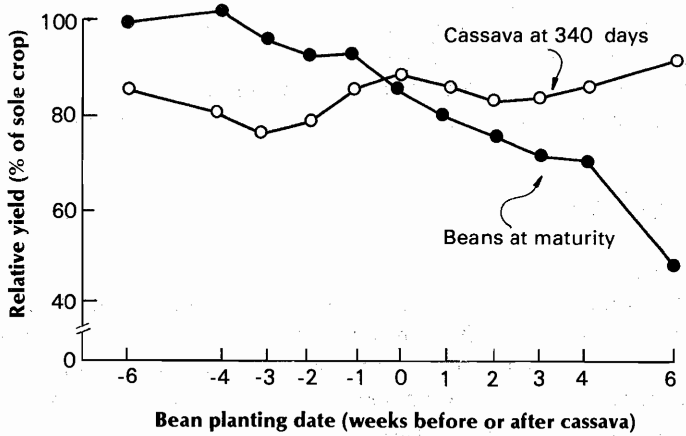


Figure 3. Relative yield of cassava and beans, in association, according to relative planting dates.
Source: Thung and Cock, 1979.

While relative planting time can help regulate light competition when the associated crops initiate their growth cycle together, the situation is different for an intercrop sown into established cassava. Here, light may be the most limiting factor for an intercrop. Nevertheless, observations made at CIAT showed that cassava intercepted less light toward the end of its growth cycle than during its phase of most active growth. This allowed the production of an intercrop under cassava during the last months before its harvest. Intercropping common bush beans at 7, 8, and 9 months after cassava showed that bush bean yield was reduced less at the latest planting date (9 months) since light conditions for the intercrop improved (Figure 4).

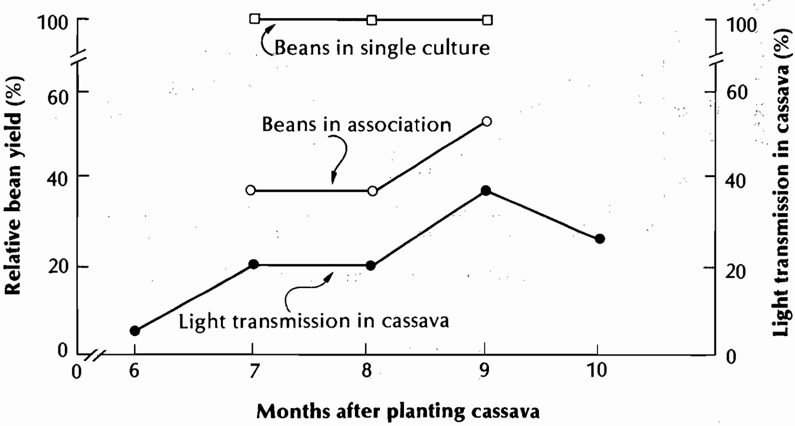


Figure 4. Effect of planting time (7, 8, and 9 months after cassava) on relative bush bean yields, as a function of light conditions under the cassava canopy.
Source: Castellanos, 1981.

It can be concluded that the later an intercrop is sown under an already established cassava crop, the better is its yield. Nevertheless, the productivity of an intercrop grown under these conditions is much below that of an association when both crops begin their growth cycle together.

Planting Density

Cassava

In traditional planting systems, cassava is frequently planted at lower densities in association than in single culture. Thirty-seven agronomists working with cassava in Latin America reported current planting densities in their countries ranging between 3000 and 25,000 plants/ha (average 11,300 plants/ha) for cassava as a sole crop and between 4000 and 18,000 plants/ha for intercropped cassava (average 8300 plants/ha) (Leihner and Castro, 1979). The reduced planting density, along with the competition imposed by one or more intercrops, may partially explain the low productivity of cassava in traditional intercropping systems. This situation can be corrected, however, by planting cassava at optimum single-culture density.

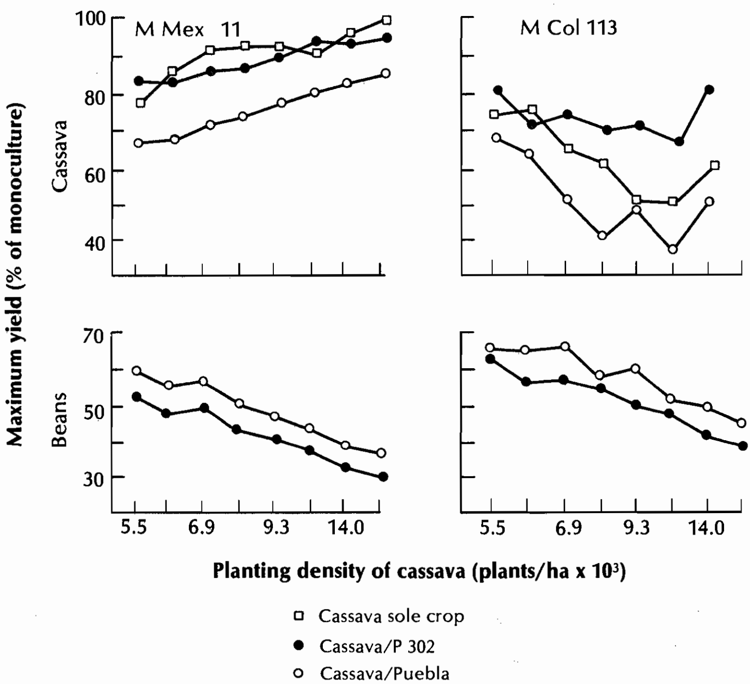


Figure 5. Relative yield response to planting densities of two cassava varieties (M Mex 11 and M Col 113) grown as sole crops and intercropped with two bean varieties (P 302 and Puebla 152).
Source: Thung and Cock, 1979.

With leafy and early branching varieties, such as M Col 113, maximum sole-crop yields of cassava are obtained at relatively low cassava planting densities (Figure 5); at the same time, these low densities produced the best yields in intercropped cassava. On the other hand, varieties with less foliage and late branching, such as M Mex 11, do not show this same degree of coincidence; nevertheless, this type of cassava in single culture still produces approximately 92% of maximum yield at intermediate planting densities, and acceptable yields (75–90% of maximum yield) of cassava can be obtained in association.

With an increment in cassava plant population, the yield of the intercrop is normally reduced (Figure 5). However, as shown by these results, only intermediate cassava plant populations are required to produce acceptable yields. Therefore, optimum sole-crop cassava plant populations can be used in intercropping without causing excessive yield reduction of the associated crop.

Grain legumes

Generally, the yield of grain legumes does not vary greatly in response to different planting densities within a relatively wide range. Trials with common beans, cowpea, and groundnut grown in single culture and intercropped with cassava showed constant yields, or not very accentuated

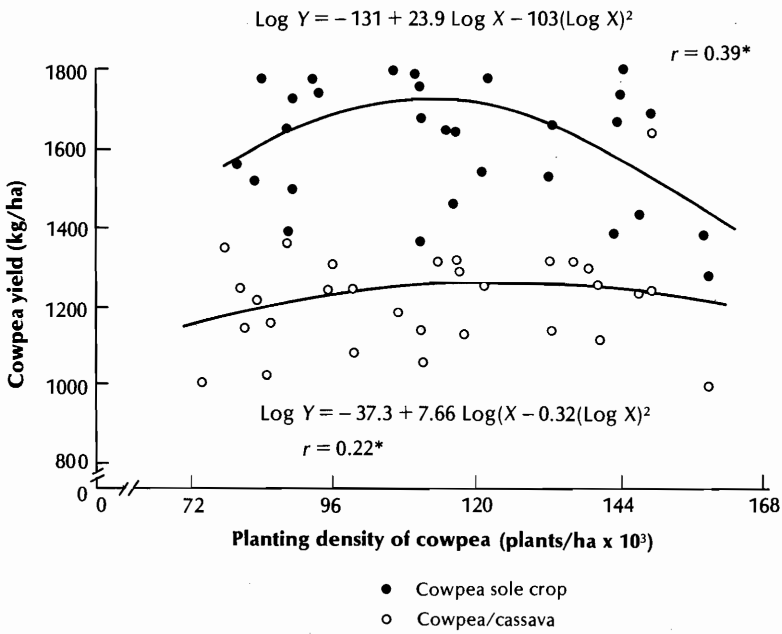


Figure 6. Effect of planting system and density on cowpea yields.
Source: Fonseca, 1981.

responses, in a planting-density range between 50 and 200% of optimum sole-crop density (Thung and Cock, 1979; Hegewald and Leihner, 1980; Fonseca, 1981). Using the optimum density for single culture, or a slightly greater density, in association frequently results in maximum yield when legumes are planted simultaneously with cassava (Figure 6).

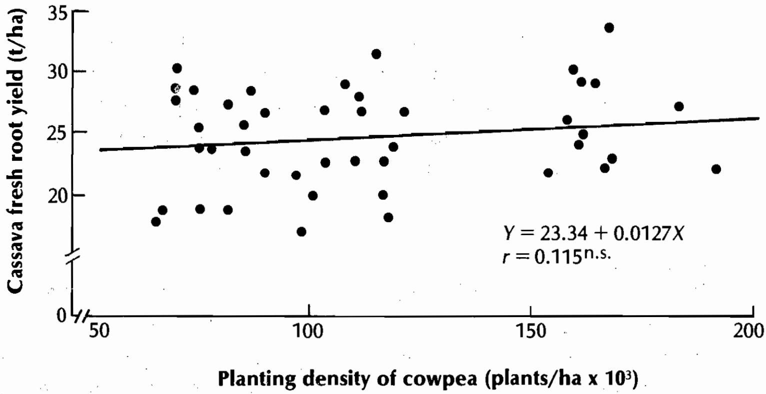


Figure 7. Relationship between the planting density of cowpea and the fresh root yield of cassava (the two crops grown in association).
Source: CIAT 1980.

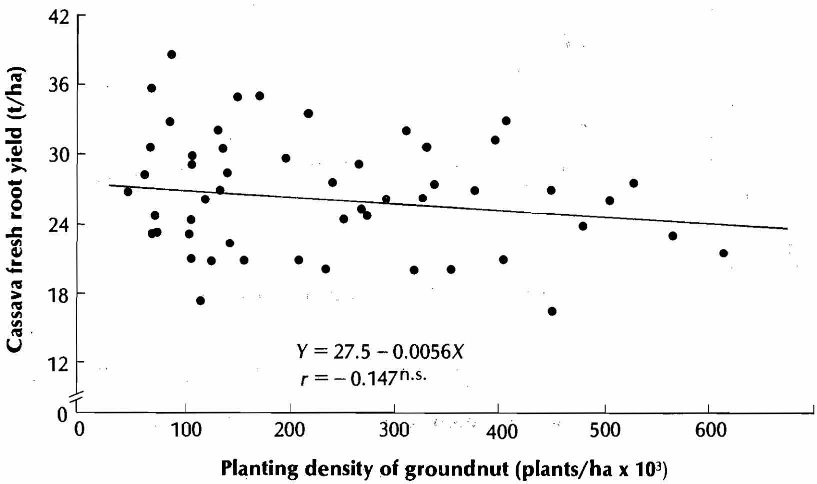


Figure 8. Relationship between the planting density of groundnuts and the fresh root yield of cassava (the two crops grown in association).
Source: CIAT, 1980.

Table 3. **Planting densities recommended for grain legumes in single culture and in association with cassava.**

	Adequate density (plants/ha)	
Species	Single culture	Association
Common bush bean (*Phaseolus vulgaris*)	200,000	250,000
Common climbing bean (*P. vulgaris*)	110,000	160,000
Cowpea (*Vigna unguiculata*)	80,000	110,000
Mungbean (*Vigna radiata*)	200,000	250,000
Peanut (*Arachis hypogaea*)	200,000	250,000

Theoretically, high grain legume densities should compete more with cassava and should reduce its yield more than low densities. However, in practice, no significant correlations have been observed between legume planting density and cassava yield (Figures 7, 8). This is why grain legume plant populations which give best results in single culture can also be used in intercropping systems with cassava. Table 3 shows optimum plant populations for grain legumes produced in single culture and in association.

Maize

The same principles regarding planting densities in single culture and in intercropping of cassava and grain legumes are also valid for cassava/maize associations. A traditional association with cassava planted at 1 × 1.2 m (8333 plants/ha) and maize at 2 × 1.2 m (three plants per hill, or 12,500 plants/ha) was compared with a more intensive system where cassava was planted at 10,417 plants/ha and maize at 41,667 plants/ha. No change in cassava yield was observed, but maize production was tripled in the more intensive system (CIAT, 1980, p. 74–76). Cassava did not suffer yield reduction at a higher maize density, due both to a spatial arrangement different from the traditional system (1.6 × 0.6 m), which minimized intercrop competition, and to a slight increase in the planting density of cassava itself. Also, a vigorous type of cassava was used (cv. Secundina), which may have tolerated the maize competition rather well. Even with a 1- × 1-meter arrangement of cassava, which is probably not adequate for this association, and a less vigorous type of cassava, the greatest efficiency, both in terms of land use and economy, was obtained with maize densities between 20,000 and 40,000 plants/ha in trials conducted in Costa Rica (Meneses, 1980). This again confirms that the use of normal sole-crop planting densities produces the most favorable results for intercropping.

Planting Pattern (Spatial Arrangement of Crops)

Spatial distribution in the field is of great importance in crop associations of two or more species, since it affects the efficiency with which solar radiation and space are utilized. At the same time, the spatial arrangement has an important influence on the degree of competition between crops. Theoretically, a planting pattern where every individual plant grows at an equal distance from the others would be ideal, allowing the most efficient use of resources for growth and production. However, practical reasons, such as land preparation and facility of planting, cultivation, and harvest, usually make a different arrangement more desirable. This applies both to cassava and to the crops associated with it.

Cassava

The most frequently used planting pattern for cassava in pure stand is 1 × 1 m or similar. However, this arrangement does not provide optimum conditions for the associations of intercrops since the cassava canopy covers the ground below more rapidly than in other types of arrangements, shading the intercrop from early on (Castro, 1980).

This led us to examine different planting patterns for cassava, providing more favorable conditions for intercropping. Experiments conducted at various locations confirmed that the variation of the spatial arrangement of cassava from square (1 × 1 m) to rectangular (2 × 0.5 m), including several intermediate patterns, did not affect cassava root yield when the same planting density was maintained (Table 4).

Table 4. **Effect of various spatial planting arrangements on yield of cassava at a constant planting density.**

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

a. At CIAT-Palmira, the effect of spatial arrangements on cassava yield was statistically not significant. No statistical analysis was performed for other locations.

Source: CIAT, 1977 and 1980.

These data suggest that a rectangular arrangement of cassava can be chosen that does not reduce cassava yield while it facilitates the accommodation of and creates more favorable conditions for an intercrop.

Grain legumes

In commercial crops of grain legumes in pure stands, normal row distance varies between 30 and 80 cm. Thung (1978) suggested an arrangement for grain legumes intercropped with cassava, planting cassava in beds at 1.80 m between rows (0.60 m between plants) and 0.90 m between legume rows, which is still within the normal variation of arrangements used in grain

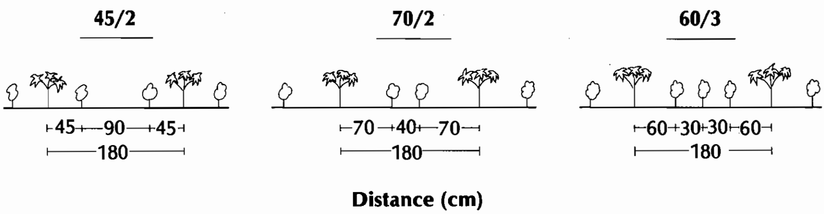


Figure 9. Spatial arrangements for cassava in association with legumes, planted on flat land.
Source: CIAT, 1979.

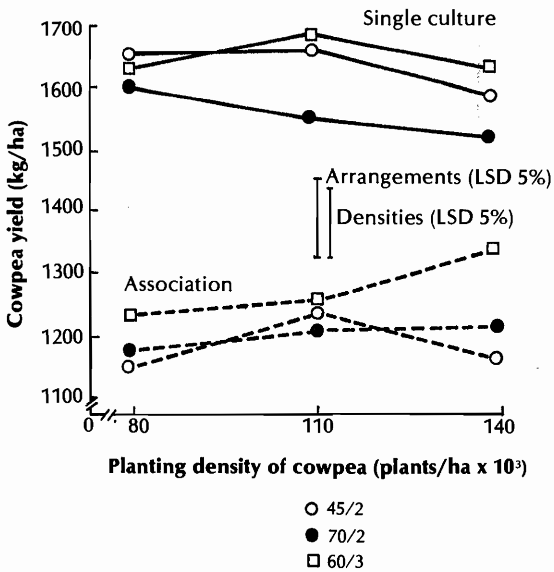


Figure 10. Yield response of cowpea in association with cassava and in single culture, to three spatial arrangements at three planting densities.
Source: Fonseca, 1981.

legume production. This same distribution of crops in feasible when cassava is grown on broad ridges. However, more flexibility is possible for accommodating legume rows between cassava when planting on flat land.

Three spatial arrangements of cowpea rows (Figure 9) planted between cassava on flat land were evaluated in the field. It was found that the more even distribution of the legumes (60/3 arrangement) more efficiently used the space available between cassava plants in a wide range of planting densities in both pure stand and association. The yield advantage of the 60/3 arrangement was statistically significant when compared to the 70/2 arrangement at 110,000 plants/ha in pure stand and when compared to both the 45/2 and 70/2 arrangements at 140,000 plants/ha in association. The less favorable result of the 70/2 arrangement in pure stand was possibly due to a high level of competition within the cowpea crop itself (intraspecific competition), whereas the generally lower cowpea yields of the 45/2 arrangement in association may have been due to a greater degree of competition between cassava and cowpea (interspecific competition) rather than competition within the cowpea crop (Figure 10).

Similar results were obtained when testing the 60/3 and 70/2 arrangements in a cassava/groundnut intercrop. The more even distribution of groundnuts achieved with the 60/3 arrangement, both in single culture and when intercropped with cassava, resulted in greater groundnut yields than in the 70/2 treatment, over the whole range of planting densities used in this experiment. The difference between the two arrangements was significant at 150,000 plants/ha in both planting systems and decreased at higher plant populations.

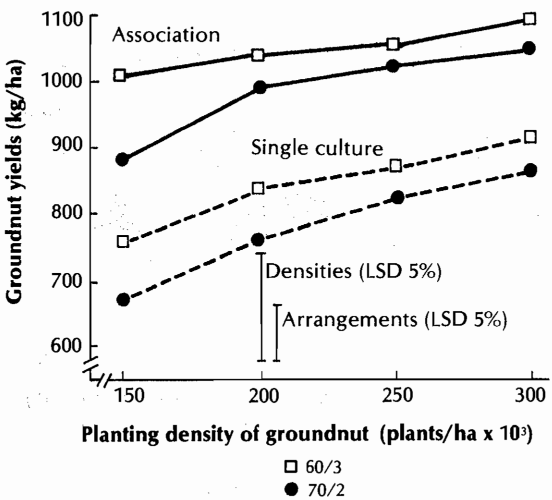


Figure 11. Yield response of groundnut in association with cassava and single culture, to two spatial arrangements at three planting densities.
Source: Fonseca, 1981.

This shows the need to consider also the interaction between the two factors—planting density and spatial arrangement. With increasing planting density, the 60/3 arrangement was each time more similar to the 70/2 arrangement. This result is logical since, even in the 60/3 arrangement, higher densities induced more intraspecific competition, so that the field situation for groundnuts was similar to the one prevalent in the 70/2 arrangement (Figure 11).

These results suggest that the more evenly distributed the legumes within the space available between cassava rows, the greater their yield, due to a more complete utilization of growth factors along with a low level of intraspecific competition. Nevertheless, it is not advisable to spread the legumes too widely within the available space, thus placing them too close to the cassava, since this would increase the competition between the two crops.

Mineral Nutrition and Fertilization

Intercropping has been considered advantageous also due to the effect it has on soil conservation. Burgos (1980) found that in various associations of cassava with other crops, absorption of soil nutrients by the crops was superior to the loss of nutrients through leaching and erosion, whereas, in a cassava sole crop, nutrient loss through leaching and erosion was several times greater than absorption by the crop.

On the other hand, the association of cassava with other crops represents an intensification of the demand for nutrients, particularly when each associated crop is planted at its normal single-culture density. In this situation, the removal of elements from the soil is greater in the intercropping system that in single culture, and, if these nutrients are not replaced by adequate fertilization, soil fertility deterioration occurs (Table 5).

Very little or no information exists on the correct fertilization of an intercropping system: nutrient requirements and response of individual crops to various elements, possible changes of response in association, aspects of nutrient competition and complementation, correct method of fertilizer

Table 5. **Removal of soil nutrients by the products (roots and grains) harvested in a cassava/mungbean association, compared to removal of cassava in single culture.**

	Nutrients removed (kg/ha)					
System	N	P	K	Ca	Mg	S
Cassava in single culture	40	5	78	19	8	6
Cassava/mungbean association	90	11	84	18	10	9

application (broadcast or banded), appropriate time for fertilizer application, and best nutrient sources. Many of these questions are still unanswered; following is some preliminary information.

Nutrient requirements of cassava and intercrops

The nutrient requirements of cassava and of some of its more frequently used intercrops have been relatively well studied. Cassava removes large amounts of nitrogen and potassium from the soil, even more so when the above-ground part of the plant is not reincorporated in the soil. However, the response of cassava root yield to fertilization with these elements is frequently not very marked, except in prolonged and continuous cassava production. Under these circumstances, response to potassium may be more accentuated. On many poor soils, cassava profits greatly from mycorrhizal association for the absorption of phosphorus. It also responds markedly to phosphorus application even though only small quantities are removed from the soil. In poor soils, such as the tropical Oxisols and Ultisols, magnesium, sulfur, and particularly zinc nutrition of cassava is of importance (Howeler, 1981).

The different grain legume species with short growth cycles have similar nutritional requirements. Although they remove large quantities of nitrogen, they have the capacity to fix this element, thus partially satisfying their nitrogen requirement. On many poor soils, grain legumes also markedly respond to phosphorus, without removing large quantities of this element. Specific requirements are observed with respect to several micronutrients, such as boron (Howeler et al., 1978) and zinc (CIAT, 1977); in some species such as groundnut, calcium is also an important nutrient. In maize, the major requirement to achieve normal growth and a good yield is for nitrogen followed by potassium and phosphorus. In many poor soils, phosphorus becomes an important macronutrient and zinc and boron important micronutrients (CIAT, 1973).

Selection of crops for association

Correcting deficiencies of infertile soils through application of soil amendments and fertilizers is biologically sound, but may not be economical when large amounts of soil amendments or costly fertilizers are necessary. An alternative approach to obtain good agricultural yields on poor soils is the selection of crops which adapt well to unfavorable conditions such as nutrient deficiency, acidity, and aluminum and manganese toxicity, and produce acceptable yields with little inputs. Specifically, the selection of species with tolerance to acid, infertile soil conditions prevalent in large parts of the tropics, would help reduce the amount of inputs required for agricultural production in those areas.

A study was conducted on an extremely acid Oxisol of the Eastern Plains of Colombia (Table 6) to evaluate growth habit and yield of six crops—cassava, cowpea, rice, maize, black common beans, and nonblack common beans—at calcitic lime levels of 0, 0.5, 2, and 6 t/ha. Without lime application, cassava

Table 6. **Soil physical and chemical characteristics at three Colombian experimental sites: Carimagua (Eastern Plains), Quilichao (Cauca Valley), and Caribia (north coast).**

Site	Soil texture	O.M. (%)	P (Bray II) (ppm)	pH	Soil content (meq/100 g) Al	Ca	Mg	K	Al saturation (%)
Carimagua	Silty clay	3.4	1.4	4.1	3.1	0.37	0.17	0.08	83
Quilichao	Clay	7.1	1.8	4.3	2.8	1.80	0.70	0.18	51
Caribia	Sandy loam	1.4	89.4	5.7	0.0	3.40	0.60	0.12	0

yielded 54% of the maximum yield obtained with 6 t lime/ha; with only 0.5 t lime/ha, root production was 76% of the maximum. On the other hand, yields of common beans (both black and nonblack), maize, and rice were minimal at the 0 lime level and only moderate with 2 and 6 t lime/ha. Cowpea was the only crop with tolerance similar to or better than cassava to acidity and low fertility. At 0 and 0.5 t lime/ha, respectively, cowpea yields were 60 and 80% of the maximum yield (Cock and Howeler, 1979).

A large collection of grain legumes was tested on a highly acid, infertile Inceptisol at CIAT-Quilichao (*see* Table 6) for both adaptation to the extreme soil conditions and suitability of plant type for intercropping. The collection included cowpea (61 varieties), mungbean (66), pigeon pea (14), winged bean (*Psophocarpus tetragonolobus*) (9), velvet bean (2), and one cultivar each of groundnut, jack bean (*Canavalia ensiformis*), and sword bean (*C. gladiata*). These were grown in a two times replicated, complete randomized block design in pure stand and intercropped with cassava.

Of all these, only cowpea and groundnut showed outstanding adaptation to soil conditions and were suitable for simultaneous intercropping, whereas the plant type and adaptation of velvet bean suggested its potential for planting in association with cassava at the end of the cassava growth cycle. All the other species either did not tolerate the extreme soil acidity, toxicity of aluminum and manganese, and infertility (mungbean, winged bean) or were unsuitable for intercropping with cassava due to their growth habit (pigeon pea, jack bean, sword bean) (CIAT, 1979, p. 60–64; Hegewald and Leihner, 1980).

Response to fertilization in pure stand and association

Response to the major nutrients of both cassava and the intercrops most frequently associated with it (grain legumes, maize) was amply studied under single-culture conditions in largely varying edaphic situations (Jacob and v.

Uexküll, 1973; Andrew and Kamprath, 1978; Howeler, 1981). However, it is important to point out that these crops, when grown in association, may show a markedly different response to that observed in single culture.

Trials were conducted at Caribia on the Colombian north coast on a medium-fertility soil (*see* Table 6) to establish the response of cassava and cowpea to nitrogen and potassium application, when grown in pure stand and in association. A fundamental difference was found in the response to nitrogen and potassium between cassava in pure stand and intercropped cassava. In pure stand, fresh root yield showed a positive response to nitrogen and potassium application only up to the first increment, the response to nitrogen being statistically significant. At higher application levels of these two elements, however, a yield decline was observed, leading to lower than check level yields—i.e., yields obtained with 0 kg/ha of nitrogen and potassium. In the case of potassium, this yield depression was statistically significant. Stem and foliage growth increased with the application of both elements, bringing about a decrease in harvest index which is often related to most yield reduction (Cock et al., 1979).

In contrast, cassava intercropped with cowpea showed a positive root yield response from the second to the fourth increment of nitrogen and potassium. Yield increase over the intercrop check levels was statistically significant in

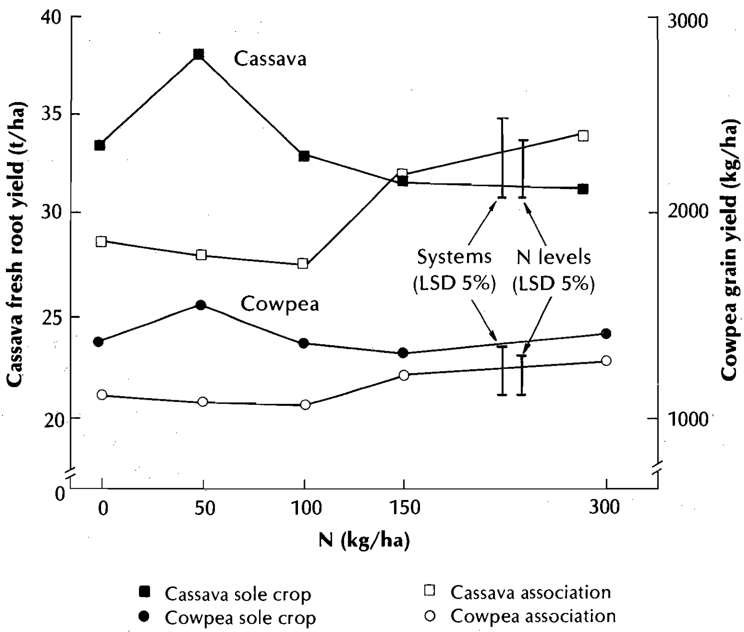


Figure 12. Yield response of cassava and cowpea in association to band-applied nitrogen, as compared to the response of the sole crops.
Source: CIAT, 1980.

the case of nitrogen and close to significant in the case of potassium. Cowpea, on the other hand, did not show an appreciable degree of response to either nitrogen or potassium, and no difference was observed in the response to these elements between the intercrop and the single culture. There was a peculiar yield reduction in both sole-cropped cowpea and intercropped cassava at the 84 kg potassium/ha level, which, although significant, probably did not reflect a true effect of potassium application since these two treatments were selectively affected by flooding in two of the trials' four replicates (Figures 12, 13).

A different situation was found when the same experiments were conducted with increments of phosphorus on the highly phosphorus-deficient and phosphorus-fixing soil of CIAT-Quilichao (*see* Table 6). Under these conditions, both cassava and cowpea yields responded positively to increasing phosphorus applications, reflecting the serious deficiency of this element in the soil (Figure 14). Cassava grown in pure stand showed an almost linear yield response to increased phosphorus levels, reaching the highest yield with the highest level of applied phosphorus. However, in association with

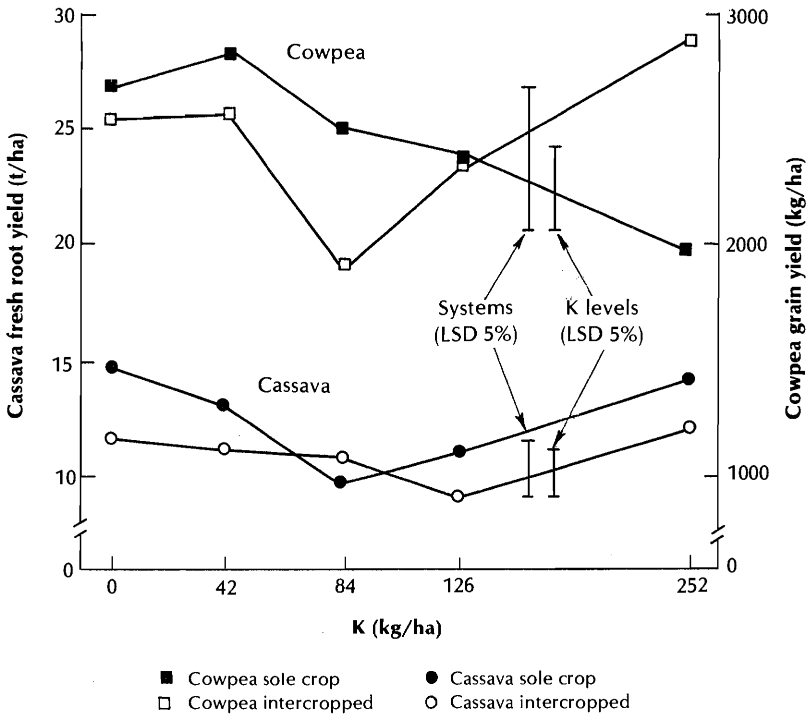


Figure 13. Yield response of cassava and cowpea in association to band-applied potassium, as compared to the response of the sole crops.
Source: CIAT, 1980.

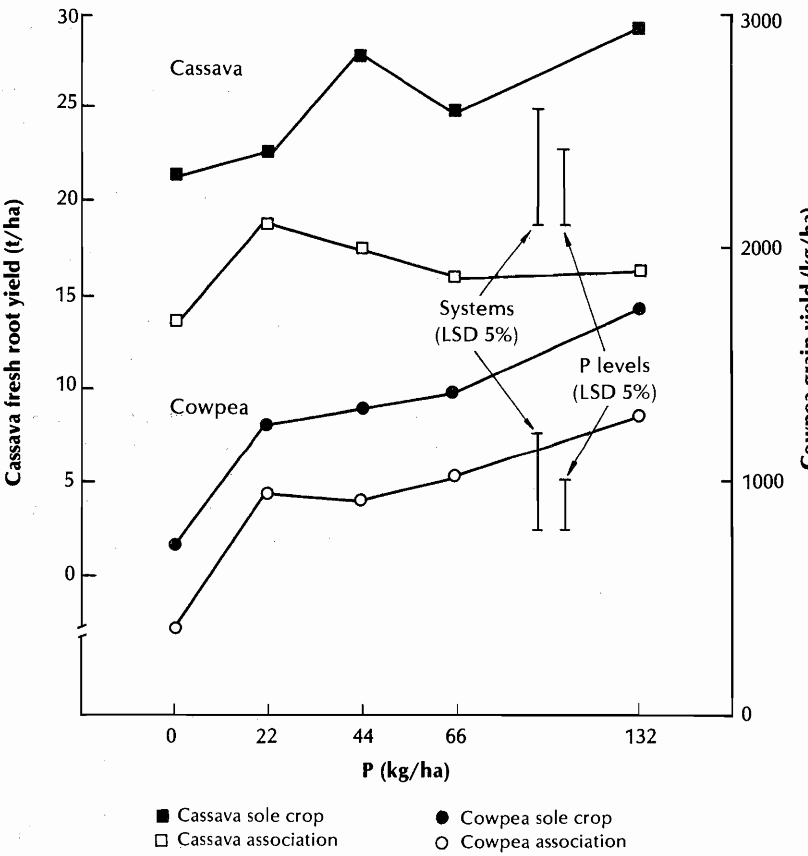


Figure 14. Yield response of cassava and cowpea in association to band-applied phosphorus, as compared to the response of the sole crops.

cowpea, cassava responded only up to the first increment of phosphorus. This somewhat different response of cassava in association than in single culture may be explained both by the strong competition for phosphorus between the two species and by the fact that higher phosphorus levels caused a drastic change in relative competitiveness of the two crops, in favor of cowpea. Cassava yield was reduced, whereas cowpea showed a strong positive yield response to phosphorus in both cultivation systems.

From the above it may be concluded that, to insure an adequate and economic supply of nutrients for intercropping systems, it is important to know the response to these nutrients of each crop when grown in association. This response sometimes shows the same tendency in single culture and in association (as was the case with cowpea and phosphorus at CIAT-Quilichao); but, on other occasions, single culture and intercrop responses can be significantly different (as in the case of the response of cassava to nitrogen and potassium at Caribia). Thus, no conclusion on the fertilization of an intercropping system can be derived only from information on the requirements and responses to certain nutrients of crops in pure stands. Rather, it is necessary to study the response to fertilization of the intercropping system, in order to establish optimum nutrient levels under different soil conditions.

Nutrient competition in crop associations

The competition for nutrients in crop associations may involve many factors. Nutrient competition occurs when the absorption zones of two or more plants overlap. This overlapping is more frequent and occurs sooner when competition is for the mobile nutrients, since these pass more readily through the soil and are absorbed more easily. Thus the zone of depletion around the roots increases in size faster and overlaps sooner (Kurtz et al., 1952; Bray, 1954).

Differences in nutritional requirements and in absorption efficiency are causes of competition between the components of a crop association. Competition for one nutrient at the same time may alter the ability of the component crops to compete for light, water, and other nutrients.

Usually, root systems of different species do not interfere with each other in crop mixtures, possibly due to both root antagonism and the tendency of the growing root to avoid moisture-depleted zones (Raper and Barber, 1970; Litav and Wolovitch, 1971; Dalal, 1974; Trenbath, 1976). This helps avoid competition for the more immobile nutrients, but, at the same time, restricts the soil volume explored by the roots. Both the stratification of root systems (i.e., the expansion of roots of different species to different soil depths) and the partial separation of roots could help reduce competition for nutrients (Cable, 1968; Chang, 1969).

In practice, competition between species presents itself as a reduction in vegetative growth and productivity. Nutrient concentration in plant tissue may also be affected by competition. The measurement of growth and yield, the response to the application of nutrients, and direct tissue analysis are therefore useful tools to evaluate and quantify competition.

For example, the response to nitrogen of cassava in association with cowpea as compared to its response as a sole crop (*see* Figure 12) shows that cassava suffered from competition for this element. By contrast, the absence of a response of cowpea to nitrogen and the legume's minimal difference in grain yield when grown as a sole crop or intercropped, suggests that cowpea did not suffer from competition for nitrogen by cassava. This is probably due not so much to cowpea's rather limited nitrogen-fixing capacity, but is a result of the rapid root expansion, both in width and depth, which may have enabled cowpea to take up nitrogen from soil levels which cassava roots did not reach.[3]

---

3. Observations of cowpea roots in this trial showed a generally poor nodulation, which decreased as nitrogen levels increased.

A similar situation was observed regarding competition for potassium. The marked yield increase of intercropped cassava at higher levels of potassium suggests this element might have been somewhat limiting in the association at low levels of applied potassium and that this situation of competition was corrected by higher potassium levels (*see* Figure 13). Here again, cowpea did not show a significant yield increase as a reponse to potassium application, and, hence, very likely did not suffer from potassium competition.

Not so in the case of phosphorus where both crops showed a marked positive response to higher phosphorus levels. This suggests that there was a strong competition of both crops for phosphorus fertilizer applied in this trial, as a result of the very low soil phosphorus and high phosphorus-fixing capacity of the soil. The specific response of cassava in association with cowpea reveals the differences in tolerance to low soil P of the two species: with little phosphorus added, cassava, the more tolerant species, showed a positive yield response. This response was not marked, however, at higher phosphorus levels, when cowpea became more competitive, causing a reduction in cassava yield. In turn, cowpea showed the highest grain yields only with the last increment of phosphorus (*see* Figure 14). As the response curves might suggest, even the highest phosphorus level may not have been sufficient to meet both crops' demand for phosphorus when grown in association as well as single culture (CIAT, 1980, p. 52–55).

Through tissue analysis, it is also possible to determine if a crop suffers more nutrient competition in association than in single culture. In the experiments on yield response to nitrogen, phosphorus, and potassium of cassava/cowpea in association and as sole crops, foliar analysis data confirm the observations made in relation to competition. Tables 7 and 8 show lower nitrogen and potassium concentrations in leaves (N) and petioles (K) of intercropped cassava, indicating that cowpea competed with cassava for these elements. Cowpea itself was not affected by competition for these two

Table 7. **Effect of various rates of band-applied N on the N leaf concentration of cassava and cowpea grown as sole crops and intercropped.**

N applied (kg/ha)	Leaf concentration of N (%)			
	Cassava		Cowpea	
	Sole crop	Intercropped	Sole crop	Intercropped
0	5.04	4.82	4.76	4.51
50	5.35	4.84	4.54	4.62
100	5.24	4.54	4.34	4.45
150	4.73	4.54	4.23	4.51
300	5.24	4.82	4.82	4.56
Average (% of single culture)	100	92	100	100

Source: CIAT, 1980.

Table 8. **Effect of various rates of band-applied K on cassava petiole and cowpea leaf K concentrations on cassava and cowpea grown as sole crops and intercropped.**

K applied (kg/ha)	Leaf or petiole concentration of K (%)			
	Cassava		Cowpea	
	Sole crop	Intercropped	Sole crop	Intercropped
0	3.23	3.27	2.13	1.93
42	3.51	2.92	1.84	2.19
84	3.67	3.55	1.78	1.78
126	4.23	4.01	1.87	1.93
252	4.41	3.88	2.29	2.29
Average (% of single culture)	100	93	100	102

Source: CIAT, 1980.

Table 9. **Effect of various rates of band-applied P on leaf P concentration of cassava and cowpea grown as sole crops and intercropped.**

P applied (kg/ha)	Leaf concentration of P (%)			
	Cassava		Cowpea	
	Sole crop	Intercropped	Sole crop	Intercropped
0	0.26	0.26	0.26	0.26
22	0.25	0.22	0.29	0.28
44	0.27	0.19	0.26	0.27
66	0.25	0.21	0.28	0.24
132	0.27	0.24	0.39	0.34
Average (% of single culture)	100	86	100	92

Source: CIAT, 1980.

nutrients. On the other hand, phosphorus concentration in both cassava and cowpea tissue was reduced in the intercrop situation, indicating that both crops competed strongly for phosphorus, apparently affecting cassava more than cowpea. The fact that at higher phosphorus levels, foliar phosphorus concentration in intercropped cowpea increased, whereas it did not in intercropped cassava, suggests that as phosphorus levels increased, cowpea became a stronger competitor leaving less phosphorus for uptake by cassava (Table 9).

Fertilizer application methods

The fertilization method to be used in intercrops, as is the case with pure stands, is determined by soil characteristics, precipitation, type of fertilizer, and crops grown.

In a sandy soil, broadcast application exposes the fertilizer to more loss through leaching than does band application. Acid tropical soils often fix phosphorus, leading to losses in the availability of this nutrient when soluble phosphorus sources are broadcast. Again, band application better protects the nutrient from being lost. When half the fertilizer was broadcast and the other half applied in bands, the greatest yields were obtained in a cassava crop grown on ridges during the rainy season in an Oxisol of Carimagua, in the Eastern Plains of Colombia. On the other hand, in dry season plantings on flat land, the best results were obtained when all the fertilizer was broadcast (Howeler, 1981).

In general, soil amendments with low solubility, such as calcitic lime, dolomitic lime, basic slag, or rock phosphate, give better results when broadcast and incorporated into the soil. With this method, the largest possible surface of contact between the amendment and the soil is achieved, thus inducing the greatest reactivity. However, fertilizers with high nutrient concentration and solubility often are used more efficiently by the crops when band-applied.

Annual crops associated with cassava, such as grain legumes or maize, have deep-reaching and finely branched root systems. In contrast, cassava has a rather sparse root system with a small number of root hairs, but it is aided in absorbing phosphorus, and possibly other nutrients and water, by mycorrhizal association (Howeler, 1981). This means that the absorption efficiency of both cassava and its intercrops could be similar in spite of morphologically different root systems. Therefore, the fertilization method in intercropping systems with cassava may be determined more by soil and climatic conditions and the type of fertilizer to be aplied than by the absorption characteristics of the crops.

These conclusions are supported by results obtained at CIAT-Quilichao and Caribia applying N-P-K broadcast or banded to cassava/cowpea intercrops. On the phosphorus-fixing soil of CIAT-Quilichao, cowpea responded slightly, although not significantly better, to band-applied than to broadcast phosphorus when triple superhosphate, a highly soluble form of phosphorus was used; cassava, however, did not respond differently to broadcasting or banding (Figure 15). At Caribia, no significant differences in cowpea yields were obtained when nitrogen in the soluble form of urea was applied in bands or broadcast. Cassava responded better to broadcast application of nitrogen, which could be related to a better uptake of nitrogen by the sparse cassava root system when broadcast rather than banded (Figure 16). In the case of potassium, applied as potassium chloride, neither cassava nor cowpea showed different responses to the two methods of application (CIAT, 1980, p. 52–55).

The cultivation of cassava with maize, here in the field of a small farmer in Ecuador, is probably the most common crop association in tropical America.

The association of cassava with bananas and peanuts, such as the one shown in this photo from Rwanda, is frequently found in Africa.

A typical system in Asia is the intercropping of cassava under coconut palm trees.

The most appropriate type of cassava for association has a late branching, erect growth habit (left); the early branching, vigorous type (right) is too dominant for many associations.

Grain legumes are especially suited for intercropping with cassava. They can be of bush type (top) or climbing type (bottom), if adequately managed.

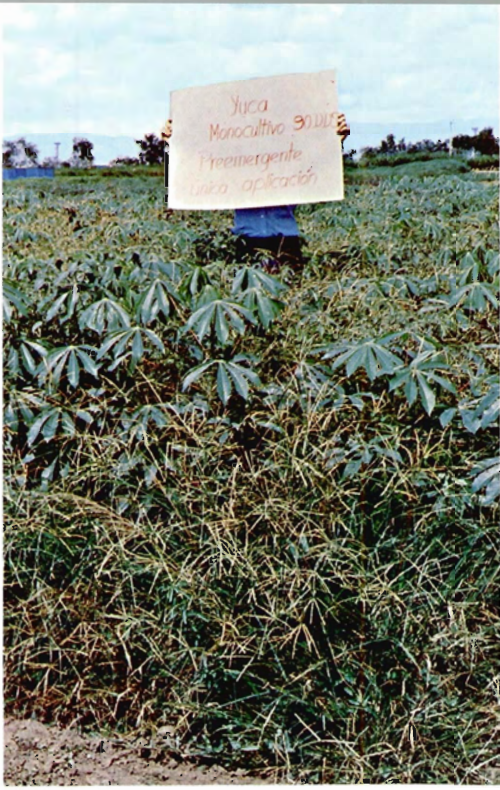
Vigorous cassava varieties are suited for association with medium-height maize types. These characteristics are found in the local cassava cultivar Secundina and maize varieties such as Suwan 1, shown in the photo.

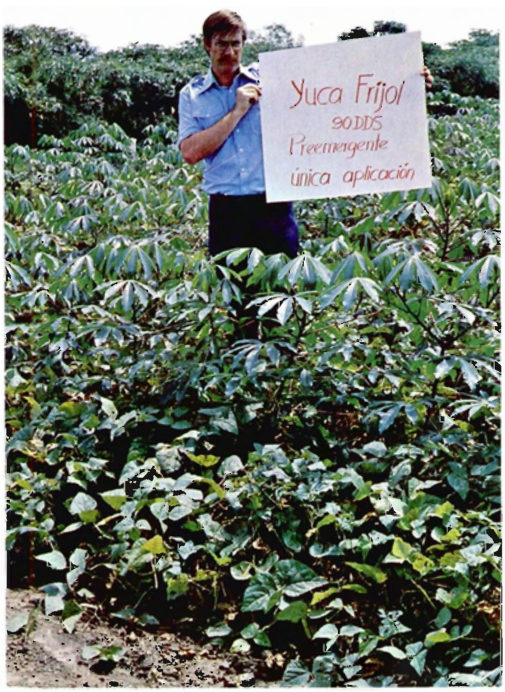
Simultaneous planting of cassava and cowpea in the 60/3 arrangement allowed a more balanced distribution of the legume between cassava rows and a higher biological production in this system, than did other arrangements. The development of the association at 15,50, and 90 days after planting is shown.

Nitrogen deficiency in the association of cassava and cowpea can reduce cassava growth without affecting the legume's productivity. Applications of N considerably improve cassava's growth and productivity, increasing its competitive ability with cowpea.

Phosphorus deficiencies and P fixation in the soil drastically affect cowpea growth but do not affect cassava, a species with more tolerance to these conditions (left, *0 kg/ha P_2O_5). The growth and productivity of the legume is significantly increased with the application of this element, thus improving its competitivity* (right, *150 kg/ha P_2O_5*).

The association of crops normally reduces the damage caused by various diseases and insect pests. However, should one of the species in the association succumb to an attack, the others remain healthy, thus avoiding total loss.





Cassava as a sole crop was completely infested by weeds after the preemergence herbicide applied at planting had lost its effectiveness (top). In contrast, the cassava/bean association showed an excellent, lasting weed control achieved through a combination of chemical and cultural means (bottom).

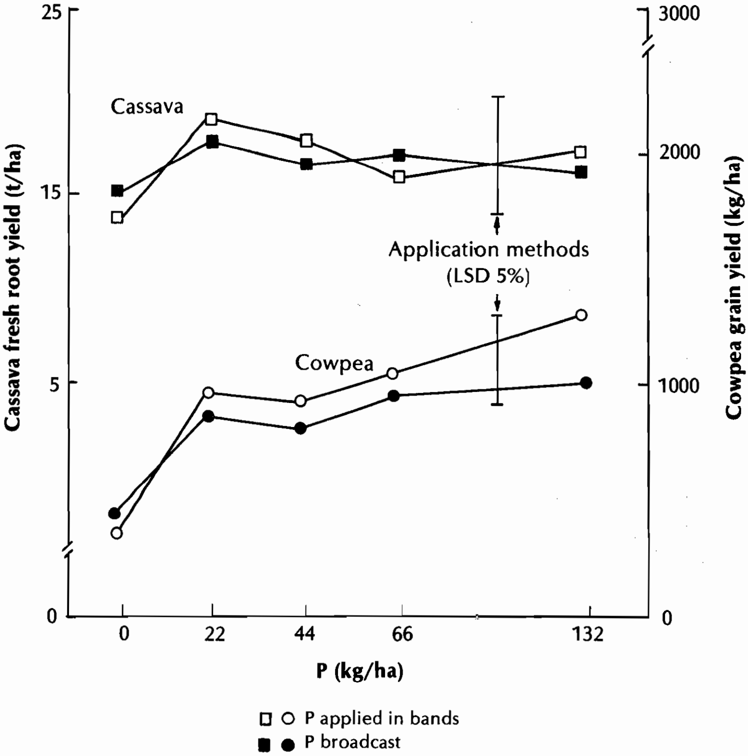


Figure 15. Yield response of cassava and cowpea in association to phosphorus fertilizer applied in bands or broadcasted.

Conclusions on fertilization

When intensive management is used, the extraction and removal of almost all soil nutrients is greater in an intercropping system than in single culture. Thus, special attention must be given to plant nutrition in association to ensure that soil fertility is not quickly eroded. Observations made to date indicate that:

1. Nitrogen uptake is almost doubled in cassava/legume intercropping and increased considerably in cassava/maize associations. Thus, nitrogen fertilizer application is required to obtain stable production from the associated system. In this case, adequate treatment might be to add each crop's individual nitrogen requirement to obtain the total amount of nitrogen needed for the association. Although this recommendation appears to suggest the use of large amounts of nitrogen fertilizer, the required application may in fact be rather small if the cassava is repeatedly grown in association with efficient nitrogen-fixing legumes. This practice not only reduces the amount of nitrogen fertilizer required by the associated crop but also, in the long run, enhances the accumula-

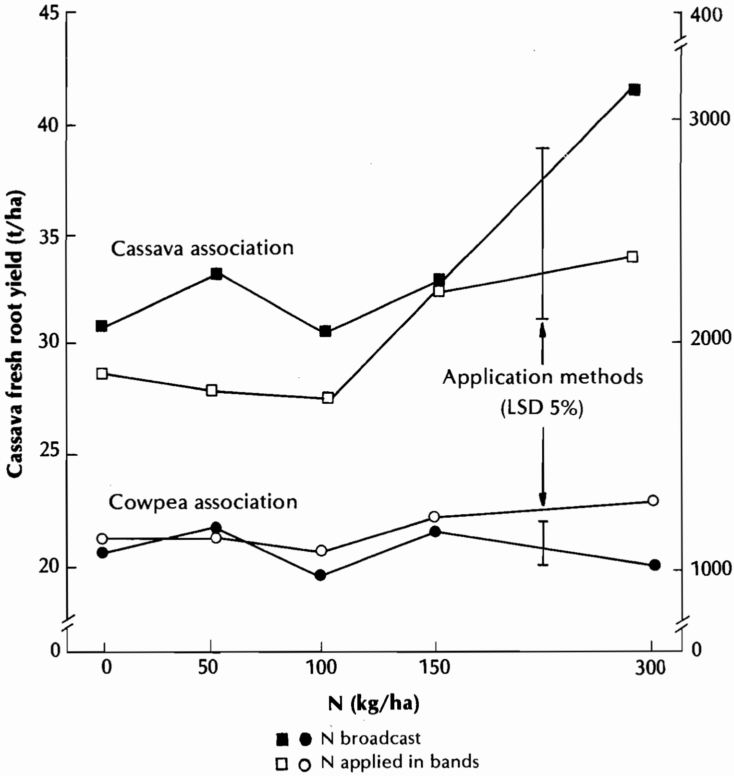


Figure 16. Yield response of cassava and cowpea in association to nitrogen fertilizer broadcast or applied in bands.
Source: CIAT, 1980.

tion of nitrogen in the soil. In turn, this reduces cassava's requirements for applied nitrogen.

2. Cassava and its associated crops remove only small amounts of phosphorus from the soil. Nevertheless, on many poor soils, cassava legumes, and maize all show a more marked response to the application of phosphorus than to that of other elements. This indicates that all three crops have higher phosphorus requirements in these soils. The dependency of legumes and maize on an adequate supply of phosphorus through fertilization is greater than that of cassava which is greatly aided in phosphorus uptake by mycorrhizal association, making it more tolerant to low concentrations of this element in the soil. The marked response to phosphorus application, especially by the associated crops (legumes, maize) would suggest that in cassava intercropping systems, the phosphorus requirement of the associated crops should be met in the first place. Cassava would benefit from this application to a greater or lesser degree, and, therefore, it would require a much smaller additional supply of phosphorus than when grown as a sole crop.

3. If the soil is not drastically depleted of potassium, cassava does not show a marked root yield response to the application of this element. Nevertheless, cassava roots extract considerable amounts of potassium from the soil which should be returned by an adequate potassium fertilization. In a mixed cropping system, the amount of potassium removed by cassava roots is normally much greater than that removed with the harvested products of most other crops. A sound fertilization practice in cassava intercropping systems should therefore supply the potassium requirement of cassava first, adding only a small amount as a safty margin for the intercrop.
4. When cassava is grown in acid soils of low fertility, crop species selected for association should have an adaptation to these conditions similar to that of cassava. Such an adaptation is shown by cowpea or groundnuts, for example. When these species are grown in association with cassava, no correction for soil pH with large amounts of lime is required, but the demand for calcium and magnesium as plant nutrients should be satisfied by incorporating 500 kg/ha of calcitic or, better, dolomitic lime (which includes magnesium) before planting. In addition, 10 kg/ha of zinc and 1 kg/ha of boron are recommended to meet the requirements for these minor elements, usually in short supply in these soils.
5. Most elements or intercropping systems respond indifferently to the fertilizer application method (band-applied or broadcast). There are some situations, however, in which a particular method is advantageous. For instance, it is preferable to band-apply soluble phosphorus sources to a phosphorus-deficient soil that fixes this element. On the other hand, low-solubility phosphorus sources, such as rock phosphate and basic slag, are more effective when applied broadcast or are incorporated into the soil. Commercial sources of nitrogen and potassium, such as urea and potassium chloride, showed similar effectiveness when broadcast or band-applied in cassava/cowpea associations. The minor elements, such as zinc and boron, can be band-applied; however, it is also possible to spray them (foliar application) on the crop or in the case of zinc for cassava, to treat the cuttings, which is a more economic method than applying these elements to the soil.

Pest Management

The epidemic outbreak of pests (insects, diseases, and weeds) constitutes one of the most serious threats to agricultural production in the tropics. Epidemics are favored by morphologically and genetically uniform crops (monocultures) grown on large extensions of land (Pimentel, 1961; Southwood and Way, 1970; Nickel, 1973). On the other hand, the combination of genetically different crops (not necessarily with large morphological differences) grown together in the same field does not provide the uniform substrate for pests to multiply rapidly and acquire epidemic dimensions. This may partially account for the greater stability of intercropping systems (Dempster and Coaker, 1974; Litsinger and Moody, 1976; Altieri et al., 1978).

Insect pests

With the exception of very few examples (Bodkin, 1912; Rao, 1970), cassava and the crops most frequently associated with it are attacked by different insect pests. This decreases the probability of insect pest population build-up and damage to mixed plantings.

Important insect pests of cassava—such as the hornworm (*Erinnyis ello*), the shoot fly (*Silba pendula*), the white fly (*Aleurotrachelus* and *Bemisia* spp.) and the lace bug (*Vatiga manihotae*)—have been evaluated in sole-cropped cassava and in cassava/dry bean associations (CIAT, 1977; Thung and Cock, 1979). In general, the incidence of all these pests was reduced and the lowest populations were observed as a result of both intercropping and chemical control. Table 10 shows counts for each insect in the two different cropping systems, with and without chemical protection, and gives a mean percentage of pest reduction due to the association. In the same way, a reduced incidence of the leaf hopper (*Empoasca kraemeri*), two chrysomelids (*Diabrotica balteata* and *Cerotoma ruficornis*), and thrips is observed in the intercropped beans as opposed to single culture beans. These observations are confirmed by data obtained in Costa Rica (Araujo and Moreno, 1978).

In addition to indicating the insect-pest control potential of crop associations in the absence of other control measures, these results suggest the possibility of combining the intercropping production system with moderate chemical control measures to obtain even better pest control. Where four to six applications of pesticides may be required in a commercial sole crop, one or two could be sufficient in association.

In the cassava/bean intercrop cited in Table 10, for example, cassava yield was little reduced by the beans when no chemical control of insect pests was carried out; bean yields in single culture and in association were almost identical, without the application of chemicals. Therefore, without the use of inputs for insect control, it was advantageous to have the two crops planted in association, in which case 1 ha produced almost the same amount of cassava and beans added together as would have been obtained from 2 ha with each of the two crops grown separately in single culture. These results emphasize the great advantage of intercropping under conditions of minimal or no use of purchased inputs (Thung, 1978).

Diseases

Genetic diversity among crops grown in association is one of the most important factors for modifying the incidence and severity of plant diseases. Furthermore, morphological dissimilarity can have an additional effect in this context, for example through the formation of barriers against pathogens disseminated by wind or water. Nevertheless, it is necessary to differentiate between pathogens and crop associations since there are cases of adverse

Table 10. **Insect populations found in cassava and beans grown in single culture and association, with and without chemical control.**

	Monoculture		Association		
Insects	With insecticide	Without insecticide	With insecticide	Without insecticide	Population reduction (%)[a]
Cassava					
			no./plot		
Cassava hornworm *(Erinnyis ello)*	0.5	0.8	0.5	0.6	15
Shoot flies *(Silva pendula)*	2.1	2.0	1.5	2.2	10
			no. in 3 leaves/plant		
Whiteflies *(Aleurotrachelus* sp.)	7.2	6.5	3.3	4.5	43
Lace bugs *(Vatiga manihotae)*	4.5	5.6	2.7	3.8	36
Beans					
			no./20 m²		
Green leaf hopper *(Empoasca kraemeri)*	89	229	80	216	7
Chrysomelids *(Diabrotica* and *Cerotoma)*	3	6	3	4	22
			no./6.45 m²		
Thrips	2	14	6	12	–

a. Reduction caused by the association. (Average of values with and without the use of insecticide.)
Source: CIAT, 1977.

pathogenic effects on cassava caused by intercrops, and *vice versa.* For example, information fron Sri Lanka indicates that the association of cassava with rubber favors the infestation of both crops with the fungus *Fomes lignosus* (Root Disease, 1943). Moreno (1979) reports increased incidence and severity of mildew (*Oidium manihotis*) in cassava associated with maize as compared to the incidence in cassava in single culture. C. Lozano (personal communication, 1981) maintains that both cassava and common beans are attacked by the same soil pathogens such as those belonging to the genera *Rhizoctonia, Sclerotinia, Sclerotium, Fusarium, Verticillium,* and *Fomes,* all of which cause rotting of both roots and hypocotyls.

However, these situations may be considered exceptions since a much larger number of examples can be cited showing the favorable effect of crop mixtures in reducing disease incidence and severity. Larios and Moreno (1976) and Moreno (1979) analyzed the disease situation of different crop associations including cassava. They found that the cassava/maize association delayed the development of superelongation of cassava (*Elsinoë brasiliensis*) and, at the same time, reduced the incidence and severity of rust (*Uromyces manihotis*). The same authors confirmed that a cassava/common bean association reduced incidence and severity of mildew, superelongation, rust (Table 11), and anthracnose (*Colletotrichum* sp.) under the conditions found in Turrialba, Costa Rica. Two reports from Nigeria (Arene, 1976; Ene, 1977) show that cassava bacterial blight (*Xanthomonas manihotis*) is reduced when cassava is intercropped with maize or melon. A possible reason for this is that intercropping provides a better and earlier soil cover, avoiding the splashing of bacteria-infested soil particles to the lower leaves of cassava (Table 12).

Cassava itself also influences the pathogenic situation of the intercrops, however, with differences depending on the crop and the pathogen. There seems to be no information regarding changes in disease incidence on maize

Table 11. **Maximum incidence and severity of cassava rust *(Uromyces manihotis)* in five different cropping systems at CATIE[a], Costa Rica.**

Cropping system	Maximum incidence (%)	Maximum severity (%)
Cassava	67.7	2.85
Cassava/sweet potato	60.0	2.11
Cassava/maize	52.6	1.86
Cassava/bean	56.6	1.67
Cassava/maize/bean	47.2	1.17

a. Centro Agronómico Tropical de Investigación y Enseñanza.
Source: Moreno, 1979.

Table 12. **Effect of a cassava/corn/melon association on the incidence of cassava bacterial blight *(Xanthomonas manihotis)* in Umudike, Nigeria.**

Cropping system	Average incidence[a] (%)
Cassava	20.3 a
Cassava/maize	16.9 b
Cassava/melon	18.9 b
Cassava/maize/melon	14.1 b

a. Means in the same column followed by the same letter are not significantly different at $P = 0.05$
Source: Ene, 1977.

Table 13. **Severity of angular leaf spot *(Isariopsis griseola)* in different cropping systems at CATIE[a], Costa Rica.**

Cropping system[b]	Severity in three development stages of beans		
	Pre-flowering	Flowering	Green pods
Bean	10.23[c]	14.37	19.56
Bean/maize	10.31	17.77	21.33
Bean/cassava	10.81	13.61	18.88
Bean/sweet potato[d]	10.26	13.13	18.89
Bean/maize/sweet potato[d]	10.46	16.11	21.03
Bean/maize/cassava	10.26	16.40	21.44

a. Centro Agronómico Tropical de Investigación y Enseñanza.
b. Simultaneous planting.
c. Data calculated according to a modified McKinney index and transformed with $(X + 0.5)^{1/2}$
d. Sweet potato was planted 30 days later than beans.
Source: Moreno, 1979.

when intercropped with cassava, but information is available for common beans and cowpea. Moreno (1979) showed that the epidemiological development of angular leafspot (*Isariopsis griseola*) in beans was slower in associations with cassava and sweet potato, while the development was faster in association with maize (Table 13). The author suggested that the favorable influence of cassava could consist in its canopy avoiding the direct impact of raindrops on beans, since the dissemination of the disease occurs through the splashing of raindrops with inoculum (Cardona and Walker, 1956).

Moreno (1979) also studied the infection of cowpea by viral diseases, such as cowpea common mosaic and cowpea chlorotic mosaic diseases, which are transmitted by chrysomelids. In a simultaneous cassava/cowpea planting, no difference in the progress of viral diseases was observed between single-culture and intercropped cowpea. However, when cowpea was planted under fully developed cassava at the end of its growth cycle, both the progress of infection and the maximum degree of infection with the two viruses was reduced, compared to cowpea as sole crop. A reduced activity of disease vectors at reduced levels of solar radiation below the cassava foliage was most likely the cause for the lower viral incidence in the cassava/cowpea association.

In general terms, the examples cited above show the potential of cassava intercropping systems to reduce disease problems. For the management of diseases in cassava-based intercropping systems, this means a reduced requirement for agrochemical inputs, as is the case with insect pests. Nevertheless, the indiscriminate association of crops, which may have one or more pathogens in common, can favor the development of diseases under specific conditions. An adequate management of diseases in intercropping systems should take this into account by avoiding the association of crop species with potential for aggravating rather than alleviating pathogenic problems.

Weeds

One of the advantages of growing more than one crop in the same field is the better coverage obtained from the beginning with the association. This diminishes light penetration to the soil, which, in turn, reduces weed growth. Cleave (1974) holds that intercropping systems could have originated specifically as a result of the low weed-control intensities necessary under conditions of intercropping.

Biological potential to reduce weed problems. In a cassava sole crop, the problem of space not covered by the crop canopy during its early growth is particularly severe since the crop has slow initial growth and requires wide spacing to accommodate later growth. It is for these reasons that an intercrop, which rapidly covers the soil without competing excessively with cassava, can make an important contribution to cultural weed control in cassava.

Leihner (CIAT, 1978, p. A64–A68; Leihner, 1980a) analyzed weed growth in a cassava sole crop compared to a cassava/common bean intercrop at CIAT-Palmira in Colombia. Without other control measures, the sole practice of intercropping beans with cassava reduced total weed dry weight to 30, 47, and 33% of the amount observed in the cassava sole crop at 45, 90, and 135 days after planting, respectively. The reduced weed weight at 135 days indicates that the associated beans had a residual control effect, since this crop had been harvested 105 days after planting. Only at 180 days after planting were equal amounts of weeds found under both cassava sole crop and cassava/bean intercrop conditions (Figure 17).

In the association, cassava yield was the same with or without additional chemical and manual weed control measures; however, in single culture, cassava suffered a yield reduction of 30% when no chemical or manual weed control was practiced. These results again highlight the advantage in production stability by intercropping under conditions of minimal use of

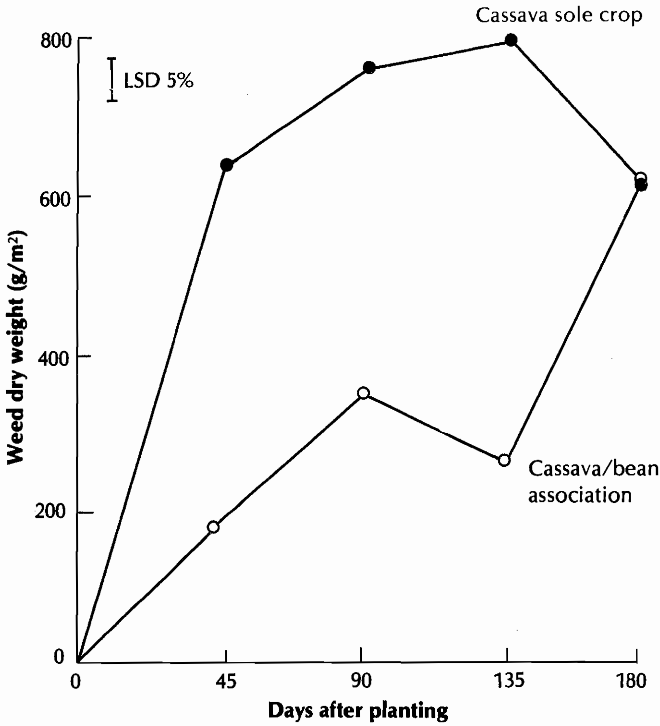


Figure 17. Increase of weed dry weight in cassava sole crop compared to the increase in a cassava/bean association. (No other weed control methods were used.) Source: CIAT, 1978; Leihner, 1980a.

purchased inpouts. At the same time, they suggest that crop association may be an adequate production system for the small farmer who normally lacks the capital to buy inputs.

Effective and stable weed control was obtained when cassava was associated with a perennial legume (*Desmodium heterophyllum*). After its establishment phase, which lasted about 50 days, soil coverage and weed control were complete until cassava was harvested. A reduction in cassava yield of 18.9% was observed when this crop was grown in association with the legume, compared to clean-weeded sole-crop cassava. The yield reduction was possibly due to the low but prolonged competition from the legume's green cover. This, however, may be considered a low price paid to maintain cassava weed-free during its entire growth cycle (CIAT, 1979, p. 54–57; Leihner, 1980a).

Chemical weed control. One of the factors limiting the use of herbicides in intercropping systems has been the lack of information on their selectivity and effectiveness when used in a mixed cropping situation. This lack of information is a result of herbicides usually being developed for the large-scale, commercial, single-culture, cash-crop situation and not for the small farmers' food crops. Taking this into account, research was initiated to identify products or product mixes, doses, and application methods suitable for chemical weed control in cassava-based intercropping systems. As a result of this investigation, several pre-emergence herbicides have been found which can be used in crop associations of cassava with maize, common beans, cowpea, mungbean, and groundnut (López and Leihner, 1980). One of the identified mixtures may also be used for the triple association of cassava with maize and yams (Table 14).

In addition to selecting herbicides for individual crops, the farmer can apply two principles to increase this selectivity: using half the recommended dose of the herbicide and applying the herbicide before planting. Using low doses (e.g., half-rates) of herbicides reduces the risk of a phytotoxic effect; at the same time, however, weed control efficiency and the duration of the effect are decreased.

Intercropping does provide an earlier soil cover than sole cropping, thus reducing the need for a long-lasting period of effective weed control. With respect to time of application, better selectivity is obtained when pre-emergence herbicides are not applied immediately after planting (i.e., before the emergence of the crop) but several days or even several weeks before planting. This is possible especially with pre-emergence herbicides with a prolonged residual effect. For example, a significant increase in the selectivity

Table 14. **Preemergence herbicides for crops associated with cassava.**

Product or mixture	Dose[a] (kg A.I./ha)	Time of application	Selective for association of cassava with:
Linuron + fluorodifen	0.25 – 0.50 1.50 – 2.10	Post-planting	Common bean, cowpea, and mungbean
Linuron + metolachlor	0.25 – 0.50 1.00 – 1.50	Post-planting	Common bean, cowpea, mungbean, groundnut, and maize
Oxadiazon + alachlor	0.25 – 0.50 0.90 – 1.40	1–2 weeks before or after planting	Maize
Diuron + alachlor	0.80 – 1.20 0.90 – 1.40	Post-planting	Maize and taro
Oxifluorfen	0.25 – 0.50	1–2 weeks before or after planting	Groundnut

a. The doses indicated above are used as follows: low doses on light soils and high doses on heavy soils. Quantities individually indicated for each product are combined to obtain the tank mix.

Source: López and Leihner, 1980.

of a pre-emergence herbicide (oxyfluorfen) was observed at CIAT-Palmira in a cassava/groundnut association when the product was applied before, instead of after, planting.

Integrated control. Frequently, the combination of different weed control methods results in a better and more economical control. At CIAT-Palmira, effective and economical weed control was achieved by intercropping cassava with common beans, profiting from the early ground cover provided by the beans and using a pre-emergence herbicide as a complementary weed control measure. The same herbicide was also applied to the cassava sole crop, but its effect had already disappeared 90 days after planting. Meanwhile, the integrated effect of intercropping and herbicide use maintained an excellent weed control for more than 6 months after planting (Figure 18) (CIAT, 1978, p. A64–A68; Leihner, 1980a).

Integrated weed control was also tested at Caribia on the Colombian north coast where purple nutsedge (*Cyperus rotundus* L.), a weed difficult to control,

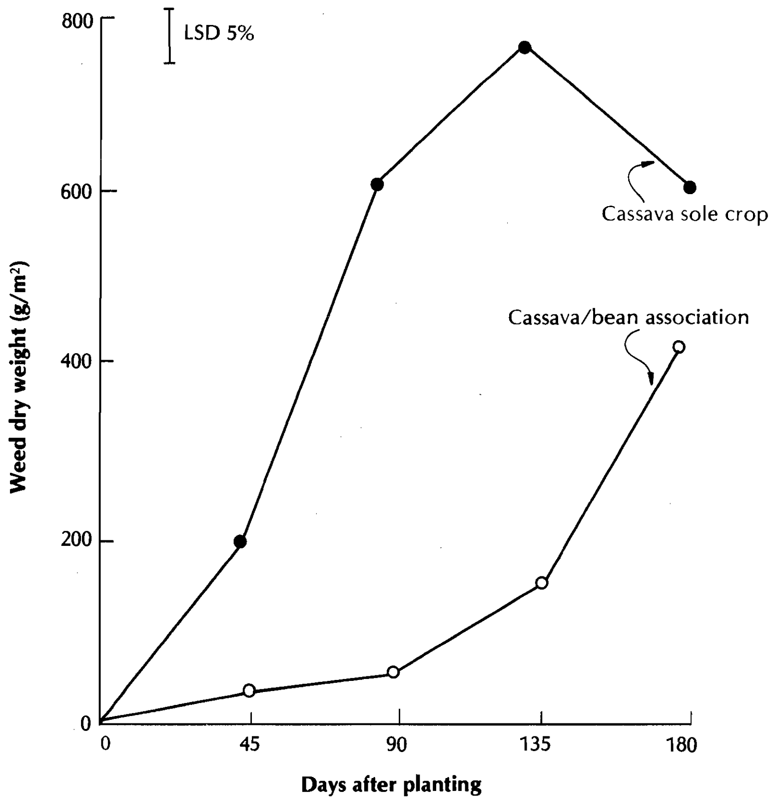
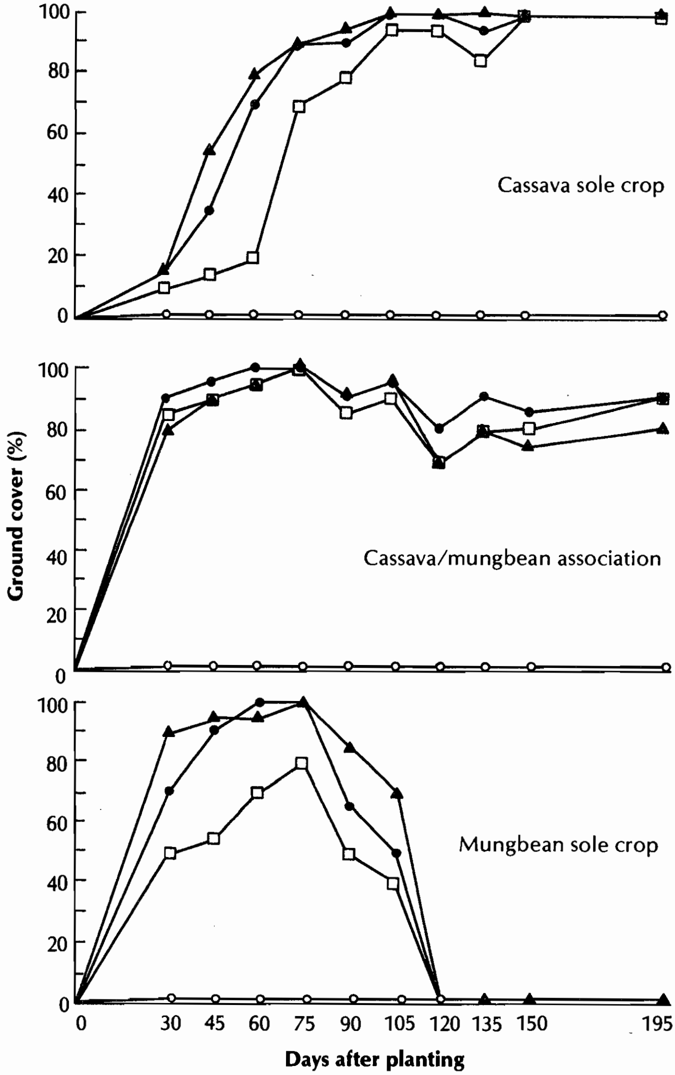


Figure 18. Increase of weed dry weight in a cassava sole crop compared to the increase in a cassava/bean association. (Additional weed control was achieved by applying a preemergent herbicide at planting.)
Source: CIAT, 1978; Leihner, 1980a.



O Preemergent herbicide
□ Preemergent herbicide and cover crop
● Preemergent herbicide, cover crop, and glyphosate
▲ Preemergent herbicide, cover crop, glyphosate, and harrowing every 10 days

Figure 19. Percentage of ground cover in an integrated purple nutsedge control system trial.

Source: Leihner et al., 1980.

predominates. Heavily infested plots (2300 tubers of purple nutsedge/m^2 to a depth of 25 cm) were treated with mechanical, chemical, and cultural weed control measures. The mechanical method consisted of harrowing during the dry season to expose purple nutsedge tubers to desiccation prior to planting. Chemical control was done by applying a pre-emergence or a mixture of pre-and post-emergence herbicides.[4] Cultural control was achieved by shading out purple nutsedge to different degrees in four cropping systems: cassava single culture, cassava/mungbean intercropped, mungbean single culture, and no cultivation.

In cassava single culture, a ground cover of 80% or more was attained 60–90 days after planting and a 80–100% cover was then maintained until harvest. Canopy formation was faster with glyphosate applied than without; and the harrowing plus glyphosate treatment provided the earliest cover. In this experiment, the purpose of intercropping cassava with mungbeans was to provide an earlier ground cover than is possible with a cassava sole crop, in order to obtain shading before pre-planting treatments lost their effectiveness. The intercrop fulfilled its purpose: a ground cover of 80–90% was obtained only 30 days after planting, irrespective of harrowing or herbicide treatment. The fast-growing sole crop of mungbeans quickly covered the ground, but this cover was not maintained very long due to its short growth cycle (Figure 19). A good and stable control in cassava single culture was obtained from the combined harrowing and glyphosate treatment, with control from cassava shade becoming effective before the pre-planting weed control treatments had lost their influence. However, a comparison among planting systems revealed that the cassava/mungbean intercrop provided the earliest and most effective control of all systems (CIAT, 1980, p. 49–51; Leihner et al., 1980).

4. A tank mix of linuron and fluorodifen at 0.5 and 2.1 kg A.I./ha was used as the pre-emergent herbicide. Glyphosate was used as the post-emergent herbicide.

Evaluation of Intercropping Systems

Intercropping as a production system is adopted both for biological and economic reasons. It is well known that a given area planted to two or more crops in association can give a greater total production than do these same crops when grown separately on the same total land area. However, biological productivity of an agricultural system is not the only important aspect; the economic result obtained with intercropping in relation to single culture is another decisive aspect in the evaluation of a production system.

In subsistence farming, most of the agricultural production is consumed directly on the farm and therefore, biological productivity is of paramount importance. On the other hand, an increasing weight has to be assigned to the economic result under conditions of transition from subsistence to commercial farming, where increasing amounts of the agricultural produce are sold outside the farm.

Biological Efficiency

IRRI (1973, 1974) and Mead and Willey (1980) have proposed a concept for the evaluation of the biological efficiency of intercropping systems which at the same time is the efficien-cy of land use. They have named it the "land equivalent ratio" (LER) concept. It is useful to express and evaluate:

- The advantage or disadvantage, in terms of biological production, of intercropping as compared to single culture **(maximum production criterion).**
- The efficiency or inefficiency of one system as compared to another one with regard to land use **(least area criterion).**
- The advantage or disadvantage of one combination of crops over another one **(crop combination comparison).**

- The advantage or disadvantage of one agronomic practice over another one within the intercropping system **(agronomic practices comparison).**

Furthermore, the LER concept is also useful in assessing crop competition, as will be shown later. The LER concept is applicable when the crops grown in association are of equal acceptability to farmers—that is, when they assign equal priority to the crops participating in the association.

Mathematically, the LER is the sum of two or more quotients (according to the number of crops in the association) and is calculated as follows:

$$\text{LER} = L_x + L_y = \frac{Ax}{P_x} + \frac{A_y}{P_y}$$

where L_x and L_y are the individual LER's of two crops, X and Y. L_x is obtained by dividing the yield of crop X in association (A_x) by the yield of the same crop in pure stand (P_x). L_y is the result of dividing the yield of crop Y in association (A_y) by the yield of that same crop in pure stand (P_y).

Acordingly, when three crops are involved in the intercropping system, the LER of the system is the sum of the individual LER's of each of the three crops:

$$\text{LER} = L_x + L_y + L_z = \frac{A_x}{P_x} + \frac{A_y}{P_y} + \frac{A_z}{P_z}$$

It is clear that the LER, strictly defined by its calculation, represents the relative land area cultivated in pure stand necessary to obtain the same production as is obtained in intercropping. Normally, due to competition among crops in association, the yield of each component crop is greater in pure stand than when intercropped. Therefore, less area is required for a single crop to attain the same production in pure stand than in association. This is reflected by A/P values normally smaller than unity. Nevertheless, a greater total area is needed for crops grown in pure stand to reach the same total production as is obtained in intercropping. This is because the sole crops are grown separately and the individual areas occupied by them have to be added to arrive at the total land area necessary for a production equal to that obtained in intercropping.

The main purpose of this text is to propose improved agronomic practices for cassava intercropping. With the help of the methodology explained above, we are now able to evaluate some of these proposed practices in the light of the LER concept.

Relative time of planting

At CIAT-Palmira, LER values were calculated for cassava/common bean associations, beans being planted before, at the same time, or after cassava. Generally, greater LER values were obtained when beans were planted before cassava. This was probably due to the fact that cassava yields were less

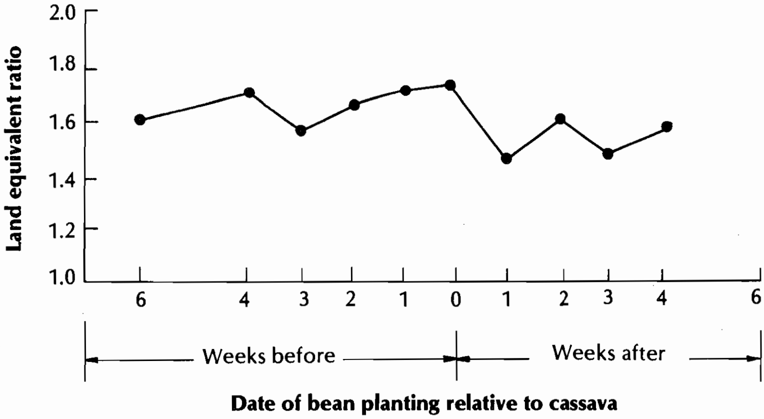


Figure 20. Influence of various relative planting dates on the land equivalent ratio (LER) of a cassava/bean association.
Source: Thung and Cock, 1979.

affected by early bean planting (when bean yields were greater), than bean yields were affected by late bean planting. (Relative yield data is presented in Figure 3.) The greatest LER value was achieved by planting both crops simultaneously, which demonstrates the comparative advantage of this practice and confirms that greatest total biological yields are thus obtained (Figure 20; Thung and Cock, 1979). Calculation of the LER, as shown in Figure 20, was based on corresponding sole crop yields from each planting date to correct for the planting date effect on bean yield. In this way, no comparison is made between intercropping and single culture; instead, a comparison is established between different intercropping practices.

Planting density

Combinations of two varieties each of cassava and beans were planted at CIAT-Palmira to determine the effect of cassava planting density on total productivity and efficiency of the intercropping system (relative yield data is presented in Figure 5). A more or less constant LER was found in three of the four combinations across a wide range of cassava planting densities. This indicates that normal, single-culture planting densities can be used in intercropping without sacrificing the total biological productivity and land use efficiency of the association (CIAT, 1977; p. C12 – C13; Thung, 1978).

The same behavior was observed in a trial at CIAT-Quilichao using a range of cowpea planting densities in a cassava intercrop. LER values were calculated based on cassava sole-crop mean yield since cassava sole crop plots were standard throughout the trial, and using the yield figure of the best cowpea sole-crop treatment. In this way, a true comparison between sole crop and intercrop efficiencies was established. The LER of the system was almost

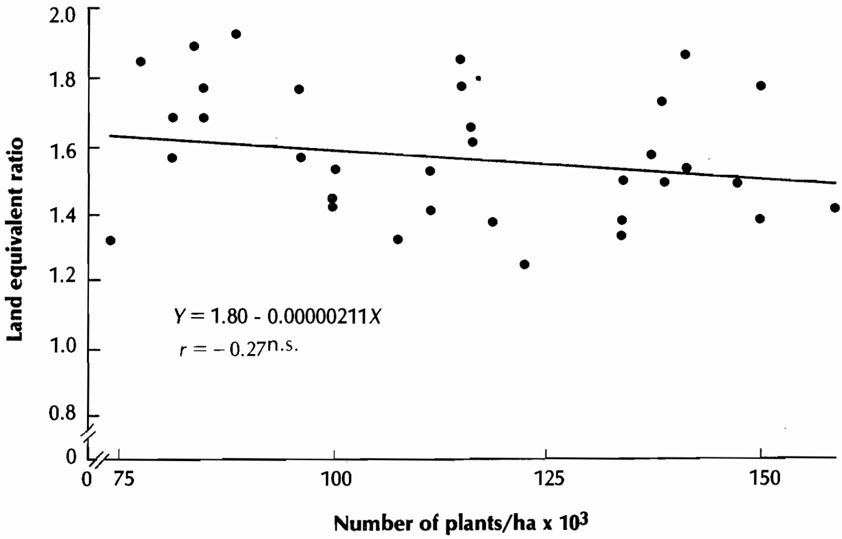


Figure 21. Effect of the variation in planting densities of cowpea in association with cassava, at constant density, on the land equivalent ratio (LER) of the system.

stable throughout cowpea densities between 7 and 15 plants/m². This confirms that, similar to cassava, sole crop densities (8–11 plants/m²) currently used for cowpea in association do not reduce the efficiency of the intercropping system, but ensure high productivity (Figure 21).

Fertilizer response

When a crop's yield responds positively to fertilization, this response can be of the same degree in association or in single culture; but it can also be more pronounced in single culture where no nutrient competition from a second crop is present. In the first situation, a constant yield difference is maintained between single and intercropping situations; in the second, an increasingly greater yield is observed in single culture as the fertilizer level increases. As a result, the individual LER of one crop remains constant or decreases with increasing fertilizer levels.

A third situation arises when there is strong nutrient competition between the crops at low fertility levels, and large amounts of fertilizer are applied to compensate for this competition. In this case, the crop's degree of response is greater in intercropping than in single culture, leading to increasing LER's with increasing levels of fertilization. Furthermore, when soil fertility increases, the LER is affected by changing degrees of competition between the crops in association. In a maize/soybean association, high nitrogen levels drastically increased the competitiveness of the maize, leading to a significant yield reduction of the intercropped soybean. As a consequence, the LER of

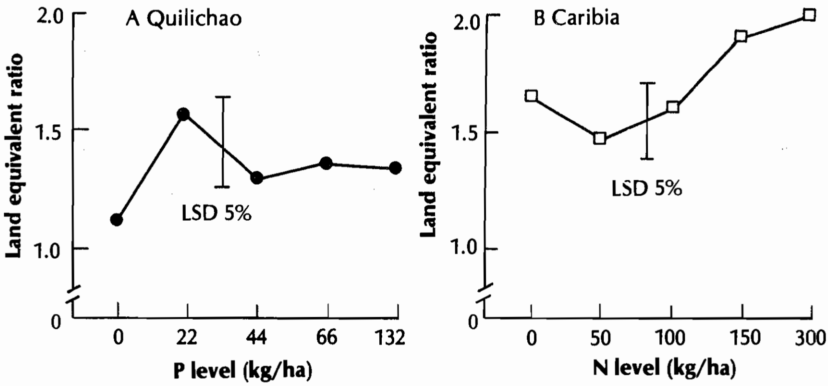


Figure 22. Effect of N and P levels on the land equivalent ratio (LER) in associations of cassava and cowpea.

the system decreased with each increment of nitrogen (Cordero and McCollum, 1979).

A similar situation was observed with increments of phosphorus in a cassava/cowpea intercrop grown at CIAT-Quilichao. Beginning with the second increment of phosphorus, cowpea gained over-proportional competitiveness compared to cassava, showing the same yield response in association as in single culture and at the same time causing a yield reduction in cassava. This resulted in a small LER[5] reduction after an initial increase. With continuous phosphorus increments, the LER was stabilized, suggesting that the phosphorus level resulting in the greatest efficiency was 22 kg P/ha (Figure 22A).

Another type of response of the LER[5] was found when a cassava/cowpea association was fertilized with increasing levels of nitrogen at Caribia. Cassava, responding with a yield reduction to increments of nitrogen in single culture, showed a strongly positive yield response in association, which resulted in individual LER values for cassava greater than unity. This circumstance, together with the absence of a variation in the nitrogen response of cowpea (a constant relation between sole crop and intercrop yield was maintained over all nitrogen levels), led to an increment in the LER of the whole system, beginning with the first increment of nitrogen, reaching LER values of close to 2 at higher nitrogen levels (Figure 22B). This high efficiency in the utilization of nitrogenous fertilizer was achieved due to the fact that cassava in association showed a positive yield response to nitrogen without modifying the competition situation between cassava and cowpea. This was true because the effect of nitrogen on cassava top growth was effective mostly after cowpea harvest.

5. The LER was calculated based on corresponding sole crop yields of cassava and cowpea, thus allowing the comparison among treatments within the intercropping system.

Positive effects of nitrogen fertilization on the LER of different intercropping systems were also reported by Oelsligle et al. (1976) and Cordero and McCollum (1979).

The time factor

The straightforward comparison of land requirement for a certain total biological production in single culture as opposed to intercropping by means of the LER is undoubtedly valid and useful. However, crop production is not solely a function of land area, crop, management, and environment as implied by the LER, but it is also related to the duration of crop growth, or time during which the land is occupied by a crop or crop combination. Particularly in more complex cropping patterns, including relay intercropping as a practice, the time span during which the whole sequence occupies the land will be different from the duration of any individual crop grown in single culture. It is, therefore, important to account for this time effect on the productivity in either system. A concept called "area time equivalency ratio" (ATER) has been developed by Hiebsch (1978). The ATER is calculated as follows:

$$\text{ATER} = \sum_{i=1}^{n} \frac{tM_i}{tI} \cdot \frac{YI_i}{YM_i} = \frac{I}{tI} \sum_{i=1}^{n} tM_i \frac{YI_i}{YM_i}$$

where

tM_i = growing period of crop i in monoculture

tI = total time of intercropping system

YI_i = yield (t/ha) of crop i in intercropping

YM_i = yield (t/ha) of crop i in single culture, and

n = total number of crops in the system

When sole crops receive the best possible agronomic management, and there is no difference in the management level between sole crops and intercrops, the ATER compares the relative productive capacities of the crop in the two systems, indicating which system was more effective in the use of area and time to produce a given quantity of yield. An example from experimental work with cassava/common bean intercrops may help explain how the ATER concept may be used to evaluate cropping systems.

Five different cropping systems—a cassava sole crop; intercrops of cassava/bush bean and cassava/bush bean/climbing bean; an association of cassava/climbing bean; and two bush bean single cultures—were grown at CIAT, according to the chronographs shown in Figure 23. In all systems with cassava, two basic management practices were tested: defoliation and

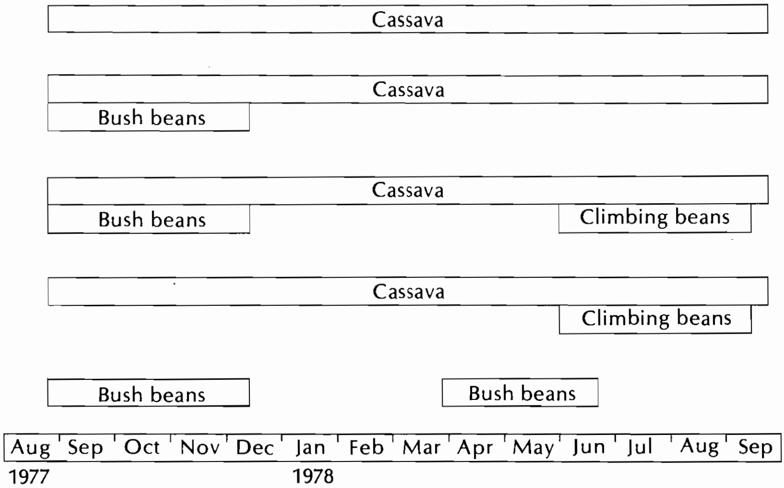


Figure 23. Chronograph of cassava/bean cropping systems trial (CIAT, 1978).

nondefoliation of cassava prior to climbing bean planting. Table 15 provides yield figures for the three crops in each of the five systems; based on these figures, LER and ATER values were calculated for the double and triple associations. LER's were high, particularly in the triple association and in the cassava/climbing bean association, when defoliation was practiced, suggesting that two to three times as much land would have been required to produce the same quantities of cassava and beans in single culture as was necessary with intercropping. When the time factor was taken into account, however, a generally smaller advantage of intercropping was evident. For example, the cassava/bush bean/climbing bean intercrop (with defoliation of cassava), which was 204% more efficient in land use than the respective single cultures, as calculated by the LER, proved to be only 56% more efficient when the time factor was taken into account (ATER concept).

This appears logical when a comparison of area-time requirements is made for the different systems instead of a straightforward comparison of land area requirements. Area-time efficiency is reduced in any system dominated by the long-land occupancy of cassava.

It is evident from these results that, although the LER is a useful concept, it may lead to an overestimation of a system's efficiency, in particular when a larger number of crops participate. The ATER concept is a much stricter criterion, allowing evaluation of both area and time as determinants of system productivity.

Crop competition

According to Willey and Rao (1980), the LER concept is also hepful in the evaluation of the degree of competition between intercrops: that is, in an association, an individual crop's competitiveness can be established in

Table 15. **Yield of cassava and beans, land equivalent ratio (LER) and area-time equivalency ratio (ATER) in various cropping systems at CIAT-Palmira.**

	Yield (t/ha)				
Cropping system	Cassava fresh root	Bush bean	Climbing bean	LER	ATER
Cassava defoliated					
Cassava sole crop	18.9	—	—	—	—
Cassava/bush beans	17.9	2.0	—	1.86	1.19
Cassava/bush beans/ climbing beans	19.0	2.0	1.7	3.04	1.56
Cassava/climbing beans	20.9	—	1.4	2.05	1.36
Bush bean sole crop	—	2.2	1.5	—	—
C.V. (%)	29.8	6.2	12.7		
SD	5.7	0.3	0.2		
Cassava undefoliated					
Cassava sole crop	28.2	—	—	—	—
Cassava/bush beans	23.0	2.0	—	1.73	1.07
Cassava/bush beans/ climbing beans	24.8	2.0	0.6	2.19	1.24
Cassava/climbing beans	31.4	—	0.5	1.45	1.20
Bush bean sole crop	—	2.2	1.5	—	—
C.V. (%)	23.7	6.2	30.3		
SD	6.3	0.2	0.2		

comparison to the other crop. In a two-crop association, the "competitive ratio" (CR) is calculated by simply dividing the individual LER of one crop by that of the other crop, and correcting the result according to the space assigned to each crop. The CR for crop X in association with crop Y is then:

$$\mathrm{CR}_x = \left[\frac{A_x}{M_x} : \frac{A_y}{M_y}\right] \frac{S_y}{S_x}$$

where A_x and A_y are the yields of crops X and Y in association, and P_x and P_y represent the respective single culture yields. S_y is the relative space occupied by crop Y, and S_x is the relative space occupied by crop X. The CR of crop Y is, by definition, the reciprocal value of CR_x.

An example from the previously reported work on the effect of planting densities and spatial arrangements in cassava/cowpea intercrops demonstrates the usefulness of this concept for the interpretation of results and for the determination of advantages or disadvantages of different agronomic practices in crop associations.

Cassava planted at a constant spacing of 1.80 × 0.60 m was intercropped with cowpea at 80,000 plants/ha distributed in two rows at 0.45-m distance on either side of cassava (*see* Figure 9, arrangement 45/2). Across rows, the whole system occupies 1.80 m—of which 0.45 m was occupied by cassava and 1.35 m by cowpea—resulting in a 1:3 relationship between cassava and cowpea. Cassava yields in association were 20.9 and in pure stand 22.9 t/ha of fresh roots. Cowpea grain yields were 1165 and 1653 kg/ha in association and single culture, respectively. The CR of cassava, based on these yields, was:

$$CR_{cassava} = \left[\frac{20.9}{22.9} : \frac{1165}{1653}\right] \frac{3}{1} = 3.89$$

While that of cowpea was:

$$CR_{cowpea} = \left[\frac{1165}{1653} : \frac{20.9}{22.9}\right] \frac{1}{3} = 0.26$$

The example shows that with the agronomic management described above (arrangement of cowpea in two rows distant from each other but relatively close to cassava, combined with a low cowpea-planting density), cassava was the dominant crop in the association, being almost four times more competitive than cowpea. In spite of the unilaterally favorable conditions for cassava, a total LER of 1.63 was achieved. This expresses the high overall efficiency of the system.

Conserving the planting density and spatial arrangement of cassava, but planting cowpea in a more even distribution and, at the same time, raising its planting density (60/3 arrangement, 140,000 plants/ha), the competitive ratios were:

$$CR_{cassava} = \left[\frac{17.7}{22.9} : \frac{1357}{1623}\right] \frac{1}{1} = 0.93$$

$$CR_{cowpea} = \left[\frac{1357}{1623} : \frac{17.7}{22.9}\right] \frac{1}{1} = 1.08$$

The CR values show that, with this agronomic management, an almost complete balance was achieved between the two species.[6] In this case, cowpea was slightly more competitive than cassava. Total LER of the system was 1.61.

6. The distribution of space at a 1:1 ratio is again explained by observing Figure 9. Cowpea in the 60/3 arrangement was planted in three rows with 30 cm between them. The two external cowpea rows each occupied 15 cm; i.e., the total space occupied by cowpea is 15 + 30 + 30 + 15 = 90 cm, which is half that of the entire 180-cm system.

One problem in using the CR index is the contribution of the area-distribution factor (S_y/S_x), which is particularly large in the first example and accounts almost entirely for the large differences between CR's of cassava and cowpea, while the yields themselves contribute little to this difference. However, even when the ratio of the component LER's alone is considered, CR's of 1.30 and 0.77 are obtained for cassava and cowpea, respectively. This shows that in all cases cassava was more competitive than cowpea under the given agronomic conditions. In the second example, the elimination of the area-distribution factor does not affect the CR's since the S_y/S_x value is unity. Analyzing the competition between cassava and cowpea in the present example by means of the CR concept, it is evident that the agronomic management of an intercropping system allows a drastic change in the competitiveness of its components in order to give preference to one or the other, or to maintain a balance between them, depending on the productions desired. This does not necessarily affect the efficiency of the system as a whole as measured by the LER.

The CR concept, then, is a useful instrument for quantifying the competitiveness of crops in an association. It is thus possible to verify the effect that different management practices have on this parameter.

Economic Evaluation

Economic evaluation is no more than an assessment of the productivity of different intercropping alternatives using criteria utilized by the farmer. These criteria will obviously depend on farmers' objectives, which, in turn, will depend mainly on whether the farmer produces principally for subsistence or for the market. In Latin America, at least, most cassava is produced for the market, which allows the different intercropping systems to be evaluated in terms of commercial value.

Comparison between systems

In comparing alternative intercropping systems, there are several advantages to assessing productivity differences in value terms as given by market prices, namely:

1. It is possible to aggregate the different crop outputs and different inputs using a common unit of measure;
2. Quality diffrences can be taken into account;
3. The researcher can evaluate different alternatives on the same basis as the farmer.

The economic evaluation will therefore assume that the farmer chooses between cropping system alternatives on the basis of greatest net income: that is, the value of the crop output minus the relevant production costs. The net income measure is effective in selecting between different cropping systems, especially when:

1. There is competition between the associated crops and the issue arises as to whether to increase relative yield of cassava over the other crop (*see* Crop competition) or vice versa;
2. There are major differences in input levels and therefore production costs;
3. There are differences in the relative value of the crops between regions, which may alter which system is most profitable.

Moreover, the system with the largest net income may be different from the system with the highest land equivalent ratio (LER). The LER principally differs from the net income measure in that in the calculation of the LER each crop has equal value, and differences in production costs are not taken into account. Thus, assessing biological productivity must be logically separated from an assessment on the basis of profitability.

Profitability assessment of associated cropping systems

Simple profitability analysis (also known as partial budgeting) will, for brevity, be discussed in terms of four principal operations: (a) specification of system alternatives, (b) calculation of gross benefits, (c) determination of production costs, and (d) calculation of net income or benefits. (For a more thorough discussion of these operations, *see* Perrin et al., 1976.)

The economic analysis, in its simplest form, seeks to determine which is the most profitable alternative. Given the nature of experimental data, this analysis is almost always done on a per-hectare basis. The first operation is thus to specify the various alternatives. These will include all those potentially usable by the farmer and will include both the different cropping systems and, within any particular system, those cultural practices that result in changes in production costs or eventual yield. An example for cassava/bean systems is presented in Table 16.

Next, the gross benefits or income for each alternative are calculated. For each treatment alternative, the utilizable or marketable output is specified for each crop within the treatment. Each crop output is then multiplied by its respective price to obtain the crop value. The different crop values are then summed to calculate the total gross income for each system alternative (*see* Table 16). Price is a critical parameter in these calculations, and the price used in the analysis should be the farm gate price—that is, the price the farmers receive for the sale of their crops.

The major difference between the two analyses is that in an economic analysis, the differences in costs of production between the various systems are deducted from the eventual value of the yield, while the biological analysis only considers differences in total production yields. The focus is on those inputs or costs which vary across treatments. Thus, for a complete budgeting, in which fixed costs, such as land and machinery, as well as variable costs are included, it is not necessary to separate between alternatives. Only a partial budgeting based on variable costs is done.

The costs most likely to vary between different cassava cropping systems are:

Table 16. **Economic analysis[1] of various cassava/bean planting systems.**

Concept	Cassava sole crop			Cassava/Bush beans			Cassava/Climbing beans			Cassava/Bush beans/ Climbing beans/		
	Amount	Unit price ($Col.)	Value ($Col.)	Amount	Unit price ($Col.)	Value ($Col.)	Amount	Unit price ($Col.)	Value ($Col.)	Amount	Unit price ($Col.)	Value ($Col.)
Gross profits												
Production values (ton)												
Cassava	28.2	3,500	98,700	23.0	3,500	80,500	31.4	3,500	109,900	24.9	3,500	86,800
Bush beans	–	–	–	2.0	12.000	24,000	–	–	–	2.0	12,000	24,000
Climbing beans	–	–	–	–	—		0.5	24,000	12,000	0.6	24,000	14,400
Total system	–	–	98,700	–	–	104,500	–	–	121,900	–	–	125,200
Production costs												
Land preparation (ha)	1	2,000	2,000	1	2,000	2,000	1	2,000	2,000	1	2,000	2,000
Labor costs (daily)												
Planting	7	150	1,050	12	150	1,950	7	150	1,050	12	150	1,950
Fertilizer aplication	5	150	750	5	150	750	5	150	750	5	150	750
Herbicide aplication	2	150	300	2	150	300	5	150	750	5	150	750
Fungicide application	–	–	–	12	150	18,000	11	150	1,650	23	150	2.450
Weeding	44.5	150	6,675	0	–	–	69.5	150	10,425	25	150	3,750
Second planting from among rows	–	–	–	–	–	–	5	150	750	5	150	750
Harvesting	19	150	2,890	39	150	5,890	40	150	6,000	60	150	9,000
Costs in money spent												
Seeds (kg)	–	–	–	33	16	528	60	40	2.400	93	31.5	2,928
Fertilizer (kg)	300	12.6	3,800	300	12.6	3,800	600	12.6	7,560	600	12.6	7,560
Herbicide (liters)	7	145	1,015	7	145	1,015	7	145	1,015	7	145	1,015
Fungicide (kg)	–	–	–	6.4	364	2,365	10.3	223	2,240	16.7	275	4,605
Total costs			18,440			20,358			36,615			38,508
Net profit:												
Profit from gross costs			80,260			84,142			85,285			86,692

1. Prices and costs expressed in Colombian pesos at an exchange rate of $Col. 44.2/dollar.

1. Costs of system establishment;
2. Labor costs, especially for weeding;
3. Required inputs costs, such as fungicide for a bean intercrop or nitrogen fertilizer for a maize intercrop.
4. Harvest costs.

Table 16 provides an example of a cost breakdown for different cassava/-bean systems. The diferences in production costs between systems are marked and are due to increased input use with the introduction of beans and substantial differences in labor costs for weeding, due to the weed control given by the bush bean intercrop. The net benefits are then calculated by subtracting total variable costs from the gross benefits.

The example shows the intercropping systems to give higher per hectare returns than the monoculture systems. Hart (1975) and CIAT (1978, 1980) have also shown that cassava intercropping systems across a range of circumstances give a higher economic return than cassava in monoculture.

References

Altieri, M. A.; Francis, C. A.; Schoonhoven, A. van; and Doll, J. D. 1978. A review of insect prevalence in maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) polycultural systems. Field Crops Research 1:33–49.

Andrew, C. S. and Kamprath, E. J. (eds.). 1978. Mineral nutrition of legumes in tropical and subtropical soils. Proceedings of a workshop held at Cunningham Laboratory, Brisbane, Australia, January 16–21, 1978. Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia. 415 p.

Andrews, D. J. and Kassam, A. H. 1976. The importance of multiple cropping in increasing world food supplies. In: Multiple cropping, ASA special publication no. 27. American Society of Agronomy, Madison, Wisconsin. p. 1–10.

Araujo, E. and Moreno R. 1978. Propagaçaõ de doenças foliares do feijaõ macassar (*Vigna unguiculata* L. Walp) em diferentes sistemas de cultivos. I. Viroses. Fitopatología Brasileira 3.

Arene, O. B. 1976. Influence of shade and intercropping on the incidence of cassava bacterial blight. In: Persley, G.; Terry, E. R.; and McIntyre, R. (eds.), Proceedings of an international workshop on cassava bacterial blight. International Development Research Centre, Ottawa, Canada. Series IDRC-09e.

Asher, C. J.; Edwards, D. G.; and Howeler, R. H. 1980. Nutritional disorders of cassava (*Manihot esculenta* Crantz). University of Queensland, St. Lucía, Australia. 48 p.

Bodkin, G. E. 1912. The cassava hawk moth (*Diplodia phonota* Ello). Journal of the Board of Agriculture (British Guyana) 6:17–27.

Bray, R. H. 1954. A nutrient–mobility concept of soil plant relationships. Soil Science 78:9–22.

Burgos, C. F. 1980. Soil-related intercropping practices in cassava production. In: Weber, E. J.; Toro, J. C.; and Graham, M. (eds.), Proceedings of an international workshop on cassava cultural practices. International Development Research Centre, Ottawa, Canada. Series IDRC-151e. p. 75–81.

Cable, D. R. 1968. Competition in the semi-desert grass shrub type as influenced by root systems, growth habits, and soil moisture extraction. Ecology 50:27–38.

Cardona, C. and Walker, J. C. 1956. Angular leaf spot of bean. Phytopathology 46:610–615.

Castellanos, V. H. 1981. Comportamiento de la yuca (*Manihot esculenta* Crantz) sometida a una poda parcial y cultivada en asociación con frijol común arbustivo y voluble (*Phaseolus vulgaris* L.). M.S. thesis, University of Costa Rica, Turrialba.

Castro, M. A. 1980. Effect of spatial planting arrangement on cassava (*Manihot esculenta* Crantz) root yield. (in press).

Chang, H.; Chand, C. H.; and Ho, F. W. 1969. Competition between sugar cane and intercrops for fertilizer tagged with P32 and Rb 86. Journal of the Agricultural Association of China. 63:43–149. As cited by Oelsligle et al., 1976.

CIAT (Centro Internacional de Agricultura Tropical). 1974. Annual report for 1973. Cali, Colombia. p. 185–204.

———. 1978. Annual report for 1977. Cali, Colombia. p. C1–C68.

———. 1979. Annual report for 1978. Cali, Colombia. p. A1–A10.

———. 1980. Cassava program annual report for 1979. Cali, Colombia.

———. 1981. Cassava program annual report for 1980. Cali, Colombia.

Cleave, J. H. 1974. African farmers: labor use in the development of small-holder agriculture. Prager, New York. 253 p.

Cock, J. H. 1982. Cassava: Future potential and development needs in the tropics. Westview Press, Boulder, Colorado. (in press).

——— and Howeler, R. H. 1978. The ability of cassava to grow on poor soils. In: Jung, G.A. (ed.), Crop tolerance to suboptimal land conditions, ASA special publication no. 32. American Society of Agronomy, Masison, Wisconsin. p. 145–154.

———; Franklin, D.; Sandoval, G.; and Juri, P. 1979. The ideal cassava plant for maximum yield. Crop Science 19:271–279.

Cordero, A and McCollum, R. E. 1979. Yield potential of interplanted annual food crops in southeastern U.S. Agronomy Journal 71(5):834–842..

Dalal, R. C. 1974. Effects of intercropping maize with pigeon peas on grain yield and nutrient uptake. Experimental Agriculture 10:219–224.

Dempster, J. P. and Coaker, T. 1974. Diversification of crop ecosystems as a means of controlling pests. In: Jones, O. P. and Solemon, M. E. (eds.), Biology in pest and disease control. Wiley, New York. p. 106–114.

Díaz, R. O. and Pinstrup-Andersen, P. 1977. Descripción agroeconómica del proceso de producción de yuca en Colombia. Centro Internacional de Agricultura Tropical, Cali, Colombia. (Preliminary edition.)

Ene, L. S. O. 1977. Control of cassava bacterial blight (CBB). Tropical Root and Tuber Crops Newsletter 10:30–31.

Ezeilo, W. N. O. 1979. Intercropping with cassava in Africa. In: Weber, E.; Nestel, B.; and Campbell, M. (eds.), Proceedings of an international workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada. Series IDRC-142 e. p. 49–56.

FAO (Food and Agriculture Organization of the United Nations). 1976. Production yearbook for 1975. Rome.

———. 1978. FAO commodity projections. Cassava: supply, demand and trade projections, 1985. ESC: PROJC/1817, Rome.

———. 1981. Production yearbook for 1980. Rome.

Fonseca, D. 1981. Efecto de poblaciones y arreglos espaciales de çaupi (*Vigna unguiculata*) y maní (*Arachis hypogaea*) en asociación con yuca (*Manihot esculenta* Crantz) sobre producción e intensidad del uso de la tierra. B.S. thesis, Facultad de Ciencias Agropecuarias, National University, Palmira, Colombia.

Hart, R. D. 1975. A bean, corn and manioc polyculture cropping system: II. A comparison between the yield and economic return from monoculture and polyculture cropping systems. Turrialba 25(4):377–384.

Harwood, R. R. and Price, E. C. 1976. Multiple cropping in tropical Asia. In: Multiple cropping, ASA special publication no. 27. American Society of Agronomy, Madison, Wisconsin. p. 11–40.

Hegewald, B. and Leihner, D. E. 1980. Intercropping grain legumes with cassava on acid infertile soils. Postdoctoral report. Centro Internacional de Agricultura Tropical, Cali, Colombia.

Hiebsch, C. 1978. Comparing intercrops with monoculture. In: Agronomic economic research on soils of the tropics, Annual Report 1976–1977. Soil Science Department, North Carolina State University, Raleigh, North Carolina. p. 187–200.

Howeler, R. H. 1981. Nutrición mineral y fertilización de la yuca (*Manihot esculenta* Crantz). Centro Internacional de Agricultura Tropical, Cali, Colombia. Series 09SC-4.

———; Flor, C. A.; and González, C. A. 1978. Diagnosis and correction of B deficiency in beans and mungbeans in a Mollisol from the Cauca Valley of Colombia. Agronomy Journal 70(3):493–497.

IRRI (International Rice Research Institute). 1974. Annual report for 1973. Los Baños, Philippines. p. 15–34.

———. 1975. Annual report for 1974. Los Baños, Philippines. p. 324–347.

Jacob, A. and Uexküll. H. von. 1973. Fertilización, nutrición y abonado de los cultivos tropicales y subtropicales, 4th ed. Ediciones Euroamericanas, México 19, D. F., México.

Kurtz, T.; Melsted, S. W.; and Bray, R. H. 1952. The importance of nitrogen and water in reducing competition between intercrops and corn. Agronomy Journal 44:13–17.

Larios, J. and Moreno, R. 1976. Epidemiología de algunas enfermedades foliares de la yuca en diferentes sistemas de cultivo. I. Mildiu polvoroso y roña. Turrialba 26:389–398.

Leihner, D. E. 1979. Agronomic implications of cassava legume intercropping systems. In: Weber, E.; Nestel, B.; and Campbell, M. (eds.), Proceedings of an international workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada. Series IDRC-142e. p. 103–112.

———. 1980a. Cultural control of weeds in cassava. In: Weber, E. J.; Toro M., J. C.; and Graham, M. (eds.), Proceedings of an international workshop on cassava cultural practices. International Development Research Centre, Ottawa, Canada. Series IDRC-151e. p. 107–111, 138–152.

———. 1980b. A minimum-input technology for cassava production. Zeitschrift für Acker- und Pflanzenbau 149:261–270.

———. 1981. Fuel from biomass—future role and potential of cassava. Entwicklung und ländlicher Raum 15(1):18–21.

——— and Castro. A. 1979. Prácticas sencillas para aumentar el rendimiento de la yuca (*Manihot esculenta* Crantz). Paper presented at the 25th meeting of the Programa Cooperativo Centroamericano de Mejoramiento de Cultivos Alimenticios (PCCMCA), Tegucigalpa, Honduras, March 19–23, 1979.

———; Holguín, J.; and López, J. 1980. Coquito (*Cyperus rotundus* L.) en el cultivo de la yuca—interacciones y control. Revista COMALFI (Colombia) 7(3,4):3–20.

León, J. 1977. Origin, evolution and early dispersal of root and tuber crops. In: Cock, J. H; MacIntyre, R.; and Graham, M. (eds.), Proceedings of the fourth symposium of the International Society of Tropical Root Crops. International Development Research Centre, Ottawa, Canada. Series IDRC-080e. p. 20–36.

Litav, M. and Wolovitch, S. 1971. Partial separation of roots reducing the effect of competition between two grass species. Annals of Botany 35:1163–1178.

Little, T. M. and Hills, F. J. 1972. Statistical methods in agricultural research. Agricultural extension. University of California. Series AXT-377.

Litzinger, J. A. and Moody, K. 1976. Integrated pest management in multiple cropping systems. In: Multiple cropping, ASA special publication no. 27. American Society of Agronomy, Madison, Wisconsin. p. 293–316.

López, J. and Leihner, D. E. 1980. Control químico de malezas en policultivos con yuca. Paper presented at the 13th Seminar of the Sociedad Colombiana de Control de Malezas y Fisiología Vegetal, Cali, Colombia. Revista COMALFI 7(1,2):19–28.

Mead, R. and Willey, R. W. 1980. The concept of a "land equivalent ratio" and advantages in yields from intercropping. Experimental Agriculture 16:217–228.

Meneses, R. 1980. Efecto de diferentes poblaciones de maíz (*Zea mays* L.) en la producción de raíces de yuca (*Manihot esculenta* Crantz) al cultivarlos en asocio. M.S. thesis, University of Costa Rica, Sistema de Estudio Posgrado, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica.

Mohan Kumar, C. R. and Hrishi, N. 1979. Intercropping systems with cassava in Kerala State, India. In: Weber, E.; Nestel, B.; and Campbell, M. (eds.), Proceedings of an international workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada. Series IDRC-142e. p. 31–34.

Moreno, R. A. 1979. Crop protection implications of cassava intercropping. In: Weber, E.; Nestel, B.; and Campbell, M. (eds.), Proceedings of an international workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada. Series IDRC-142e. p. 113–127.

——— and Hart, R. D. 1979. Intercropping with cassava in Central America. In: Weber, E.; Nestel, B.; and Campbell, M. (eds.), Proceedings on an international workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada. Series IDRC-142e. p. 17–24.

Nestel, B. 1973. Cassava: Present and future. In: Nestel, B. and McIntrye, R. (eds.), Proceedings of an interdisciplinary workshop on chronic cassava toxicity. International Development Research Centre, Ottawa, Canada. Series IDRC-010e. p. 11–26.

Nickel, J. L. 1973. Pest situation in changing agricultural systems: a review. Bulletin of the Entomology Society of America 54:76–86.

Nitis, I. M. 1977. Stylosanthes as a companion crop to cassava (*Manihot esculenta*). IFS Research Grant No. 76. Faculty of Veterinary Science and Animal Husbandry, Udayana University, Depensar, Bali.

Oelsligle, D. D.; McCollum, R. E.; and Kang. B. T. 1976. Soil fertility management in tropical multiple cropping. In: Multiple cropping, ASA special publication No. 27. American Society of Agronomy, Madison, Wisconsin. p. 275–292.

Okigbo, B. N. and Greenland, D. J. 1976. Intercropping in tropical Africa. In: Multiple cropping, ASA special publication No. 27. American Society of Agronomy, Madison, Wisconsin. p. 63–102.

Perrin, R. K.; Winkelmann, D. L.; Moscardi, E. R.; and Anderson, J. R. 1976. From agronomic data to farmer recommendations. CIMMYT Information Bulletin 27. Centro Internacional de Mejoramiento de Maíz y Trigo, Mexico, D. F.

Pimentel, D. 1961. Species diversity and insect population outbreaks. Annals of the Entomology Society of America 19:136–142.

Rao, B. S. 1970. Pest problems of intercropping on plantations. In: Blencowe, E. W. and Blencowe, J. W. (eds.), Crop incorporated society of plants. p. 245–252.

Raper, C. D., Jr. and Barber, S. A. 1970. Rooting systems of soybeans. I. Difference in root morphology among varieties. Agronomy Journal 62:581–584.

Root disease in replanted areas. 1943. Ceylon. Rubber research scheme, Sri Lanka. Advisory circular 10:1–2 (supl.).

Ruthenberg, H. 1971. Farming systems in the tropics. Clarendon Press, Oxford, England.

Sánchez, P. A. 1976. Properties and management of soils in the tropics. Wiley, New York.

Southwood, T. R. L. and Way, M. J. 1970. Ecological background to pest management. In: Concepts of pest management. North Carolina State University Raleigh. p. 6–28.

Suryatna Effendi. 1979. Cassava intercropping patterns and management practices in Indonesia. In: Weber, E.; Nestel, B; and Campbell, M. (eds.), Proceedings of an international workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada. Series IDRC-142e. p. 35–37.

Thung, M. 1978. Multiple cropping based on cassava. Postdoctoral Report. Centro Internacional de Agricultura Tropical, Cali, Colombia.

——— and Cock, J. H. 1979. Multiple cropping cassava and field beans: status of present work at the International Center of Tropical Agriculture. In: Weber, E., Nestel, B.; and Campbell, M. (eds.), Proceedings of an international workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada. IDRC-142e. p. 7–16.

Trenbath, B.R. 1976. Plant interactions in mixed crop communities. In: Multiple cropping, ASA special publication no. 27. American Society of Agronomy, Madison, Wisconsin. p. 129–170.

Willey, R. W. and Rao, M. R. 1980. A competitive ratio for quantifying competition between intercropss. Experimental Agriculture 16:117–125.