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9. ABSTRACT

This Ph.D. thesis is based on field experiments conducted by the author during 16 months residence in the village of Tracuateua, municipio of Braganca, state of Para, Brazil, in 1973-1974. A literature review showed that the practice of growing two or more useful plants simultaneously on the same plot is widespread in the tropics, but it provided little indication of why this polyculture leads to increased yields. Experiments were conducted to explore the possibility that the improved soil cover leads to reduced weed growth and reduced nutrient losses. Rice, maize, manioc, and cowpeas were grown in pure stands and in simultaneous polyculture, with and without weeding, and with and without potassium fertilization. The results showed that simultaneous polyculture, especially of rice and manioc, produces better soil cover, leading to increased yields. Methods of phosphorus application and varietal evaluation with simultaneous polyculture are described. Application of the experimental findings would improve the nutritional and economic level of the Bragantina region.

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SIMULTANEOUS POLYCULTURE OF TROPICAL FOOD CROPS WITH SPECIAL REFERENCE TO THE MANAGEMENT OF SANDY SOILS OF THE BRAZILIAN AMAZON

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment for the Degree of

Doctor of Philosophy

by

Donald Charles Kass

May, 1976

Biographical Sketch

Donald Charles Lieber Kass was born in New York, New York on September 9, 1945. He received the B.S. degree in Botany from the University of Chicago in 1967 and the M.S. degree in Soil Science from Cornell University in 1970. From 1970 to 1972, he served as Peace Corps Volunteer in the state of Pará, Brazil, during which period his interest in the Brazilian Amazon was developed and his contacts with the agricultural research structure of the area were formed. He returned to Cornell in 1972 to pursue the Ph.D. degree in Soil Science and resolved to do a thesis on simultaneous polyculture which he had observed as a widespread practice in northern Brazil. In 1973, he returned to the state of Pará to do the thesis research. The experimental work was carried out in the village of Tracuateua in the municipio of Bragança where the author spent sixteen months and tried to set up a seed cooperative and was instrumental in establishing a delegation of the rural workers' syndicate. The time spent in the village had a considerable impact on the author's thinking about subsistence agriculture.

The author was married on August 17, 1973 to Maria Leonina Pereira da Silva.

DEDICATION

The author would like to dedicate this thesis to the memory of

Marie Moss Lieber

Otto Schwarzkopf

Jessie Freeman MacDonald

Augusta Doneman Howard

the author's grandmother and three very good friends who died while he was working on the thesis. The author is very proud to have enjoyed the affection of these persons who were, each in a different way, a source of inspiration to him. Their absence diminishes the satisfaction which finishing the thesis should have brought.

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Chapter One

Introduction and Thesis Objectives

1.1. Introduction

Agricultural systems in which two or more useful plants are grown simultaneously on the same area have been receiving increasing attention in recent years. At the 1975 meetings of the American Society of Agronomy, twelve papers were presented on the subject. The practice has long been recognized as a way in which farmers in the tropics and subtropics produce food and cash crops with limited land resources (Donald, 1963; Miracle, 1967; Ruthenberg, 1971), and associations of cereal crops have long been common in Europe and North America (Zavitz, 1927; Bussell, 1937; Jensen, 1952; de Wit, 1960). However, little critical experimental work done before 1970. Some authors (Anthony and Willimott, 1957; Evans, 1960; Evans and Sreedharan, 1962; Grimes, 1962) had shown benefits accruing from the practice in the tropics before 1970; but the value of crop associations had been deprecated by several authors (de Wit, 1960; Donald, 1963; van den Bergh, 1968) on theoretical grounds, mostly based on experience in the temperate zone. However, since 1970, several workers (Agboola and Fayemi, 1971; Andrews;, 1972; Osiru and

Willey, 1972; Willey and Osiru, 1972; Enyi, 1973; Haizel, 1974; Dalal, 1974), all of them working in the tropics, compared combinations of tropical crops with pure stands and have obtained results indicating the greater production potential of agricultural systems where more than one crop is grown on the same field. Bradfield (1972, 1974) emphasized that such systems offered considerable potential for increasing food production in the tropics.

The author's interest in the use of such systems began in the period of 1970-1972, which he spent in the Bragantina region of the Brazilian Amazon. It has been estimated that more than 99% of the rice and maize and more than 67% of the manioc produced in that region is grown in association with other crops (Penteado, 1967). Despite the ubiquity of such a method of production, most agricultural scientists in the area felt that the system was less efficient than production in pure stands. However, no experimental work had been done to compare yields of rice, maize, and manioc when grown in pure stands with the yields when grown in association with each other. It was this lack of information which prompted the selection of the present thesis topic.

1.2. Thesis Objectives

The fact that manioc has generally shown a response to potassium on light textured soils (Stephens, 1960; Djokoto and Stephens, 1961a; Ofori, 1973;) such as those of the

Bragantina region and that rice straw contains considerable amounts of this element (Tokunaga, 1975) suggested to the author that this might explain the use of this management practice in the Bragantina region. Supplies of potassium would be expected to be deficient in these light textured soils at the end of the rainy season. Most of the potassium would be expected to come from the ash produced by burning the original vegetation prior to cropping (Sanchez, 1972) and would be subject to heavy leaching losses during the first six months of the rainy season. Rainfall during this period has been reported to exceed 2000 mm (Bastos, 1972). Since manioc is planted at rather low populations (approximately 10,000 plants per hectare), considerable areas would be left bare until a canopy developed where it planted in pure stands. The planting of rice at the same time as the manioc would be expected to provide greater ground cover, which should reduce weed growth, erosion, and consequent nutrient losses. Furthermore, with a greater mass of growing crop, more nutrients would be taken up, and a smaller amount would remain in the soil subject to leaching losses.

To test the validity of these hypotheses, five different crop combinations (rice in pure stand followed by cowpeas in pure stand; manioc in pure stand; manioc associated with rice; manioc associated with maize; and manioc associated with rice and maize) were grown with and without weeding and with and without potassium fertilization in a replicated experiment

on a Quartzipsammentic Haplorthox, the predominant soil subgroup of the Bragantina region of the Brazilian Amazon. The effects of crop associations and different management practices on yield, leaching losses, manioc nutrient uptake, and weed growth were determined.

The use of crop associations would present new problems with respect to methods of fertilizer application and to methods of selection of adapted varieties, which have been studied almost exclusively with respect to pure stands. Two small experiments were therefore carried out to see how fertilizer might be applied and varieties selected when more than one crop species is planted.

In much of the experimental work with crop associations, soils have not been adequately characterized. In the present work, it has been attempted to characterize the soils as completely as possible where the experiments were carried out. The extent of such soils in the Brazilian Amazon was estimated.

Finally, a section has been included on the history and pattern of land use of the Bragantina region of the Brazilian Amazon since the experimental work was intended to be relevant to the problems of that area.

Chapter Two

Literature Review

2.1. Some problems of terminology

The term, mixed cropping or "the simultaneous growth of two or more useful plants on the same plot "(Ruthenberg, 1971), has unfortunately been also used by Ruthenberg (1971) to mean "two or more crops grown simultaneously and intermingled; no row cultivation". Thus, according to Ruthenberg's classification, mixed cropping would not include intercropping, which he defines as "two or more crops grown simultaneously in alternate rows in the same ground"; nor "interplanting (long term annual or biennial crops interplanted with short term annual crops during the early stages of plant development)"; nor "interculture (arable crops grown under perennial crops)"; nor "relay-planting (the maturing annual crop interplanted with seedlings or seeds of the following crop)". Neither can the term multiple cropping be used for the situations with which we are concerned here since Dalrymple (1971) has defined multiple cropping as the use of land for more than one crop per year and has concerned himself only with crops grown in succession, not mixtures. The term intercropping is most frequently encountered in the literature

used less narrowly than as defined by Ruthenberg (Grimes, 1962; Agboola and Fayemi, 1971). Indeed, very few authors follow Ruthenberg's classification. Thus one encounters a paper entitled, "The agronomic significance of mixed cropping: 1. Maize interplanted with cowpeas" (Haizel, 1974), in which what Ruthenberg defines as "intercropping" is described.

It seems to the author that all of the terms discussed in the preceding paragraph have already been used inconsistently by one or more authors. He therefore proposes the term, simultaneous polyculture, which, to his knowledge, has not been used by anyone to denote anything other than "the simultaneous growth of two or more useful plants on the same plot." Such a term would include what Ruthenberg (1971) defines as mixed cropping, intercropping, and interculture as well as those phases of interplanting and relay-planting where more than one crop is growing.

2.2. Occurrence of simultaneous polyculture

Simultaneous polyculture is widespread among agriculturists where at least one factor of production, usually land is limiting. Such agriculturists would include shifting cultivators in the Amazon and Congo basins (Miracle, 1967), Taiwanese rice and vegetable growers (Ruthenberg, 1971; Iso, 1954), western European and North American cereal growers (de Wit, 1960; Jensen, 1952) as well as Americans who plant alternate rows of vegetables in a home garden and those who used to plant maize and cucurbits in the same hill. Under-

sowing a cereal with pasture grasses and legumes would also have to be considered simultaneous polyculture. Thus the practice is quite widespread but has been significantaly reduced by the introduction of specific herbicides (Okigbo and Greenland, 1975). Indeed, it may not be too farfetched to state that monoculture generally develops from simultaneous polyculture after some innovation such as mechanization or the use of chemicals make polyculture no longer practical or economic.

It is hard to quantify how widespread is the practice of simultaneous polyculture; but some idea can be derived from Table 1, taken from the 1960 World Census of Agriculture, Volume 5 (FAO, 1971) and from the Brazilian agricultural census of 1950.[1] The Brazilian data are interesting in that they show simultaneous polyculture to be much more common in the northern and northeastern part of the country where farms tend to be small and unmechanized than in the southern and southeastern parts where larger, more mechanized farms are common.[2]

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1. This census states the quantity of each major crop coming from pure stands, mixed plantings with annual crops, and mixed plantings with perennial crops for each municipality of Brazil, of which there are approximately 2000. The reliability of the data may be questioned, however. The author was unable to determine whether similar surveys had been carried out in 1960 or 1970.

2. The following data were calculated from the 1970 Brazilian agricultural census (IBGE, 1974).

Thus, simultaneous polyculture tends to be associated with smaller, unmechanized farms. As Ruthenberg (1971) points out, simultaneous polyculture is not exclusively found in shifting cultivation systems in the tropics but also in semi-permanent cultivation systems, permanent cultivation systems, systems with arable irrigation farming, as well as systems with perennial crops (Ruthenberg, 1971). Thus, further evidence is obtained that simultaneous polyculture is related to land and labor availability rather than to the level of technology or to the methods used to conserve water and soil fertility. The persistence of simultaneous polyculture in systems where land is used very intensively would indicate that the practice offers certain advantages and cannot be attributed to primitive farmers' "dislike of orderliness and precision" as was stated by one investigator (Grimes, 1962).

2. Continued

Region	Number of farms with tractors	Percent of farms with tractors	Mean area per farm in annual crops (Ha.)
North	735	0.3	2.34
Northeast	4158	0.1	3.26
Southeast	55055	5.9	10.11
South	42654	3.3	8.38
Central West	7455	2.9	10.38

Table 1

Two measures of the extent of simultaneous polyculture

A. Observations on extent of crop mixtures (A form of simultaneous polyculture). (FAO, 1973)

Country	Observation made by FAO
Dominican Republic	40% or more maize grown with other crops
El Salvador	Maize and beans, maize and sorghum, maize and other crops in mixtures
Jamaica	50% of maize mixed with other crops
Mexico	20% of maize mixed with other crops
Brazil	6-11% of rice and maize mixed with other crops
Paraguay	1/3 beans, 1/10 sweet potatoes, 1/10 maize mixed with other crops
Venezuela	1/6 rice, 1/3 maize, 1/2 beans, 1/5 cassava, 1/2 cotton mixed with other crops
India	5-6% of rice and 70-80% of other crops grown in mixtures
Indonesia	Maize and rice grown in mixtures
Pakistan	Wheat, barley, cotton, and oil seeds frequently grown in mixtures
Central African Republic	1/4 cotton, 1/3 coffee, 1/5 cassava grown in mixtures
Libya	Considerable part of area in maize and beans grown in mixtures
Senegal	1/4 of area in groundnuts and millet grown in mixtures
Southern Rhodesia	1/2 of area planted in mixed crops

These are the only countries about which such observations were made by FAO.

Table 1, Continued

B. Percent of production of major crops coming from associations with other crops (a type of simultaneous polyculture) and pure stands as reported in 1950 Brazilian agricultural census. (IBGE, 1950b).

1. Cotton

Country as whole
81% of production from pure stands
19% of production from simultaneous polyculture

Northeast
64% of production from pure stands
36% of production from simultaneous polyculture

2. Peanuts

Country as whole
90% of production from pure stands
10% of production from simultaneous polyculture

3. Rice

Country as whole
82% of production from pure stands
18% of production from simultaneous polyculture

Northeast
32% of production from pure stands
68% of production from simultaneous polyculture

4. Beans

Country as whole
40% of production from pure stands
60% of production from simultaneous polyculture

5. Manioc (Cassava)

Country as whole
81% of production from pure stands
19% of production from simultaneous polyculture

Northeast
66% of production from pure stands
34% of production from simultaneous polyculture

Table 1, B., Continued

6. Maize

Country as whole
64.5% of production from pure stands
35.5% of production from simultaneous polyculture

2.3. Some problems of methodology

There are two major problems in investigating simultaneous polyculture: what criteria to use in comparing the relative production of different cropping systems and what planting arrangements and densities to use in experimental work.

a. Measurement of production.

Most authors have used yield of the crops concerned as the measure of production. Such a procedure might be reasonable where two grain crops are concerned. Where different plant parts are involved such as cotton and maize (Grimes, 1962), cotton and legumes (Anthony and Willimott, 1957), or cereals and undersown pasture grasses and legumes (Thomas and Bennett, 1975; Shelton and Humphreys, 1975a), the practice becomes somewhat more questionable since one considers the total dry matter yeild in the case of the pasture species and only the seed yield in the case of the cereal. From the standpoint of biological productivity, it would of course be more reasonable to consider total dry matter production; and some authors have considered this as well as seed yields (Haizel, 1974; Enyi, 1973; Dalal, 1974). However, total dry matter production may be of little importance to the farmer

who is concerned with only those plant parts of nutritional or economic value. For the cash crop farmer, the relative value of the crops may be the deciding factor in determining the merits of monoculture or simultaneous polyculture. Several authors have therefore included economic analyses in their studies of simultaneous polyculture (Willey and Osiru, 1972; Andrews, 1972; Evans and Sreedharan, 1962; Grimes, 1962), in some cases even considering the possibility of differing relative values of the crops studied (Willey and Osiru, 1972; Evans and Sreedharan, 1962).

While these methods may be of value to the farmer, they do little to elucidate the biological factors which may be involved in making simultaneous polyculture more advantageous (Donald, 1963). Donald (1963) proposes a "competition index", developed by G. A. MacIntyre, which he claims could indicate whether two species have a mutually beneficial or harmful effect. The competition index is defined as:

$$\frac{(N_A' - N_A)\ (N_A' - N_B)}{N_A N_B}$$

Where N_A plants of species A compete with N_B plants of species B on a unit area, and the yield per plant of species A in the mixture equals the yield per plant of N_A' plants in a pure stand on a unit area, and the yield per plant of N_B' plants in a pure stand on a unit area. A competition index of less than one would indicate a beneficial association while an index of more than one indicates a harmful associa-

tion. In order to determine N_A' and N_B', it would be necessary to grow each species in pure stands at a sufficient range of densitiies to construct a density yield curve (Donald, 1963). Haizel, (1974), Willey and Osiru (1972) and Osiru and Willey (1972) attempt to calculate this competition index for the crop mixtures which they studied although they determined N_A' and N_B' from pure stands grown at the same density as that used in the mixture.

Another measurement of the possible advantages offered by simultaneous polyculture is proposed by van den Bergh (1968) and utilized by Haizel (1974) and Shelton and Humphreys (1975a). van den Bergh proposes a measure known as the relative yield total (RYT), which is the sum of the relative yields of all of the species in the mixture. The relative yield is defined as the ratio of the yield of the species in a mixture r_M to the yield of the species in pure stand r_P, i.e. r_M/r_P. When RYT is greater than unity, it is supposed to indicate that the two species are not competing for the same space, which is defined according to de Wit (1960) to be any factors for which the species may be competing (Shelton and Humphreys, 1975a; Haizel, 1974). It may be seen that the RYT is merely a complicated way of comparing the yield of the mixture to the mean of the yields of the species in pure stands as is used, as we shall see, by C. M. Donald (1963) to evaluate the results of studies of simultaneous polyculture in forage species. An RYT of greater than unity would indi-

cate that the yield of the mixture is greater than the mean of the yields of the pure stands.

Another measure of competition in mixtures is the "relative crowding coefficient" (de Wit, 1960) or "relative competitive ability "(Donald, 1963), which relates the amount of the environment appropriated by a species in a mixture to its proportion in the mixture seeded. Again, as in the other models of de Wit, the environment is assumed to be constant, a condition which he admits will rarely hold (de Wit, 1960). The relative crowding coefficient of species 1 with respect to species 2 can be defined as follows:

$$k_{12} = \frac{Y_1 \; z_2}{z_1(M_1 - Y_1)}$$

where: Y_1= yield of species 1 in mixture

z_1= proportion of species 1 in seeded mixture

z_2= proportion of species 2 in seeded mixture

M_1= Yield of species 1 in pure stand

$z_1 + z_2 = 1$ by definition

Similarly the relative crowding coefficient of species 2 with respect to species 1, k_{21}, can be defined[1]. If the product

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1. These definitions are based on formulas for Y_1 and Y_2 given by van den Bergh (1968):

$$Y_1 = \frac{k_{12}z_1}{k_{12}z_1 + z_2} \cdot M_1 \qquad Y_2 = \frac{k_{21}z_2}{k_{21}z_2 + z_1} \cdot M_2$$

where: Y_1=Yield of species 1 in mixture

Y_2=Yield of species 2 in mixture

of the two relative crowding coefficients, i.e. $k_{12} \times k_{21}$ is greater than unity, it is supposed to indicate that simultaneous polyculture offers advantages over pure stands (Shelton and Humphreys, 1975a; Harris, 1970).

A similar measure proposed by de Wit (1960) is the relative reproduction rate (R.R.R. or α) defined as follows:

$$\alpha = \frac{\text{ratio of the proportion of species 1 in the harvest mixture to the proportion of species 1 in the seeded mixture}}{\text{ratio of the proportion of species 2 in the harvest mixture to the proportion of species 2 in the seeded mixture.}}$$

(Donald, 1963)

Three situations can occur:

1. $\alpha = 1$ and the proportion of the species harvested is the same as that seeded.

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1. continued

M_1=Yield of species 1 in pure stand
M_2=Yield of species 2 in pure stand
z_1=Proportion of species 1 in seeded mixture
z_2=Proportion of species 2 in seeded mixture

$z_1 + z_2 = 1$

Hence: $k_{21} = \dfrac{Y_2 \; z_1}{z_2 \; (M_2 - Y_1)}$

2. One species has a higher reproductive rate than the other and will eventually crowd out the other
3. The two species interact either beneficially or antagonistically.

If the logarithm of the proportion of the species in the sees harvested is plotted against the logarithm of the propor- of the species in the seed sown, the graph will be a straight line with slope of + 1, passing through the origin in situation 1 and not passing through the origin in situation 2. In situation 3, the slope of the graph will be greater than one in the case of a beneficial interaction and less than one in the case of a harmful interaction (Donald, 1963; de Wit, 1961). According to de Wit (1961), the "space" for which the species compete is greater than that in a pure stand. He cites two examples: a clover-grass mixture, where the nitrogen fixed by the clover increases the "space" available in the mixture; and non-synchronous growth curves of the two species in the mixture so that one species can utilize nutrients, water, light, etc., not needed by the other at a particular stage of growth. He knows of no examples of diminuition of the "space" caused by the interaction of the two species (de Wit, 1961).

b. Production per unit time.

The problem of non-synchronous growth is another aspect

of simultaneous polyculture which simple yield figures may not represent adequately. The growth duration of the species involved is rarely, if ever, the same so that different time periods are involved in comparing the pure stands and simultaneous polyculture. Two authors (Dalal, 1974; Andrews, 1972) have at least recognized the problem and have stated yields in terms of production per unit area per unit time. On such a basis, Andrews (1972) always finds the balance to be in favor of simultaneous polyculture of sorghum, millet, and cowpeas; but Dalal (1974) finds the maize-pigeon pea mixture to produce less grain per hectare per week than a pure stand of maize although the difference was not significant for a mixture planted in alternate rows. However, to make the comparison valid, cropping systems should be compared over the same total time period since rainfall and radiation may vary over the cropping season. As a result, a comparison of production per unit time of a short season crop growing in the more favorable period with a mixture growing into the less favorable period is clearly biased. Hence, Dalal's comparison is not really valid since he is comparing maize growing over a 16 week period with a maize-pigeon pea mixture growing over a 24 week period (Dalal, 1974). He should divide the maize yield by 24 weeks since the area is not producing anything during the eight weeks following the maize harvest while it

is producing in the case of simultaneous polyculture. To make the comparison truly valid, another crop should be found to plant after the maize and to be harvested at the same time as the pigeon peas. The non-existence of such a crop or alternative land use is one of the arguments for the use of simultaneous polyculture (Anthony and Willimott, 1957). So, to provide a realistic evaluation of simultaneous polyculture, alternative uses for the whole period in which the area is cropped would have to be considered.

c. Crop arrangement: intercropping versus mixed cropping

The results of Dalal (1974) described above indicated that there might be a difference in the yield obtained from intercropping, where the crops are grown in alternate rows, and mixed cropping, where the crops are grown simultaneously and intermingled with no row cultivation being practiced or possible (Ruthenberg, 1971). Working with pots, Harper (1961) obtained no significant differences in total yield from alternate rows, paired rows, and various random arrangements of two bromegrass species. However, relative yield of the two species did vary, even among the different random arrangements; but Donald (1963) suggested the possibility of the differences being an artifact brought about by the proportion of plants growing at the rim of the pot. Donald (1963) cited several experiments with pure stands of maize and wheat showing no effect of irregular as opposed to regular spacing

on yield. Evans (1960) found no significant differences in maize and groundnut yields when grown in alternate rows, uniformly mixed, or grown at different plant populations. Agboola and Fayemi (1971) compared planting cowpeas, calopogon, and greengram in the same or alternate rows with maize in four different cropping seasons with and without fertilizer but could find no significant difference between planting the legume in the same or alternate rows as the maize. Dalal (1974), however, found that mixed cropping of maize and pigeon peas significantly reduced the yield, total dry matter, and potassium and nitrogen content of maize as compared with the yield in alternate rows. Pigeon peas mix-cropped with maize had significantly lower production of total dry matter, calcium, magnesium, and nitrogen than when intercropped. Soil characteristics were generally unchanged by either planting method but mineral nitrogen levels (NH_4^+ and NO_3^-) were significantly lower in the mix-cropped than in the intercropped plots. Dalal concluded that there was greater competition for light and nutrients under mixed cropping and that the maize roots perhaps inhibited effectual nodulation of the pigeon pea roots in close proximity to the maize roots had ineffectual nodules while those farther away, of which there were more in the intercropped treatments, had healthy nodules (Dalal, 1974). These results made up the only evidence that mixed cropping was inferior to intercropping, but Dalal

measured many parameters which were ignored by other workers. Most investigators working with simultaneous polyculture used intercropping in their experimental work because of the greater ease of operations and of the possibility of the results being applicable to higher levels of management where row cropping would be used (Enyi, 1973; Willey and Osiru, 1972; Osiru and Willey, 1972; Andrews, 1972).

d. Crop density.

The plant population used in a study of simultaneous polyculture will affect the results obtained and the validity of a comparison of these results to pure stands (Donald, 1963). Six different methods of determining what plant populations to use in comparisons of simultaneous polyculture with pure stands have been used by investigators. These are described below:

1.) Additive method (Haizel, 1974). If one plants x plants of species A per unit area and y plants of species B per unit area in pure stands, one plants in the mixture x plants of A plus y plants of B per unit area. C. M. Donald (1963) states that such a procedure will reduce the yield per plant of both species A and B since all plants will be exposed to an intensified level of competition compared with the corresponding pure culture. Nevertheless, this method is used by Agboola and Fayemi (1971) and Evans and Sreedharan (1962).

2.) Secondary crop seeded within the primary crop without changing the density of the primary crop (Enyi, 1973a). In this case, there is no comparison with a pure stand of the secondary crop.

3.) Additive method with both species at a range of densities (Evans, 1960). A factorial experiment results with high medium, and low densities of one crop being combined with high, medium, and low densities of the other crop. At some combinations, the level of competition should be less than or comparable with that in pure stands.

4.) Substitutive method (Haizel, 1974). The population per unit area of the species in pure stand is twice that in the mixture but the total plant population in pure stands and mixtures is the same. This method is used by Papadakis, 1941; Anthony and Willimott, 1957; Grimes, 1962; and Dalal, 1974.

5.) Substitutive method with the half-normal density of the pure stand also included as a treatment. A separation of the effects due to competition and population is claimed to be possible by this method (Andrews, 1972:1974).

6.) The replacement series. A mixture is formed by replacing a certain proportion of one species by another, thus keeping total population pressure constant. A single plant of one species is not necessarily regarded as being equivalent to a single plant of another species (Willey and Osiru, 1972;

Osiru and Willey, 1972).

It can be seen that none of these methods provides a sure means of ensuring that the population pressure in the mixture is the same as tnat in the pure stand. Indeed, if non-optimal populations are used in the pure stands, treatment with simultaneous polyculture might appear to be more advantageous.

This discussion of methodological problems in studies of simultaneous polyculture should emphasize that it is extremely difficult to design experiments for comparing simultaneous polyculture with pure stands that will provide a true basis for comparison. Both the criteria for comparison and the attainment of comparable situations are open to question. It should also be noted that all of the experiments referred to in this section concerned only simultaneous polyculture of two species while it is most common to encounter farmers using much more complex mixtures (Andrews, 1972). The methodological difficulties in investigating simultaneous polyculture are most probably a contributing factor to the paucity of results obtained.

2.4 Summary of experimental findings.

A summary of experimental conditions and of the results obtained by various investigators attempting some sort of evaluation of simultaneous polyculture of annual crops as compared with monoculture is presented in Table 2.

Table 2

Comparison of experimental conditions and results obtained in investigations of simultaneous polyculture in the tropics

A. Associations involving legumes

Source	Anthony and Willimott,1957
Crops	Cotton; Groundnuts; Soybeans; *Phaseolus angularis*; Cowpeas
Varieties	Cotton- BAR SP/84; legume varieties not stated
Country	Sudan
Soils	Latosols with "pea iron gravel", acid, generally free-draining,leached
Climatic data	Rainfall: 1450 mm; 130 days measurable rain per year; dry season: Dec.-Feb. Rains usually begin in March but are unreliable. Planting begun in April.
Number years	2
Number sites	1
Fertilization	None
Experimental conditions	Cotton in pure stands and intercropped with legumes. Two planting dates and two spacings for cotton used. Also two planting dates for legumes used. Substitutive method.
Findings	Cotton yields always reduced by intercropping but generally compensated by legume yield. Earlier planting of legumes had less adverse effect on cotton yield, but yield of legumes except for groundnuts generally lower with earlier planting. *P. angularis* had least adverse effect on cotton.

Table 2, continued

Source	Evans, 1960
Crops	Maize; Sorghum; Groundnuts
Varieties	Groundnuts- Asiriya Mwitunde; Maize-Katambili; Sorghum- Dobbs
Country	Tanzania
Soils	One site more fertile than other
Climatic data	One year drier than other
Number years	2
Number sites	3
Fertilization	In first year, more fertile site (Ilonga) not fertilized; less fertile site (Mwanhala) received 130 lb/A double superphosphate broadcast before planting and 130 lbs/A ammonium sulphate side-dressed. No fertilizer applied in second year.
Experimental conditions	Maize or sorghum and groundnuts in pure stand and intercropped at three plant populations. Additive method.
Findings	Generally higher production obtained from intercropping except at one site in year of high rainfall . Generally low and medium populations showed more benefit from intercropping than high populations.

Table 2, continued

Source	Evans, 1960
Crops	Maize; Groundnuts
Varieties	Groundnuts- Asiriya Mwitunde Maize- Katambili
Country	Tanzania
Soils	More fertile of sites
Climatic data	Drier year
Number years	1
Number sites	1
Ferilization	None
Experimental conditions	Maize and groundnuts grown in pure stands with and without weeding and intercropped and mix-cropped, grouped and at uniform spacings. All treatments at three plant populations. Additive method.
Findings	No significant differences among intercropping, grouped or uniformly spaced mixed cropping. Weeds reduced yield as much as another crop of groundnuts but less than another crop of maize.

Table 2, continued

Source	Evans and Sreedharan, 1962
Crops	Castorbeans; Groundnuts; Soybeans
Varieties	Not stated
Country	Tanzania
Soils	No description
Climatic data	None given
Number years	2
Number sites	1
Fertilization	No information given
Experimental conditions	Castorbeans planted at three planting dates intercropped with either groundnuts or soybeans. Additive method.
Findings	Groundnuts and soybeans affected adversely by castorbeans when castorbeans planted early, not if planted later. Despite adverse effect, total yield always higher with intercropping than mean of pure stands.

Table 2, continued

Source	Agboola and Fayemi,1971
Crops	Maize with nine different legumes
Varieties	Maize- var. NS_1 Legumes: 1. Greengram (Phaseolus aureus)-var.5301 2.Cowpea (Vigna sinensis)- var. local 3. Cowpea(V. sinensis)- var. New Era 4. Cowpea(V. sinensis)- var. local white 5. Mucuna (Mucuna utilis) 6. Calopogon (Calopogonium mucunoides) 7. Popondo (Phaseolus lunatus) 8. Stylo (Stylosanthes gracilis) 9. Soybean (Glycine max)- var. Para yellow
Country	Nigeria
Soils	"Ferruginous tropical soils", moderately to strongly leached with low base and humus content. Ibadan group: friable, porous sands; also well-drained brown, fairly clayey coarse-textured soil. Iwo series: pH-6.7; total N-1000 lbs/A; exchangeable K- 200 lbs/A; available P - 20 lbs/A.
Climatic data	None given
Number years	1
Number sites	1
Fertilization	None
Experimental conditions	Nine different legumes mix-cropped with maize. Additive method. Pure stand of maize only.
Findings	Cowpeas and calopogon did not reduce maize yields as compared with pure stand. Greengram reduced maize yield only slightly. These three legumes selected for further experimentation.

Table 2, continued

Source	Agboola and Fayemi, 1971
Crops	Maize; Cowpea; Calopogon; Greengram
Varieties	Maize- NS_1; Cowpea- local brown mottle; Greengram-var. 5301 ex. Fed. Agric., Ibadan; Calopo- not stated.
Country	Nigeria
Soils	"Ferruginous tropical soils", moderately to strongly leached with low base and humus content. Ibadan group: friable, porous sands; also well-drained brown, fairly clayey coarse-textured soils. Iwo series: pH-6.7; total N- 1000 lbs/ A; exchangeable K- 200 lbs/ A; available P- 20 lbs/ A.
Climatic data	None given
Number years	2 (4 cropping seasons)
Number sites	1
Fertilization	Included as treatment: 50 lbs/A N as ammonium sulfate; 9 lbs/A P_2O_5 as simple superphosphate; 50 lbs/A K_2O as KCl.
Experimental conditions	Pure stand maize and maize intercropped and mix-cropped with legumes. Also pure stand maize following pure stand legumes. All treatments with and without fertilization. Additive method.
Findings	Legumes intercropped or mix-cropped with maize had same effect on maize yield as fertilizer application, especially in 2nd, 3rd, and 4th cropping season. Authors felt moisture might have been limiting in 1st and 3rd crop so recommended intercropping in 2nd and 4th crops when moisture less limiting. Maize reduced legume yield more than legume reduced maize yield. Little difference between intercropping and mixed cropping. Maize did best with calopogon but greengram was highest yielding legume.

Table 2, continued

Source	Andrews, 1972
Crops	Sorghum; Maize; Millet; Cowpeas
Varieties	Guinea zone sorghum- Dwarf line 2123 Cowpeas- NEP 593 Millet- Ex Bornu Maize- Bomo local improved
Country	Nigeria
Soils	No description
Climatic data	Rainfall: 35-55"; Rainy season: 135-195 days.
Number years	1
Number sites	1
Fertilization	At planting: P_2O_5- 31 lbs/A; N- 45 lbs/A. Sidedressed: N- 33 lbs/A.
Experimental conditions	Pure stand sorghum compared with sorghum intercropped with maize or millet followed by cowpeas. Substitutive method. No pure stands of millet, maize, or cowpeas.
Findings	Intercropping dwarf sorghum with millet or maize followed by cowpeas gave greater grain yield and return than pure stand sorghum. Millet seemed to compete better than maize. Both maize and millet compensated well for reduced population when intercropped. Less lodging of millet and maize when intercropped than in pure stands. (Pure stands grown in previous year.)

Table 2, continued

Source	Andrews, 1972
Crops	Sorghum; Maize; Millet; Cowpeas
Varieties	Guinea zone sorghum- Dwarf line 2123 Cowpeas- NEP 593 Millet- Ex Bornu Maize- Bomo local improved
Country	Nigeria
Soils	No description
Climatic data	Rainfall: 35-55"; Rainy season: 135-195 days.
Number years	1
Number sites	1
Fertilization	At planting: P_2O_5- 31 lbs/A; N- 22 lbs/A. Sidedressed:N- 47 lbs/A.
Experimental conditions	Sorghum intercropped with millet followed by cowpeas in 1:1, 2:2, and 2:1 row planting patterns. Also pure stands with skip rows corresponding to intercropping patterns.
Findings	Experimental design permitted separation of effects from reduced population and from competition. As crops became more separated spatially, effects of intercropping reduced. Sorghum did best in 2 row millet: 1 row sorghum pattern. This planting pattern also led to highest yield of cowpeas following millet. Millet did best in 1:1 or 2:1 row intercropping with sorghum. Intercropping always led to increased total yield. Reduction of yield due to reduction of population much less than proportion of reduction.

Table 2, continued

Source	Willey and Osiru, 1972
Crops	Maize; Beans (Phaseolus vulgaris)
Varieties	Maize- Katumani (280 cm height; 120 day maturity); Beans- Diacolnima (partly erect; 90 day maturity)
Country	Uganda
Soils	Deep ferralitic soils, high in potash, low in N and P.
Climatic data	Altitude: 1200 mm; Rainfall: 1300 mm, 436 mm for first, 578 mm for second experiment.
Number years	2
Number sites	1
Fertilization	Area previously in fertilized legumes. First experiment received 70 kg/ha of P_2O_5 as single superphosphate and 50 kg/ha of K_2O as KCl. Second experiment received only 70 kg/ha of P_2O_5 as single superphosphate.
Experimental conditions	Pure stand maize; 2/3 maize, 1/3 beans; 1/3 maize, 2/3 beans; and pure stand beans at four plant populations. Intercropping. Replacement series.
Findings	Highest total grain yield from 2/3 maize,1/3 bean mixture. Intercropping most beneficial at higher populations. Competition indices for intercropping always less than one. Intercropping always more profitable even over wide range of relative maize and bean prices.

Table 2, continued

Source	Osiru and Willey, 1972
Crops	Sorghum; Beans (Phaseolus vulgaris)
Varieties	Sorghum- Sel. MVS 16 (65 cm height; 120-125 day maturity) Beans- Diacolnima (partly erect; 90 day maturity)
Country	Uganda
Soils	Deep ferralitic soils, high in potash, low in N and P.
Climatic data	Altitude: 1200 m; Rainfall: 1300 mm, 440 mm in course of experiment.
Number years	1
Number sites	1
Fertilization	Area previously in fertilized legumes. Applied NPK: 130-50-70. (High N to eliminate effect of N fixation by legumes).
Experimental conditions	Pure stand sorghum; 2/3 sorghum, 1/3 beans; 1/3 sorghum, 2/3 beans; and pure stand beans at four plant populations. Intercropping. Replacement series.
Findings	Bean yields decreased steadily from pure stands to lower proportion in mixture. Highest total grain yield from 2/3 sorghum, 1/3 bean mixture. Intercropping most beneficial at higher plant populations. Competition indices for intercropping always less than one. Benefit from intercropping felt due to better utilization of environment.

Table 2, continued

Source	Enyi, 1973a
Crops	Maize; Sorghum; Cowpeas; Pigeon peas; Beans (*P. vulgaris*)
Varieties	Maize- Ilonga composite; Sorghum- Serena; legume varieties not stated
Country	Tanzania
Soils	Clay soil on Faculty of Agriculture Experimental Farm, Mongoro, W. Tanzania; pH- 6.5.
Climatic data	None
Number years	1
Number sites	1
Fertilization	$(NH_4)_2SO_4$: 400 kg/ha; K_2SO_4: 200 kg/ha; double superphosphate: 300 kg/ha.
Experimental conditions	Intercropping and pure stands of maize and sorghum. No pure stands of legumes.
Findings	Intercropping with legumes reduced LAI of cereals but LAI more related to grain yield of sorghum than of maize. Grain yields for maize reduced by cowpeas and beans but increased by pigeon peas. Total grain yields of sorghum not reduced significantly by legumes but increased with pigeon peas. Better results with pigeon peas attributed to later maturity,less competition.

Table 2, continued

Source	Haizel, 1974
Crops	Maize; Cowpeas
Varieties	Maize-Mexican 17 (tall, upright); Cowpeas-New Era (spreading with climbing tendencies)
Country	Ghana
Soils	Light silty loam; University Farm, Legon.
Climatic data	None; irrigation needed in one year, not in other.
Number years	2
Number sites	1
Fertilization	None; area previously in grass fallow.
Experimental conditions	Two maize and two cowpea populations in pure and mixed stands. Intercropping. Additive and substitutive methods.
Findings	Grain production but not total dry matter production not adversely affected by intercropping. Maize production decreased and cowpea production increased by intercropping. Competition indices always less than one. RYT always greater than one for intercropping.

Table 2, continued

Source	Dalal, 1974
Crops	Maize; Pigeon peas
Varieties	Maize- cult. X 306; Pigeon peas- cult. GI 274 A
Country	Trinidad
Soils	Loam soils, University field station, St. Augustine, Trinidad; 12% clay; pH-5.2; C.E.C.- 12 me/100 g soil.
Climatic data	Precipitation: 100 mm per month with 50 mm added in March and April. Temperature: 25-26 C.
Number years	1
Number sites	1
Fertilization	None
Experimental conditions	Pure stands, intercropping, and mixed cropping. Substitutive method.
Findings	Maize yields reduced but pigeon pea yields not significantly reduced by intercropping or mixed cropping. Total grain yield always higher with mixed or intercropping than mean of pure stands. Grain yields per hectare per week lower with simultaneous polyculture than with pure stand maize. Intercropping and pure stands similar in stover yield, Ca , Mg, and N uptake but mixed cropping inferior. Pigeon peas had taken up only small proportion of total nutrients taken up at time of maize harvest.

Table 2, continued

Source	Pinchinat and Oelsligle, 1974
Crops	Maize; Manioc; Rice; Soybeans; Sweet potato; Beans (P. vulgaris)
Varieties	Maize- Eladio Hernandez; Rice- CR-1113; Soybeans- Jupiter; Manioc- Valencia, Mangui (See Experimental conditions); Sweet potatoes- local; Beans- 27 -R (bush type) and CATIE 1 (climbing type)(See Experimental conditions).
Country	Costa Rica
Soils	Colorado soil derived from volcanic ash. Typic Distrandept, fine, isohyperthermic. P_2O_5 (Olsen)-3 ppm; pH-5.4; bases (me/ 100g): Al- 0.12; Ca- 8.0; Mg-2.0; K-0.49 in surface 0-20 cm. Loamy texture, 8% organic matter. Dominant clays: allophane, halloysite, and kaolinite.
Climatic data	Rainfall: 2700 mm per year; solar radiation: 10-16 kcal/ cm^2/ month.
Number years	1
Number sites	1
Fertilization	None, low, and high NPK levels used for all treatments but amounts differed with cropping systems.
Experimental conditions	Maize mix-cropped with manioc (var. Mangui) two weeks after maize planting and intercropped with rice (Treatment A-1) or soybeans followed by rice (Treatment A-2) three months after maize planting. Maize mix-cropped with manioc(var. Valencia) three months after maize planting and intercropped with 27-R beans(bush type) followed by soybeans three months after maize planting (Treatment B-1) or intercropped with CATIE beans (climbing type) followed by sweet potatoes(Treatment B-2).

Table 2, continued

Source	Pinchinat and Oelsligle, 1974
Experimental conditions, continued	Monocultures of rice, soybeans followed by soybeans and CATIE-1 beans followed by sweet potatoes. Substitutive method since higher populations used in monoculture treatments.
Findings	Soybeans, bush-type beans and sweet potatoes appeared to be better competitors than rice and climbing-type beans since they gave a higher percentage of their monoculture yield under simultaneous polyculture. Because of the high value of beans, systems which contained beans and didn't contain rice were most profitable. Maize-manioc-bean- sweet potato system most productive in terms of energy while maize-manioc-bean- soybean system most productive in terms of protein. All simultaneous polyculture treatments produced more energy and protein than analogous pure stands.
Source	Pinchinat and Oelsligle, 1974
Crops	Manioc; Beans (P. vulgaris); Rice; Maize
Varieties	Manioc-Mangui and Valencia. Others not stated.
Country	Costa Rica
Soils	Colorado series, presumably same as above
Climatic data	Nothing stated, presumably as above
Number years	1
Number sites	1
Fertilization	Basal at time of planting of short-term crops: N- P_2O_5- K_2O: 100-200-200. N as NH_4NO_3- 100 kg/ha after harvest of short-term crops.

Table 2, continued

Source	Pinchinat and Oelsligle, 1974, cont.
Experimental conditions	Two cultivars of manioc in pure stand and intercropped with rice and beans and mix-cropped with maize planted two months after manioc planting.
Findings	Simultaneous polyculture gave greater cash return at local market prices but pure stands of manioc more profitable at export prices. No difference in effect of two manioc cultivars on intercropped or mix-cropped species. Rice seemed more adversely affected by simultaneous polyculture than other crops.
Source	Pinchinat and Oelsligle, 1974
Crops	Maize; Beans (P. vulgaris)
Varieties	Maize- Maicena; Beans- cult. CATIE -1
Country	Costa Rica
Soils	Colorado series (Typic Distrandept, fine, isohyperthermic). pH- 5.5; available P- 13 g/ml; 0.8 me K/ 100ml; 10 me CEC/100 ml; 99% base saturation.
Climatic data	Rainfall: 2700 mm; solar radiation: 10-16 kcal/ cm^2/ month.
Number years	1
Number sites	1
Fertilization	All treatments received 200 kg P_2O_5/ ha and 100 kg K_2O/ ha as simple superphosphate and KCl. Each cropping system received four levels of N (0, 100, 200, and 300 kg/ha as NH_4NO_3) broadcast and incorporated prior to planting.

Table 2, continued

Source	Pinchinat and Oelsligle, 1974,cont.
Experimental conditions	Pure stands of maize and beans and population of pure stands of each crop combined with 100% and 50% of pure stand population of other crop. Additive method. Pure stand beans- 200,000 plants/ ha; pure stand maize-50,000 plants/ ha.
Findings	RYT always higher for intercropped treatments. Benefits from intercropping greatest at highest N level and with combinations of two pure stand populations or of 100% of maize and 50 % of bean pure stand populations. Relative yields of maize and beans differed little at 0, 100, and 200 kg/ ha of N although maize responded to up to 100 kg/ ha of N and beans to 200 kg/ha of N. Because of high bean price, greatest return for highest N level with bean monoculture. With no fertilizer, greatest return from 100% of pure stand bean population combined with 100% of pure stand maize population. Highest energy production with 100 % of pure stand maize population combined with 50% of pure stand bean population. Highest protein with 50% of pure stand maize population combined with 100 % of pure stand bean population except for highest N level where bean monoculture gave most protein.
Source	Pinchinat and Oelsligle, 1974
Crops	Maize; Soybeans
Varieties	Maize- Eladio Hernandez(tall statured) in first planting and Tupeno Planta Baja (short statured) in 2nd and 3rd plantings; Soybeans- Bragg in 1st planting and Jupiter in 2nd and 3rd planting

Table 2, continued

Soils	Colorado soil(Typic Distrandept, fine, isohyperthermic) adjacent to area used for maize, manioc, rice, soybean,sweet potato, bean experiment.
Climatic data	Rainfall: 1100 mm for first crop 700 mm for second crop 950 mm for third crop Insolation: 13 kcal/cm^2/month- 1st crop 14 kcal/cm^2/month -2nd crop 14 kcal/cm^2/ month-3rd crop
Number years	1 (3 crops)
Number sites	1
Fertilization	NPK applied to each crop. 150-20-70, 164-48-24, and 160-120-60 to 1st,2nd, and 3rd maize crops respectively. 10-20-20, 24-48-24, and 30-60-30 to 1st, 2nd, and 3rd soybean crops respectively. Sum applied to simultaneous polyculture treatments. Initial application of 400 kg/ha of P_2O_5 to experimental area.
Experimental conditions	Additive method: maize and soybean populations 50,000 and 40,000 plants/ha respectively in all treatments. Pure stands in 60 cm rows; intercropping in 60 cm and 30 cm rows; mixed cropping in 60 cm rows.
Findings	Simultaneous polyculture was beneficial in all cases except 2nd crop due to insufficient rainfall. Intercropping in alternate 30 cm rows gave highest RYT since maize yields higher in such cases than in monoculture. Soybeans more adversely affected by simultaneous polyculture than maize. Light penetration measured in simultaneous polyculture treatments but no pure stand data given for comparison.

Table 2, continued
B.
Associations without legumes

Source	Grimes, 1962
Crops	Maize; Cotton
Varieties	Not stated
Country	Kenya
Soils	Pale grey silty sand of low fertility. One site had three year fallow. Other site had six year bush fallow.
Climatic data	No information
Number years	1
Number sites	2
Fertilization	300lbs/A ammonium sulfate
Experimental conditions	Maize and cotton in pure stands and intercropped. Substitutive method.
Findings	Maize yields increased but cotton yields reduced by intercropping,but total cash return greater than with pure stands.

Table 2, continued

Source	Andrews, 1974
Crops	Sorghum; Millet(*Pennisetum typhoides*)
Varieties	Millet- Ex Bornu Sorghum- four Nigerian lines tall- FFBL 3-1-6 semi-dwarf- 5912 453 dwarf- 2123
Soils	No information
Climatic data	None
Number years	1
Number sites	1
Fertilization	P_2O_5- 50 kg/ha at planting. N- 80 kg/ha in two applications.
Experimental conditions	Four varieties of sorghum in pure stand, skip rows, and intercropped with millet
Findings	Greater total yield by planting alternating rows of sorghum and millet but yield not much reduced by skip rows. Millet did better with shorter varieties of sorghum. Larger sorghum years if intercropped millet harvested early, as is local practice.

It can be seen that all investigators cited showed that simultaneous polyculture led to increased yields and/or financial return in almost all of the experimental combinations tested. Methods for summarizing such results in more concise form were provided by Donald (1963) who was evaluating the use of mixtures in forage species. In his first method, he considered the results in terms of the higher and lower yielding species in pure stands. Donald found that in 84% of the cases, the mixture yielded less than the higher yielding component in pure stand; in 93% of the cases, the mixture yielded more than the lower yielding component in pure stand; and in 71% of the cases, the yield of the mixture was greater than the mean yield of the two pure stands. A similar comparison for the experiments summarized in Table 2 is presented in Table 3. The results are quite similar to the results of Donald for forage species (Donald, 1963). Mixtures yielded more than the mean yield of the pure stands in 92% of the experimental situations. However, with the field crops, the mixture yielded more than the higher yielding species in pure stand in the majority of experimental situations; while the mixture had yielded less in the majority of the experiments with forage species summarized by Donald (1963).

Table 3. Relationship of grain or seed cotton per unit area from a mixture of two species to that of constituent species in pure stand (Numbers refer to number of mixtures tested)

Source		a	a	a	b	c	c	c	c	c	c	d	e	e	f	f	f	g	h	i	j	j	To-tal	Per-cent	Percent obtained by Donald (1963) 1
Higher yielding species		G	H	G	M	M	M	G	M	S	M	M	I	S	M	M	M	M	S	M	M	M			
Lower yielding species		F	F	F	E	G	G	S	G	G	G	J	S	C	C	D	A	B	B	C	B	H			
Relationship of yield of mixture to yield of higher yielding pure stand	above	3	2	2	0	5	5	3	8	9	1	2	3	0	2	2	3	5	2	1	5	4	67	56	16
	below	0	1	0	2	4	4	6	1	0	3	0	0	3	2	2	1	3	6	3	7	5	53	44	84
Relationship of yield of mixture to yield of lower yielding pure stand	above	3	3	2	2	9	8	9	9	9	1	2	3	3	4	4	4	8	8	4	12	6	113	94	93
	below	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3	7	6	7
Relationship of yield of mixture to mean yield of two pure stands	above	3	3	2	2	9	6	7	9	9	4	2	3	3	4	4	4	8	8	3	10	6	109	92	71
	below	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	1	2	3	11	8	29

Key to sources

a. Evans and Sreedharan, 1962
b. Grimes, 1962
c. Evans, 1960
d. Dalal, 1974
e. Andrews, 1972
f. Agboola and Fayemi, 1971
g. Willey and Osiru, 1972
h. Osiru and Willey, 1972
i. Haizel, 1974
j. Pinchinat and Oelsligle, 1974

Key to crops

A. Greengram
B. Beans
C. Cowpeas
D. Calopogon
E. Cotton
F. Castorbeans
G. Groundnuts
H. Soybeans
I. Millet
J. Pigeon Peas
M. Maize
S. Sorghum

1. For forage species

In the second method of Donald, experimental results were classified as to whether the yield of one or both species in the mixture was increased or depressed as compared with the yield in pure stand. Such a calculation for the experiments summarized in Table 2 is presented in Table 4. It can be seen that in the case of the field crops, either one or both species was depressed in the mixture; no case of both species yielding more in the mixture was recorded although Donald (1963) noted this phenomenon in 22% of the experimental situations which he reviewed with forage species.

Table 3 and 4 indicate that for the experiments with field crops for which such calculations were possible, the yields of the mixtures almost always higher than the means of the yields in pure stand although the yield of one or both species was always in the mixture than in the pure stand. It should follow that the yield reductions experienced by each species in a mixture was less than 50% of that in the pure stand so that the combined yield was higher than the mean of the yield of the two pure stands. This phenomenon was further clarified by Andrews (1972) who included treatments in which the area which would have been occupied by the second crop in the mixture was left unplanted. In this manner, he was able to separate the effects due to a decrease

Table 4. Comparison of yields of species in mixtures to their yields in pure stands for experimental situations listed in Table 2 for which such a comparison is possible from the data given
(Numbers refer to number of mixtures tested)

Source	a	a	a	b	c	c	c	c	c	c	d	e	e	f	f	f	g	h	i	j	j	Total	Result of Donald (1963) for forage species
Higher yielding species	G	H	G	M	M	M	G	M	S	M	M	I	S	M	M	M	M	S	M	M	M		
Lower yielding species	F	F	F	F	G	G	S	G	G	G	J	S	C	C	D	A	B	B	C	B	H		
One species yielded more in pure stand; one species yielded less	2	2	2	0	0	0	1	0	7	2	0	0	0	2	2	3	4	2	2	0	4	35	51
Both species yielded more in mixture than in pure stand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
Both species yielded less in mixture than in pure stand	1	1	0	2	9	9	8	9	2	2	2	3	3	2	2	1	4	6	2	12	5	85	3

Key to sources

a. Evans and Sreedharan, 1962
b. Grimes, 1962
c. Evans, 1960
d. Dalal, 1974
e. Andrews, 1972
f. Agboola and Fayemi, 1971
g. Willey and Osiru, 1972
h. Osiru and Willey, 1972
i. Haizel, 1974
j. Pinchinat and Oelsligle, 1974

Key to crops

A. Greengram
B. Beans
C. Cowpeas
D. Calopogon
E. Cotton
F. Castorbeans
G. Groundnuts
H. Soybeans
I. Millet
J. Pigeon Peas
M. Maize
S. Sorghum

in plant population and those due to competition between the two species. Thus, while an acre of sorghum and millet yielded 2581 and 2730 pounds respectively in pure stand, the yields were 2481 lbs/A for millet and 2472 lbs/A for sorghum when alternate rows were skipped. When alternating rows of millet and sorghum were planted, the millet yielded 2123 lbs/A and the sorghum, 1929 lbs/A. Andrews concluded that of the 25.3% reduction in sorghum yield occasioned by intercropping, 4.2% was due to reducing population and 21.1% due to competition between the sorghum and the millet. Similarly, of the 22.2% reduction in millet yield occasioned by intercropping, 9.1% was due to reducing the population of the millet and 13.1% was due to competition between the millet and the sorghum (Andrews, 1972). This phenomenon was also described by Donald (1963) for oats underseeded with red clover.

Jensen and Federer (1964) found that enhancing effects on the yield of tall wheat varieties due to their being grown in alternate rows with dwarf varieties was twice the depressing effects on the yield of dwarf varieties due to their being grown in alternate rows with tall varieties. They concluded that alternate rows of tall and short statured wheats might produce more total yield per unit area than either alone or than the mean of the two grown separately.

In general, the experience with varietal mixtures of a single species has not indicated yield increases as great as those which have been reported with mixtures of species. Jensen and Federer (1965) found that when single rows of four wheat lines were flanked by two rows of different lines, overall yield of the plot was increased by 3%, 7.2% and 17.4%, for three of the lines as compared to the yield of a pure stand of the line but decreased by 17.5% for a fourth line. This result indicated the importance of proper choice of varieties if varietal mixtures are to produce increased yields. Only Agboola and Fayemi (1971), Andrews (1974), and Pinchinat and Oelsligle (1974) have investigated the differences between different varieties of a species when grown in association with another species.

Increased yields of mixtures of two and especially three lines of soybeans as compared to means of the yields and even as compared to the most productive of the lines in the mixture have frequently been reported (Brim and Schutz, 1968). Lin and Torrie (1971) observed greater benefits from mixtures when closer spacings and alternating single rather than double rows were used. Increases of more than 15% over the mean of the yields of the component soybean genotypes and of more than 5% over the yield of the highest yielding component were

never observed by these authors (Brim and Schutz, 1968; Lin and Torrie, 1971). Statistically significant increases were seldom observed although both of these authors considered these results to be an adequate refutation of the contention of Sakai (1955) that increments to the yield of one plant in competition would be offset by a decrement to the yield of another. It should be noted that it is more critical for a varietal mixture to give a higher yield than the highest yielding component of the mixture since the components are generally of equal value, unlike the case in a mixture of two species. Greater stability in yield from year to year was observed for varietal mixtures than for pure lines of soybeans (Brim and Schutz, 1968; Lin and Torrie, 1971). To summarize the yield increases obtained with varietal mixtures, although smaller than those reported for simultaneous polyculture have been sufficient to make workers in the field conclude that varietal mixtures offer considerable prospect for increasing yields.

Experimental work with temperate zone crops has been almost exclusively limited to mixtures of small grains (oats, barley, wheat) sometimes with peas. Summarizing the results presented by Bussell (1937) in New York, Jensen (1952) found that the field blend of oats and barley produced 103% of the average of single crop yields when the results of forty-seven

experiments were combined. Zavitz (1927) in Ontario, Canada, found that mixtures consisting of oats and barley; oats, barley, and peas; oats and wheat; oats and peas; oats; barley, wheat, and peas; oats and wheat; oats, peas, and wheat; barley and peas; barley, peas, and wheat; and barley and wheat all produced more than the mean of single crop yields. Only in the case of peas and wheat was the mixture disadvantageous. Jensen (1952) ran eleven trials with oat and barley mixtures in New York in 1948-1950 and obtained higher yields with mixtures in eight of the trials. Working in Lithuania, Douydaitis, Baliuevicute, and Kemestye (1973) reported that barley-pea and pea-oat mixtures gave higher yields than the means of the yields of the crops grown alone when the results of three years' experiments were averaged. In general, small increases in yield have been obtained in the temperate zone through the use of simultaneous polyculture of cereals and peas. The magnitude of the increases is not sufficient, however, to offset the inconvenience that widespread adoption of the practice would entail.

In 1963, C. M. Donald stated, "In terms simply of yield there seems to be no benefit from mixing forage species. But whether this is true when pasture is grown beneath coconut palms or when other dissimilar species are associated is not

known." (Donald, 1963). In the previous discussion, the same criteria used by Donald in arriving at this conclusion have been applied to the experimental results obtained witn field crops in the tropics. By these criteria, there would seem to be considerable evidence that mixing field crop species increases yield although it should be remembered that yield in field crops takes into consideration only a certain part of the total dry matter production while yield in forage crops takes into consideration all of the above ground dry matter.

2.5. Explanations for yield increases and other advantages accruing from simultaneous polyculture

The previous section has shown that in most investigations of simultaneous polyculture of annual crops in the tropics, an increase in the total yields as compared with the yields of pure stands is obtained. No explanation for this increase has been given. In the present section, various explanations for these yield increases and for other advantages accruing from simultaneous polyculture will be considered.

a.) Reduced incidence of diseases and pests

It has frequently been suggested that species grown under simultaneous polyculture are less subject to epidemics of plant diseases and pests (Evans, 1960; Ruthenberg, 1971; Apple, 1972). Presumably, pest and disease organisms will spread less rapidly when the distance between susceptible

plants is greater. Also, all of the plants in the field will not be susceptible to the same pests and diseases (van der Bergh, 1968). A situation similar to horizontal resistance (van der Plank, 1968) in a single species is thus created. It has been shown that if fewer than half of the plants in a population are resistant, the population may have complete protection against significant damage from disease (Suneson, 1960; Jensen and Kent, 1963). The slowdown of disease spread in a heterogeneous population is one of the major justifications for the use of multiline varieties (Jensen, 1952; Borlaug, 1958; Suneson, 1969; Browning, Frey, and Grindeland, 1964; Grafius, 1966).

No investigator of simultaneous polyculture has cited this factor as a cause of the increased yields observed in simultaneous polyculture. In an article which concludes that mixtures in forage species rarely leads to increased yields over pure stands of properly chosen genotypes, van den Bergh (1968) does mention that differences in susceptibility of plants in a mixed culture should lead to reduced rate of disease spread. However, he also states that mixtures might lead to increased disease problems, noting that vernal grass carries a virus not harmful to itself but very injurious to ryegrass. Willey and Osiru (1972) note that an attack of

gall midges on the bean pods of their experiment seemed to be "rather worse in the mixed plots, perhaps because the mixtures provided a more humid and shady environment. Only a few plants were attacked, however, so it was considered that the overall effect on yield was negligible." (Willey and Osiru, 1972). It must be stated, therefore, that despite the reasonableness of the suggestion, there seems to be as much negative evidence as positive that simultaneous polyculture confers reduced disease susceptibility. What is needed is an experiment specifically designed to measure the phenomenon, not casual observations in experiments designed for other purposes.

There is clearly an insurance value in planting two or more different crop species instead of one so that a severe attack of pests, or diseases will not bring total disaster to the farmer. But, the "insurance factor" could as easily be provided for by planting adjacent pure stands (Grimes, 1962). However, adjacent pure stands would not permit the plants not affected by the disease attack to realize increased growth by exploiting that part of the environment not exploited by the plant injured by disease(Andrews, 1972). Thus the yield per plant of the healthy plants will be greater than they would have been had the disease not reduced the growth of the diseased plants (de Wit, 1960; Reestman, 1946; Klages, 1936). Such a benefit could not be obtained by two adjacent pure stands since the healthy plants could not exploit

the environment not exploited by the diseased plants. The amount of benefit to the healthy plants will of course depend on the time at which the disease attack occurs (de Wit, 1960). Thus, in the year (1935) of a stem rust attack in South Dakota, durum wheat accounted for more than 80% of the weight of the grain harvested when a 50-50 mixture of durum and varieties of hard red spring wheat very susceptible to stem rust was planted. Competitive ability early in the growing season also has a an effect since with another hard red spring variety, no such effect was seen and barley accounted for more than 70% by weight of the harvested crop when a 50-50 mixture of barley and oats was sown in the same year although the barley was more affected by the rust than the oats (Klages, 1936; de Wit, 1960).

b.) Adaptation to microvariability of area planted.

This is one of the traditional arguments advanced in favor of sowing a mixture of species in pastures (de Wit, 1960; van den Bergh, 1968) and it really depends on the fact that particular species exploit a particular environment more effectively than another species. The traditional farmer who plants rice in a low spot and cucurbits where ash has accumulated is actually practicing monoculture on a minute scale but the effect for the whole field is simultaneous polyculture.

He is also clearly being as sophisticated as a New York State farmer who sows a mixture of birdsfoot trefoil and alfalfa in a field whose pH varies so that the birdsfoot will grow in areas of low pH and the alfalfa in area of high pH. Simultaneous polyculture is simply a way of ensuring that the right crop gets in the right place with a minimum of labor. This aspect of simultaneous polyculture was only mentioned by one investigator (Anthony and Willimott, 1957) and not tested experimentally in any of the papers reviewed. De Wit (1960) indicates that adaptation to variability in soil pH is the major factor justifying the use of barley-oat mixtures in Denmark:

c.) Adaptation to the light and shade requirements of the individual crops

As was pointed out earlier, this hypothesis as stated by Ruthenberg (1971) indicates that certain crops have a shade requirement that is satisfeid by simultaneous polyculture. While certain plants are tolerant of shade and will continue to photosynthesize at lower light intensities than other crops, they are by no means shade requiring, provided moisture and nutrients are adequate. There remains the possibility, however, of a multistoried canopy as exists

in a tropical rainforest where tall plants fail to intercept all of the incident light and understory species thrive on the light that penetrates through the upper stories. Willey and Osiru (1972) mention increased utilization of light as a possible explanation of higher yields obtained by a maize-bean mixture than by pure stands of either crop; no data are presented to support the theory. Andrews (1974) notes that millet yielded less when interplanted with tall sorghum varieties than with dwarf varieties which presumably competed less for light. The dwarf varieties of sorghum yield more than the tall variety making the tall millet - dwarf sorghum mixture especially productive.

Competition for light is surely involved in the increased overall yields of wheat observed when tall and short statured genotypes are planted in alternate rows (Jensen and Federer, 1964, 1965). Surrounding each tall rice plant with four dwarf plants produced yeilds greater than a pure stand of either dwarfs or tall plant types although surrounding each dwarf plant with tall plants led to the lowest yeilds observed (Jennings and Aquino, 1968).

One investigator to address himself directly to the problem is Enyi (1973a) who grew maize and sorghum in pure stands and intercropped with beans (Phaseolus vulgaris), cow-

peas (Vigna unguiculata) and pigeon peas (Cajanus cajan) and measured leaf area index (LAI) of the maize and sorghum in all of the treatments. Since sorghum yield was less adversely affected by intercropping with legumes than was the maize yield, and since he found leaf area index to be more highly correlated with yield in maize than in sorghum, Enyi concludes that reduction in leaf area index leads to reduced maize yield when it is intercropped with legumes. In the case of sorghum, he hypothesizes that reduction in grain yield is probably due to lower leaf efficiency when the leaves are shaded by legumes (Enyi, 1973a). A consideration of Enyi's data, which are presented below will show that his conslusions are probably unjustified:

	SORGHUM			MAIZE		
Crop Combination	Grain Yield kg/ha	LAI (Sorghum)	Legume seed yield kg/ha	Cereal grain yield kg/ha	LAI (Maize)	Legume seed yield kg/ha
Cereal alone	3800	4.2		6510	5.3	
+ Beans	3480	2.0	340	4260	3.3	120
+ Pigeon Peas	2810	3.0	3490	6550	4.4	1860
+ Cowpeas	2930	2.0	610	3390	2.7	120

Monteith(1969) states that with leaf area indices of 4.7 and 6.9 respectively, maize and sorghum intercept 95% of the incident solar radiation (5% transmittance). Thus, in the case of the pure stands, there should have been little light available beneath the maize but a considerable amount beneath the sorghum. The higher yield and less interference with the cereal (larger LAI) presented by the pigeon peas is attributed to their later development since they realized most of their growth after the cereals were harvested (Enyi, 1973a).

The beans and cowpeas probably are climbers and should have interfered considerably with the cereals although the yields of both cowpeas and beans reported by Enyi are quite low. Haizel (1974), however, reports greatly increased yields of cowpeas over pure stands when interplanted with maize which he attributes to better exposure of the cowpea leaves to light when they have the maize plants available for support. Enyi gives no data of legume yields in pure stand.

The data of Enyi do indicate that many tropical crops may be leaving considerable light unutilized which could be used by an associated crop. Several authors (Harper, 1961; Donald, 1963) have emphasized that a slight advantage with

respect to light interception by one species in an association can rapidly lead to dominance by that species in the association. Shading can reduce this difference however. It has been pointed out that while grasses tend to shade out legumes in pastures, the legumes are less affected than the grasses by reduced light intensities; and at low light intensities the growth curves of legumes and grasses are similar (Ludlow, Wilson, and Heslehurst, 1974). This phenomenon has been used to explain better legume establishment in a grass-legume pasture established under maize in Malawi than in a pasture sown without a nurse crop (Thomas and Bennett, 1975).

Pinchinat and Oelsligle(1974) measured reduction in light penetration in soybeans and maize intercropped in 60 cm and 30 cm rows. Light penetration along the maize and soybean rows was only slightly (less than 5%) lower along the maize rows than along the soybean rows at the wider spacing; and little difference was observed at the narrower spacing. No light penetration data for the pure stands were given. Despite the similarity in light penetration, the maize but not the soybeans yielded more in the narrower rows than in the wider rows. The same results were obtained in two different cropping seasons.

It may be concluded that competition for light and adaptation to differing light availability is probably a significant factor in simultaneous plolyculture. However, without any studies where light transmission through a crop association was actually measured and compared to that in pure stands, any statement of the importance of light utilization in simultaneous polyculture would be speculative.

d.) Provision of a continuous and varied supply of fresh food

This factor is clearly unrelated to yield and is also not very obviously subject to experimental verification. But it may be asked whether simultaneous polyculture is necessary to supply these ends since they could be obtained by staggered plantings of pure stands; but they might be obtained more easily through simultaneous polyculture. Indeed, the farmer may be forced into a form of simultaneous polyculture just becasue of the small quantity of each species required at each time. Weeding and soil erosion may also be reduced by simultaneous polyculture when small, frequent plantings of different species are required; but this will be discussed in later sections.

e.) Provision of better soil cover with simultaneous polyculture

Provision of good soil cover should reduce (1) weed

competition; (2) soil losses due to erosion (Andrews, 1972; Ruthenberg, 1971; Miracle, 1967; Anthony and Willimott, 1957); (3) loss of soil organic matter by exposure of bare soil to direct sunlight and hence higher temperatures and (4) loss of nutrients by leaching since growing plants will take up nutrients that may be carried down to lower depths by large amounts of water percolating through an uncropped soil.

It can be seen that provision of soil cover will be most important in areas where temperature and precipitation are high and where soils have little capacity to retain added nutrients, principally due to low cation exchange capacity. Such conditions are met throughtout much of the humid tropics where simultaneous polyculture is widely practiced but where little research on the practice has been carried out. As can be seen from Table 2, all of the investigations reviewed were carried out in the wet-dry tropics where annual precipitation is less than 1500 mm per year although rainfall during the cropping period may be intense. Hence, erosion control is mentioned by Anthony and Willimott (1957) and Andrews (1972) although they were working in areas where total annual precipitation is less than 1500mm. Another indication that ground cover is important is indicated by

the fact that all associations studied involve either a fast-growing cereal and a slower-growing legume (Dalal, 1974; Haizel, 1974; Enyi, 1973; Osiru and Willey, 1972; Willey and Osiru, 1972; Agboola and Fayemi, 1971; Evans, 1960); a fast and a slow-growing cereal (Andrews 1974, 1972) or an erect slow-growing plant and a prostrate legume (Evans and Sreedharan, 1962; Anthony and Willimott, 1957).

The only investigator to measure soil changes under simultaneous polyculture was Dalal, 1974. Although he measured soil and plant levels of Ca, Mg, K, N, and P sixteen weeks after planting, he gave no data concerning the level of these elements in the soil at time of planting nor their level in the weeds growing on the plots left fallow, making it difficult to draw any conslusions about leaching or erosion losses. Some of Dalal's data were used to produce Table 5 where the levels of Ca, Mg, K, and P in plants and soil sixteen weeks after planting are given. It can be seen that the plot with maize alone showed considerably less total Ca than the other plots. No such difference could be seen for Mg. In the case of K, the soil of the fallow plot had the highest level of this element; but if the K content of the plants was added to that of the soil, the plots containing maize either in pure stands or

Table 5

Nutrients in plant and soil 16 weeds after planting pigeon peas and maize in Trinidad (after Dalal, 1974)

Cropping system	Calcium kg/ha			Magnesium kg/ha			Potassium kg/ha			Phosphorus kg/ha		
	Soil[1]	Crop	Total[3]	Soil[1]	Crop	Total[3]	Soil[1]	Crop	Total[3]	Soil[1]	Crop	Total[3]
Maize alone	1042[2]c	10a[2]	1052	294e[2]	12f[2]	306	42m[2]	51i	93	10o	13p	23
Pigeon peas alone	1167d	6b	1173	311e	3g	314	48mn	10j	58	10o	1q	11
Mixed cropping	1146cd	10a	1156	294e	9h	303	38m	37k	75	9o	9r	18
Intercropping	1104cd	9a	1114	305e	9h	314	38m	471	85	10o	11p	21
Fallow	1188d		1188	299e		299	57n		57	11o		11

1. Calculated on basis of 2,000,000 kg of soil per ha-20 cm

2. Numbers followed by same letter do not differ significantly at p = 0.05

3. This column is the sum of two preceding columns and cannot be analyzed statistically

associated with pigeon peas had considerably higher levels of K than the plots left fallow or planted with a pure stand of pigeon peas. A similar effect was shown for P indicating that for these two elements, plant uptake was the major factor determining nutrient loss and neither leaching nor erosion could have been particularly important.

It should be noted that the pigeon peas had only developed slightly (the pigeon peas were harvested 24 weeks after planting) at the time the plant and soil samples were taken and that rainfall never exceeded 100 mm per month[1] during the experiment so that leacing losses would have been quite unlikely although the soil was of light texture (12% clay). No fertilizers were applied in this experiment (Dalal, 1974).

It must be concluded that the hypothesis of increased soil cover leading to reduced erosion and leaching losses with simultaneous polyculture does not appear to have been tested in the humid tropics, where it is most likely to be significant nor in a manner which is likely to indicate whether the hypothesis has any validity. In the experimental work to be presented in this thesis, the author hopes to make a contribution in this area. It should also be noted that reduced losses due to leaching and erosion would not necessarily

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1. In two months, irrigations of 50 mm per month were applied. (Dalal, 1974)

lead to increased crop yields except over several seasons.

Although suppression of weeds is a commonly cited reason for sowing pasture species with a cereal crop as a nurse crop (Donald, 1963), only one investigator of simultaneous polyculture has noted reduced weed growth with intercropping (Andrews, 1972). Evans (1960) has compared weed growth in pure stands with the growth of associated crops under simultaneous polyculture. He notes that maize reduced groundnut yields as much as weeds do, but groundnuts reduce maize yield less than weeds do (Evans, 1960). In the experimental work to be reported in this thesis, weed dry matter production has been determined in all treatments.

f.) Reduced labor requirement for land preparation

It will of course follow that if a higher combined yield can be obtained from simultaneous polyculture than from two pure stands, the same yield as the two pure stands can be obtained from a smaller area if simultaneous polyculture is practiced, with a saving in the labor of land preparation (Evans, 1960). Evans (1960) has calculated that up to 1.5 acres of pure stands would be necessary to obtain the yields which he obtained with a one acre mixture of maize or sorghum and groundnuts. In areas where land rather than labor is scarce, as in Taiwan, simultaneous polyculture has persisted

at a relatively advanced level of technology (Iso, 1954; Ruthenberg, 1971). In many cases, a second crop is seeded into a developing crop (defined by Ruthenberg as relay cropping) so that the time of simultaneous polyculture is not the whole growth period of both crops (Evans and Sreedharan, 1962; Anthony and Willimott, 1957). Often, the farmer's principal consideration is to plant a cash crop (Grimes, 1962) or a subsistence crop (Anthony and Willimott, 1957); and simultaneous polyculture is a means for the cash crop farmer to produce a subsistence crop or for the subsistence farmer to produce a cash crop with minimal effort. In interplanting[1] or interculture[1], similar benefits may accrue in an area prepared for a long season or perennial crop especially where land preparation for the second crop is made difficult or impossible by heavy rains (Miracle, 1967; Andrews, 1972; 1974).

Simultaneous polyculture permits the growing of cotton in the southwest Sudan since there is too much rain for good lint production when the cotton is planted at the beginning of the rainy season. It would be difficult to prepare land for cotton at the height of the rainy season; and preparing the land before the rainy season would leave it exposed to high rainfall. There is not enogh time for a legume crop to mature before it is too late to plant cotton. Only by planting cotton

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1. See definition, p. 5

in the developing legume crop can two crops be realized. (Anthony and Willimott, 1957).

g.) Non-yield related agronomic benefits

Reduced lodging in barley when it was mixed with oats was reported by de Wit (1960). Neither millet nor maize lodged when intercropped although they frequently did in pure stand in Nigeria (Andrews, 1972). Interplanting maize with cotton reduced wind damage to cotton in Kenya (Grimes, 1960). A grain-legume mixture undersown in maize led to better legume establishment than a directly sown pasture in Malawi. It was explained that the shade offered by the maize made conditions equally unfavorable for the grass as for the legume resulting in better establishment of the latter. (Thomas and Bennett, 1975)

h.) Economy of labor resulting from having more species on a smaller area

If simultaneous polyculture reduces weed growth, the labor inolved in weeding should be reduced. If the same yield can be realized from a smaller area (Evans, 1960), there will be less area to weed resulting in an economy of labor. Andrews (1972) reports that it was hardly necessary to week cowpeas following millet intercropped with sorghum.

i.) Associations of crops may have more resistance to drought than pure stands

This argument has been advanced only by Andrews (1972) with reference to millet-sorghum associations while other authors have generally noted that competition for water may be more intense under simultaneous polyculture (Kurtz, Melstead, and Bray, 1952; Milthorpe, 1961; Donald, 1963). Milthorpe (1961) states that a canopy composed of a short and a tall species will lose more water than one composed of just a tall species. But he further states that "the greater the amount of leaf growth made before plants come into contact with each other, then the more extensive is their root system and the less likely is the plant to suffer from drought" (Milthorpe, 1961). From this it follows that plants grown at lower densities will develop larger root systems and suffer less from drought (Donald, 1963). It is this fact which is the basis of Andrews' argument since populations of each species used in an association are generally lower than in pure stands of that species. Hence, each plant can develop a larger root system, which in the case of sorghum will be deeper than that of the associated millet or cowpeas which are shallow rooting plants, (Andrews, 1972). Milthorpe (1961) states that competition generally does not affect rooting depth as much as the

roots' lateral extension. Hence, the sorghum will be better able to sustain drought when grown in association with a shallow rooting crop than when grown in a pure stand (Andrews, 1972).

J.) A larger share of the environment may be exploited by two crops than by one.

It is this argument that is most frequently cited by investigators to explain increased yeilds obtained with simultaneous polyculture (Anthony and Willimott, 1957; de Wit, 1960; Donald, 1963; Agboola and Fayemi, 1971; Willey and Osiru, 1972; Osiru and Willey, 1972; Enyi, 1973a; Dalal, 1974; Haizel, 1974) states that if the total environment for which two species are competing remains constant, it can be demonstrated that the highest yield will be obtained by a pure stand; therefore, benefits from simultaneous polyculture can occur only if a greater amount of environmental inputs are available to the mixture than to a pure stand. The expansion of environmental inputs available to mixtures is most obvious when the growth periods of the two species do not coincide (Anthony and Willimott, 1957; Evans and Sreedharan, 1962; Enyi, 1973a; Dalal, 1974; Haizel, 1974) has already been discussed. Enyi (1973a) reports that pigeon peas are a superior intercrop for maize or sorghum than cowpeas or

Phaseolus spp. beans since pigeon peas flower much later than the other legumes so that at the time the maize or sorghum flower, the pigeon peas have produced only 10% of their total dry matter production while the beans and cowpeas are alrady flowering. Since the greater part of nutrients are taken up by legumes at the time of flowering or later, intense competition occurs between the maize or sorghum and the cowpeas or beans but not with the pigeon peas, which do not require a great amount of nutrients until after the maize and sorghum have completed growth (Enyi, 1973a). This relationship is further explored by Dalal (1974) who measured dry matter and nutrient content of mixtures of pigeon peas and maize at the times of maize and pigeon pea harvest. His results are shown in Table 6. From Table 6, it should be clear that the pigeon peas showed little growth and took up very small amounts of K, Ca, Mg, N, and P up to the time of maize harvest although maize produced somewhat less and took up a smaller amount of nutrients when associated with pigeon peas. Although there are considerable differences between pigeon peas grown in pure stand and associated with maize, it will be seen that these differences are non-significant at the time of pigeon pea harvest. Thus, in the time dur-

Table 6

Grain yield, dry matter production, and nutrient content of maize and pigeon peas grown in pure stands, mix-cropped, and intercropped at time of maize harves (16 weeks after planting) and of pigeon pea harvest (24 weeks after planting) (Dalal, 1974)

Cropping system	Grain Yield kg/ha		Dry matter production kg/ha			K content kg/ha			Ca content kg/ha		
	Maize	Pigeon Peas	A[1]	B[2]	C[3]	A[1]	B[2]	C[3]	A[1]	B[2]	C[3]
Maize, pure stand	3130a		6408			50.8			10.3		
Pigeon peas, pure stand		1871g		822	5127h		10.1	36.9j		6.2	21.7e
Mix cropping	2025b	1710g	4204	221	3808i	34.5	2.1	32.2j	8.0	1.8	14.9f
Intercropping	2606c	1854g	4718	340	4893h	43.8	3.7	33.0j	6.8	2.5	19.13

Cropping system	Mg content (kg/ha)			N content (kg/ha)			P content (kg/ha)		
	A[1]	B[2]	C[3]	A[1]	B[2]	C[3]	A[1]	B[2]	C[3]
Maize, pure stand	12.3			66.2			13.2		
Pigeon peas, pure stand		2.5	13.5m		17.1	119.4 p		1.0	6.4r
Mixed cropping	8.0	0.9	7.8n	44.6	3.7	99.8 q	8.9	0.3	5.4r
Intercropping	7.4	1.2	12.3m	48.6	5.7	128.6 p	10.9	0.3	6.5r

1. A= Maize at time of maize harvest (16 weeks after planting)
2. B= Pigeon peas at time of maize harvest (16 weeks after planting)
3. C= Pigeon peas at time of pigeon pea harvest (24 weeks after planting)

ing which there is no competition with maize, the pigeon peas which were stunted by their association with maize are able to compensate completely for their reduced growth during the period of simultaneous polyculture.(Dalal, 1974)

Andrews (1972) notes that sorghum interplanted with millet is etiolated at the time of the millet harvest but then recovers. The yield of castorbeans seeded into groundnuts has been shown to decrease as the duration of the simultaneous polyculture increases; but this is also due to increasing difficulty in establishing castorbeans in the legumes, especially soybeans (Evans and Sreedharan, 1962).

Another way in which simultaneous polyculture may exploit the environment more than a pure stand occurs when one of the species in the association is a legume (de Wit, 1961). As can be seen from Table 2, with the exception of the experiments of Andrews (1972,1974) and Grimes (1962) and of the barley-oat mixtures discussed by de Wit (1960), all of the associations investigated by other workers involve a legume. The possibility that the leguminous component of the mixture is supplying nitrogen to the association has been considered by several authors (Agboola and Fayemi, 1971; Enyi, 1973a; Dalal, 1974; Haizel, 1974). Willey and Osiru (1972) and Osiru and Willey (1972) have used very high levels

of nitrogen fertilization on the maize-bean and sorghum-bean associations which they studied so that the effect of nitrogen transfer from the legume to the cereal does not obscure the other aspects of the association.

One of the chief aims of the experiment conducted by Agboola and Fayemi (1971) was to find legumes which could serve as a source of nitrogen to maize. They found that cowpeas, calopogon (Calopogoium mucunoides), or greengram (Phaseolus aureus) mix-cropped or intercropped with maize could be as effective as 50 lb/A of nitrogen as ammonium sulfate or as rotations of legumes with maize in maintaining maize yields. In the absence of fertilizer, maize always produced more when grown in simultaneous polyculture with legumes in pure stands. In the presence of fertilizer, there was a depression of maize yields in simultaneous polyculture as compared to pure stands.

Although Dalal (1974) found no increase in maize yield or whole plant maize nitrogen content when maize was grown with pigeon peas, treatments in which maize was intercropped with pigeon peas showed significantly higher mineral nitrogen levels in the soil sixteen weeks after planting than those in which pure stands of maize or pigeon peas were grown

or in which pigeon peas and maize were mix-cropped. Dalal felt that the closer association of maize and pigeon peas roots which occurred in mixed cropping led to reduced fixation of nitrogen as evidenced by the greater numbers of ineffective nodules on the pigeon pea roots.

Pinchinat and Oelsligle (1974) found that maize yielded higher when soybeans were planted between the maize rows than when the maize was grown in pure stand. When row spacings were increased or when maize and soybeans were planted in the same row, maize yields were lower than in the pure stands although the same plant populations obtained in all cases. Closer association of maize and soybean roots at the narrower spacing may have resulted in greater availability of N to the maize leading to higher yields although more than 150 kg/ha of N was applied to the maize crop in all cases. No such benefits to maize were observed when maize and beans (P. vulgaris) were intercropped on a similar soil using varying levels of N fertilization. Reduction in maize yield due to the presence of beans was least at the highest level of N.

Willey and Osiru (1972) and Osiru and Willey (1972) feel that the increased yields which they obtained in mixtures is due to a more efficient use of environmental re-

sources by the mixtures but they present no evidence as to how this factor might have operated. They suggest that the different heights of the plants involved or that differences in rooting depth led to greater utilization of soil resources but make no investigations of these phenomena.

It can be seen from the previous discussion that although many authors speculate that a larger share of the environment was utilized by associations than by pure stands in order to explain the increase yields they obtained with simultaneous polyculture, very few provide data to support the hypothesis. Although Dalal (1974) and Agboola and Fayemi (1971) supply such data, their data concern only one aspect of the environment, the supply of nutrients; and Willey and Osiru (1972) and Osiru and Willey (1972) show increased yields from intercropping even at a high fertility level where the phenomena described by Dalal (1974) and Agboola and Fayemi (1971) should not have been operating.

It should be noted that control of weeds, increased utilization of light, and a longer period of active growth may also fit into the category of increased utilization of environmental resources with simultaneous polyculture. What is necessary are experiments designed to measure each of these phenomena so that their relationship to increased

production can be shown more clearly.

k.) Reduced intraplant competition with simultaneous polyculture

Intraplant competition refers to how a plant distributes photosynthate and nutrients among its respective parts. Donald (1963) points out that a plant experiencing insufficient competition from its neighbors may produce an excessive number of sinks (tillers, inflorescences etc.) and have insufficient photosynthate and nutrients at a later stage to realize maximum yield from such a number of sinks.because the sinks compete with each other for photosynthate and nutrients (intraplant competition). Hence some degree of competition from its neighbors will be necessary to prevent the formation of an excessive number of sinks.

Donald (1963) suggests that the attainment of maximum yield per unit area depends on varying times of incidence of interplant and intraplant competition. He further suggests that maximum yield occurs when intraplant competition is at its least intensity, a condition which we have seen requires some degree of interplant competition. Clearly, the times of incidence of interplant competition will be different when a plant is surrounded by a species with different periods of active growth than from when it is surrounded by individuals

of its own species. This difference in time of competition has been cited by several authors (Haizel, 1974; Dalal, 1974; Enyi, 1973a) as a reason for increased yields under simultaneous polyculture.

A proper study of the relationship of interplant and intraplant competition would require the measurement of yield components and the varying of densities in pure and mixed stands. The "competition index" of Donald (1963) and the "plant equivalents" of Willey and Osiru (1972) are attempts to measure the competition offered to an individual plant by individuals of the same and different species.

Willey and Osiru (1972) found that maize yield per plant was higher in mixtures than in pure stands at comparable population pressures. Similarly, all yield components (cobs per plant, grains per cob, and weight per cob) increased with yield per plant, which indicated, according to the authors, that the greater competitive ability of maize with respect to beans was not limited to any particular growth period. Beans, on the other hand, had a lower yield per plant when associated with maize than when grown alone at higher seeding densities. But, when the yield components of beans were considered, only the number of seeds per pod and not the number of pods nor the weight per seed was affected by competition

with maize indicating that the competitive effect of the maize only became important later in the development of the beans (when the pods were filling) and only at high population densities.

Clearer evidence of the effect of timing of interplant competition was obtained by Osiru and Willey (1972) in an experiment with sorghum and beans. Again, sorghum yields per plant were greater in mixtures than in pure stands. At lower populations, this increase was associated with an increase in the number of heads per plant while at higher populations, this increase was associated with an increase in the number of grains per head. Weight per grain was higher in mixtures at all populations. It should be clear that the beans offered less competition to the sorghum than other sorghum plants would have at later stages of development, leading to increases in those yield components which are determined at later stages of development. Thus, the timing of interplant competition would seem to have had an effect on the number of sorghum heads per row but did increase the weight per head, 100 grain weight, and number of grains per head of the sorghum as compared with pure stands. De Wit (1960) attributed the greater 1000 grain weight of oats grown in a mixture with barley than of those

grown in pure stands to the fact that the barley matured after all of the yield components of oats with the exception of 1000 grain weight had been determined.

1.) Greater yield stability

Perhaps because very few experiments with simultaneous polyculture have been carried on for more than a single cropping season, no investigator has suggested that a greater stability of yield is obtained through simultaneous polyculture . However, less variability in yield from year to year has been observed with multiliness of oats and soybeans and has been cited as one of the major benefits to be derived from their use (Jensen, 1952, 1965; Lin and Torrie, 1971). Consideration of data presented by Evans (1960) and Agboola and Fayemi (1971) shows that total yield derived from simultaneous polyculture varied less from year to year than did the yields derived from pure stands.

E.) Conclusions

If nothing else, the previous section should offer to investigators some fruitful areas for research in connection with simultaneous polyculture. Each of the ways in which simultaneous polyculture may be operating to produce increased yields has generally been investigated by only one or two authors usually working with diverse crops, making it difficult

to arrive at any conclusions that might apply to situations other than those studied. Nor is it to be expected that the same factors will be operating or be of the same importance in different environments involving different.crops. Even when crop species are comparable, varieties, soil characteristics, and climatic conditions are not always well described. Furthermore, with few exceptions, many of the experiments have only been carried out for a single cropping season.

The multiplicity of factors which may be operating also makes a comprehensive study quite difficult. Measuring light transmittance, weed growth, labor required for weeding, yield components, availability of soil water, plant and soil nutrient levels at different times, and dry matter and grain production in an experiment with pure stands and mixtures of crops grown at different densities and under different management systems would require the efforts of investigators with different specialties and the committment of a considerable amount of resources. Such experimentation would have to be carried on over several cropping seasons, on a range of soil types, using varieties of different growth habit in order to be of relevance to more than the particular situation studied. The fact that simultaneous polyculture seems to lead to increased production under circumstances prevailing in many

areas in the world would appear to justify such an effort.

2.6. Disadvantages of simultaneous polyculture

It should be pointed out that there are some drawbacks to simultaneous polyculture which are reflected in the fact that it is not as widely practiced as its advantages would seem to suggest. The major disadvantages would be as follows:

a.) Difficulty in mechanization (Evans, 1960; Andrews, 1972). The problem is greatest with respect to harvest than with respect to other operations (Donald, 1973). While it is possible to modify a seed drill to plant more than one species (Andrews, 1972) and cultivation and fertilizer operations need not be different than for pure stands, harvest is further complicated by the fact that the two species are not generally ready for harvest at the same time, further complicating field operations. One could conceive of some mixture where mechanical harvest of one component need not affect the other as in an association with groundnuts or root crops although this possibility does not seem to have engaged anyone's attention. Intercropping, of course, provides fewer complications in this regard than does traditional mixed cropping. Andrews (1972) and Willey and Osiru (1972) discuss the possibility of using intercropping in a highly intensified, mechanized agriculture although neither of these

authors states how harvesting would be carried out. Another possibility is to harvest one crop by hand and the other crop mechanically. In interculture, where the separation between perennial species is large, mechanization should present few difficulties except as the size and root system of the perennials increase. In general, however, simultaneous polyculture does present inconveniences and often obstacles to farmers wishing to mechanize their operations, especially harvest. It thus remains a practice for areas where labor is relatively abundant, which includes a great part of the earth's surface and would include an even greater part if economic, social, and institutional barriers to the use of both land and labor were removed.

b. Difficulty in carrying out operations specific for individual crops

The use of selective herbicides is the most obvious example (Okigbo and Greenland, 1975) of the difficulties one would encounter in simultaneous polyculture where the species are generally of different plant families with different physiology and types of nutrient response. The latter problem has been addressed by Dalal (1974) who found extremely different response curves for nitrogen in maize and pigeon peas. He states that the optimum nitrogen level for maize, 200 kg/ha, would adversely affect pigeon peas which showed a maximum response to nitrogen at 20 kg/ha (Dalal, 1974). Similarly,

applying nitrogen to a cereal undersown with a legume may increase cereal dry matter and grain yield bu reduce the proportion of legumes in the resulting pasture (Shelton and Humphries 1975c; Thomas and Bennett, 1975). It may even be supposed that the shifting of the balance in favor of sorghum in the sorghum-beans combination studied by Osiru and Willey (1972) might have been accentuated by the high levels of nitrogen fertilizer used in this study.

c.) Interplant competition might become excessive with simultaneous polyculture.

Under poor managment, simultaneous polyculture may not be particularly beneficial. All of the cases in which the yield of the mixture was less than the mean yield of the two pure stands listed in Table 3 can be attributed to excessive plant populations (Haizel, 1974; Evans, 1960). Where Willey and Osiru (1972) and Osiru and Willey (1972) find the greatest benefits from simultaneous polyculture at higher populations, it might also be surmised that the plant densities in pure stands were excessive. The fact that total yield from simultaneous polyculture is almost always higher than the mean of the pure stand yields (See Table 3) might very well indicate that simultaneous polyculture has greater flexibility in adapting to suboptimal conditions.

Another important factor is the proper choice of associated species. Of nine legumes screened for use in simultaneous polyculture with maize. Agboola and Fayemi (1971) report that only two did not significantly reduce maize yields. Enyi (1973) states that cowpeas and beans (Phaseolus spp.) offer more competition to maize and sorghum than do pigeon peas and that sorghum yield is less affected by intercropping with legumes than is maize yield. Often the choice of a mixture will be determined by which element is more desired: Anthony and Willimott (1957) report that cotton yield was reduced more by groundnuts than by soybeans, cowpeas, or Phaseolus angularis but the groundnuts yielded more than the other legumes.

It should be obvious that if more total yield is realized from simultaneous polyculture than from pure stands, the total requirements for water, light, and nutrients will be correspondingly greater. The data given in Table 6 show this to be true for nutrients. Hence, where the supply of such requirements is reduced, total yield from simultaneous polyculture should be correspondingly reduced. Evans (1960) reports that total yields from mixtures were lower in a dry year than in a wet year in Tanzania but that the relative benefits from simultaneous polyculture as compared to pure stands were

even greater in the dry year. It may of course be possible that it would be more advantageous to plant a pure stand of a more drought tolerant plant when moisture is limiting than a mixture of plants with high and low moisture requirements. However, Evans (1960) reports that this was not the case with groundnut-sorghum mixtures in a wet and a dry year in Tanzania. The sorghum yields less in the mixture than in the pure stand in the dry year; but the groundnuts yield considerably more in the mixture than in pure stand, making the total yield of the mixture higher than the mean of the pure stands (Evans, 1960). Such a result casts some doubt on the suggestion of Agboola and Fayemi (1971) that pure stands of maize be used instead of legume-maize mixtures in dry seasons especially since their own data show that the unfertilized maize yielded significantly more when associated with legumes than in pure stands. Even with fertilization, the reduction in maize yields in the mixtures is more than compensated by the legume yields (Agboola and Fayemi, 1971). The results of Kurtz _et al_. (1952) are often cited to show that simultaneous polyculture increases competition for nitrogen and water. Although maize yields were clearly reduced by the intercrop when nitrogen and water were inadequate, it should be noted that the experiments involved seeding maize into an already established legume or grass sod

(Kurtz et al., 1952) and should not perhaps be generalized to other situations. Since root extension is related to expansion of the above ground parts (Milthorpe, 1961), it should be clear that the maize was probably unable to establish much of a root system under such circumstances and was hence very susceptible to water stress.

d.) The Montgomery effect

The so-called Montgomery effect, that the highest yielding variety in a pure stand does not always compete well in mixtures (Jensen, 1952; de Wit, 1960; van den Bergh, 1968) is analogous to the observations of Harlan and Martini and Suneson with regard to varieties of a single species (Donald, 1963). However, the problem is one that the plant breeder rather than the farmer will have to solve. Varieties will have to be selected under suboptimal conditions, i.e. under simultaneous polyculture, since the farmer for reasons outlined above is unlikely to change his practice. Testing sorghum varieties under intercropping with millet has been described by Andrews (1974).

e.) Simultaneous polyculture will lead to more rapid soil exhaustion

It follows that if simultaneous polyculture produces higher yields than monoculture, nutrient removal in crops will be greater. As there will be proportionately less weeds and crop residues to return to the fields as in commonly the practice under the intensive systems where simultaneous polyculture

is common, soils will become depleted of nutrients more rapidly under simultaneous polyculture. Simiarly, more productive agricultural system will have a larger water requirement, leading to depletion of soil moisture reserves. This argument leads to the conclusion that what is most desirable are weedy fields planted with crops whose harvest index is low since this will keep soil exhaustion at a minimum. Unfortunately, the aim of agriculture is not merely conservation of natural soil fertility. For a given level of productivity, it is possible that simultaneous polyculture is the most efficient means of utilizing available light, water, and nutrients. While a less efficient system may remove smaller amounts of nutrients, such nutrients are subject to losses through leaching and erosion so that the fact that they are not taken up into harvestable parts of crop plants does not necessarily constitute a benefit.

This discussion of the disadvantages of simultaneous polyculture has shown that they should not be of particular importance to the farmer whose resources with the exception of labor are limited although there might be considerable obstacles to the adoption of the practice in capital intensive agriculture where labor is in short supply. Indeed, there does not seem to be much prospect for the area under simultaneous polyculture becoming more widespread in the near future as it is, as we have

seen, primarily a practice for small farmers. Efforts of some authors (Andrews, 1972; Willey and Osiru, 1972; Osiru and Willey, 1972) to make the practice suitable for mechanized and intensive agriculture still leave some problems unsolved. The work of Bradfield (1972, 1974), although generally lacking in experimental data, does offer some prospect for at least a partial mechanization of simultaneous polyculture; but only a limited number of the world's farmers posess the resources necessary to adopt the methods proposed by Bradfield.

f.) Varietal differences within the species

Simultaneous polyculture, by putting emphasis on mixtures of two different species, may obscure the fact that varieties of a single species may differ as much as members of two different species with respect to the parts of the environment which they exploit (Pinchinat and Oelsligle, 1974). This variation within species must be properly exploited if the full benefits of simultaneous polyculture are to be obtained, Although the few experiments which have been carried out involving different varieties of species in simultaneous polyculture (Agboola and Fayemi, 1971; Andrews, 1974; Pinchinat and Oelsligle, 1974) have not shown a beneficial effect with one variety and not with another, such a situation is quite

conceivable as the differences in yield among the sorghum varieties studied by Andrews (1974) were considerable. Pinchinat and Oelsligle (1974) have shown that climbing beans are such more adversely affected by competition with manioc and maize than are bushy types.

2.7. Summary and Conclusions

A review of the published investigations of simultaneous polyculture indicate that the production obtained is almost always greater than the mean of pure stands of the crops in question. When other criteria such as the competition index (CI) of Mac Intyre (Donald, 1963) or the relative yield total (RYT) of van den Bergh (1968) are applied to the data (Osiru and Willey, 1972; Willey and Osiru, 1972; Haizel, 1974), the results also indicate definite benefits deriving from simultaneous polyculture. However, the investigators offer very little information as to why increased yields occur with simultaneous polyculture. The best documented explanations are that (1) environmental resources are drawn upon for a longer period by two species than by one (Enyi, 1973; Dalal, 1974); (2) nitrogen fixed by one of the crops becomes available to the other (Agboola and Fayemi, 1971; Dalal, 1974); and (3) competition by individuals of a different species is less than that of individuals of the

same species at certain critical periods (Willey and Osiru, 1972; Osiru and Willey, 1972; de Wit, 1960). Little evidence is presented to support other hypotheses such as better light utilization, provision of better soil cover, reduced competition from weeds, increased protection from diseases and pests, and increased resistance to drought. The work of Andrews (1972), which showed little decrease in yields when pure stands were planted with skip rows, while illuminating no specfic mechanism, indicates that that many species show great flexibility in exploiting parts of the environment left unutilized by an associated species. As was pointed out earlier, as long as the yield of each species is not reduced by more than 50% by being grown in association with another species, simultaneous polyculture will lead to greater productivity and more efficient land use. Indeed, the yield reduction experienced by one species may be even greater than 50% if the yield decrease of the associated species is correspondingly less. A species in a mixture in which the other species is damaged may utilize the environmental resources left unutilized by the damaged species (Reestman, 1946; Evans, 1960). Such a situation may even occur when both species are healthy but where one is unable to utilize all of the environmental resources (Osiru and Willey,

1972).

One of the obstacles to a greater understanding of simultaneous polyculture is that the factors operating vary from situation to situation. The fact that the present review has shown that an overall consideration of the different experimental studies leads to the conclusion that simultaneous polyculture is almost always beneficial is perhaps more significant than any single in-depth study could be.

Chapter Three

Soils of the Experimental Area and Extent of their Occurrence in the Brazilian Amazon

3.1. Soils of the experimental area.

The soils of the areas where the experiments to be described in Chapter Five were carried out on the Tracuateua Experiment Station[1] have been described in the soil survey of the experiment station (Rodrigues, Morikawa, Sousa dos Reis, Serra Freire, and Lima, 1974) as dystrophic Red and Yellow Quartz Sands with mottles from the surface to 60 cm (Areias Quartzosas Vermelhas e Amarelas distroficas com mosqueados ate 60 cm). This soil has tentatively been classified as a Quartz-ipsammentic Haplorthox, sandy, oxidic, isohyperthermic in the U.S. soil taxonomy (Personal communication, Dr. Richard Arnold, Department of Agronomy; Cornell University; Ithaca, New York 14853).

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1. Presently known as UePAE de Tracuateua (state level research unit) (Unidade de Pesquisa no Ambito Estadual) of EMPRAPA (Empresa Prasileira de Pesquisa Agropecuaria), the Brazilian government agricultural research corporation. The station was originally set up by the Brazilian Ministry of Industry Agriculture, and Commerce in 1922 for tobacco research. It has changed hands and functions many times during the last fifty years, functioning as a research station Of IPEAN, the Ministry of Agriculture research institution for the eastern Amazon, in Belem since 1970. The station presently contains 220 hectares (da Silva, Viegas, da Rocha, and Andrade, 1975).

It is impossible from the soil and climatic data presently available to be sure of the classification as a Haplorthox as opposed to a Haplustox.

The classification as an Oxisol is based on the occurence of more than 15% clay-sized particles in some subhorizon of the B horizon. If no subhorizon were to attain 15% clay content, the soil would be considered an Orthoxic Quartzipsament, oxidic, coated, isohyperthermic. From the soil survey of the Tracuateua Experiment Station, it is apparent that soils with less than 15% clay content in all horizons do occur on the experiment station (Rodrigues et al., 1974). Hence, Oxic Quartzipsamments would be expected to be quite frequently associated with Quartzipsammentic Haplorthoxes since the differentiating criterion is a relatively arbitrary one.

It should also be noted that many soils which would be classified in the U. S. Soil Taxonomy as Quartzipsammentic Haplorthox are classified by the Brazilian ministry of agriculture as dystrophic Red and Yellow Quartz Sands (Areias Quartzosas Vermelhas e Amarelas Distroficas) although the analytic data for such soils indicate a clay content in the B horizon of over 15%. Whether the soil is classified as Quartzipsammentic Haplorthox or Orthoxic Quartzipsamment, one is dealing with soils of very similar characteristics being predominantly sandy or sandy loam texture, deep, moderately well to well drained, of low native fertility and cation

exchange capacity, never having more than 35% clay in the B horizon. Further data concerning the mineralogy of these soils will be given in the last section of this chapter.

3.2. The occurrence of similar soils in the Brazilian Amazon

Although it was known that sandy soils are extensive in the Amazon region it is of interest to quantify their extent and applicability of the research results obtained in this study. Unfortunately, the category into which such soils were classified in the soil survey of the Bragantina[1] region and of other areas of Brazil, the Yellow Latosol (Latosol amarelo) comprises soils of a wide range of texture up to as much as 80% clay in the B horizon (UNESCO, 1971; Sombroek, 1966). Such soils are not quite comparable to the soils occuring on the Tracuateua Experiment Station, although chemical and physical properties of such heavier textured soils are often quite similar to those of the lighter textured soils because of the nature of the clays of the heavier textured soils (Sombroek, 1966). The soils described as Yellow Latosols in

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1. The 15 townships (municipios) forming the homogeneous microregion in which the Tracuateua Experiment Station is located are known collectively as the Zona Bragantina or Bragantina region. For localization of the Tracuateua Experiment Station, Bragantina region, Pará state, in the Brazilian Amazon. The reader is referred to Figure 1 on the following page.

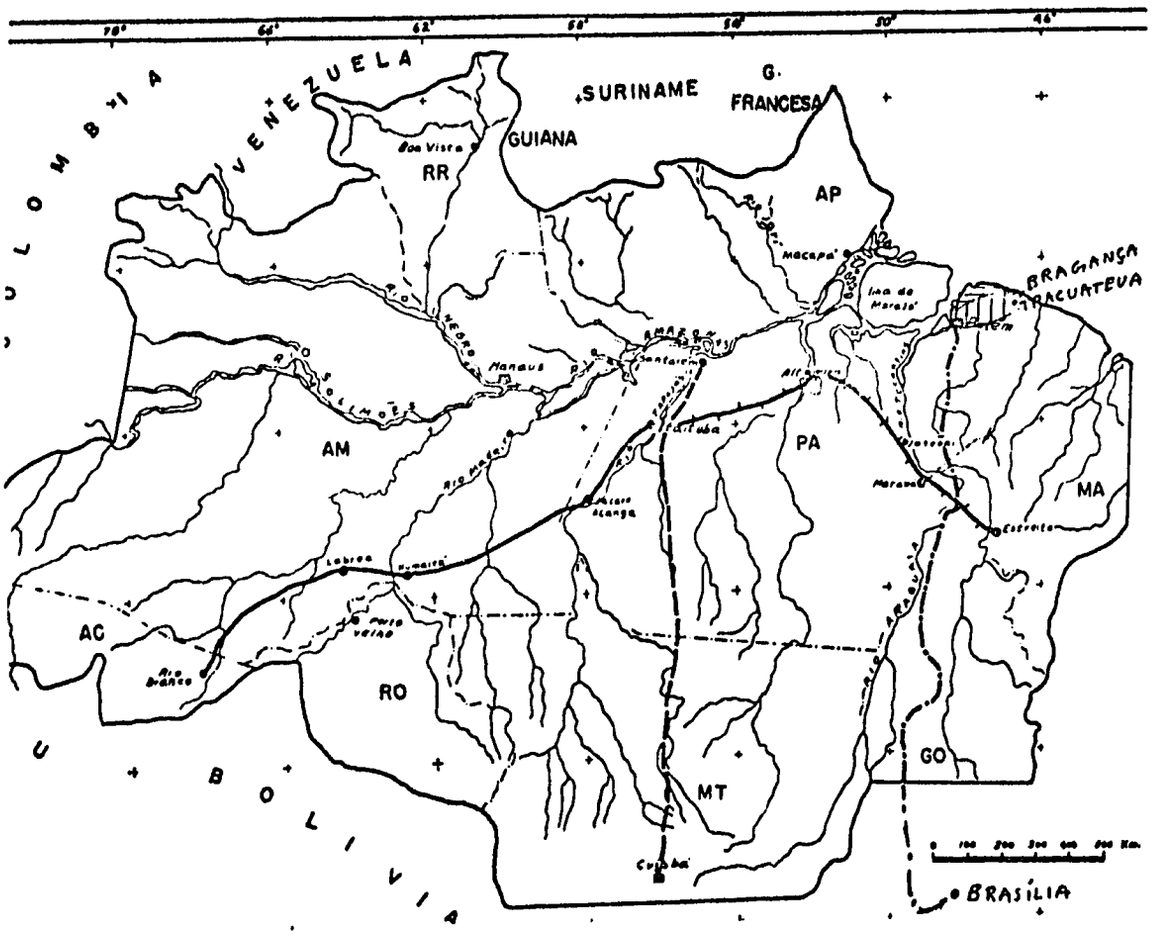

Figure 1. Map of Brazilian Amazon, showing state boundaries, and localization of Bragantina and Salgado regions, Tracuateua Experiment Station, and Transamazon, Belém-Brasilia, and Santarem-Cuiaba highways (from Falesi, 1972b).

|||| Bragantina region

≡ Salgado region

— Transamazon highway
+-+ [section mapped (Felesi, 1972b)]
-·- Belém-Brasilia highway

-- Santarem-Cuiaba highway

PA- Para state
RR- Roraima territory
AP- Amapa territory
AM- Amazonas state
AC- Acre state
RO- Rondonia territory
GO- Goias state
MT- Mato Grosso state
MA- Maranhao state

the soil survey of the Bragantina region never show any horizons with more than 30% clay (Vieira, dos Santos, Falesi, and Oliveira Filho, 1967); so it can be assumed that these soils are quite similar to those on the Tracuateua Experiment Station. Of the 16,428 km^2 surveyed in the Bragantina region, it has been estimated that Yellow Latosols occurred on 12,906 km^2 or 78.56% of the mapped area. All of the Yellow Latosols described in this survey have at least 80% sand in the surface horizon and more than 60% sand in all horizons. As was pointed out before, this survey includes the soils with less than 15% clay in the B horizon in the Yellow Latosols. (Vieira et al., 1967).

It can be concluded that the soils on the Tracuateua Experiment Station are representative of the greater part of the Bragantina region. Excluding the city of Belém, the area covered by the soil survey is occupied by about 400,000 persons which is 18% of the population of the state of Pará or about 11% of the population of the entire Brazilian Amazon region (IBGE, 1974). Since approximately 12% of the area covered by the soil survey of the Bragantina region was occupied by urban area, hydromorphic soils, and humic gley soils, little used for agricultural production, it can be seen that probably 90% of the agricultural production of the Bragantina and Salgado[1]

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1. The Salgado region, the coastal region lying to the north of the Bragantina region was included by Vieira, dos Santos,

regions comes from these light-textured Yellow Latosols. As can be seen from Table 7, this production is not inconsiderable, accounting for 15% of rice, 29% of bean and cowpea, 20% of maize, 36% of manioc (cassava), 29% of tobacco, and 44% of black pepper production of the state of Pará. Thus, it can be seen that these light-textured Yellow Latosols or Quartz-ipsammentic Haplorthoxes represent a source of livelihood for many persons, producing a considerable amount of subsistence and cash crops. Sombroek (1966) notes that the majority of present day Amazonian shifting cultivation is located on light and medium textured soils such as medium-textured Yellow Latosols and Yellow Latosolic Sands.

Moving out of the Bragantina and Salgado regions, much less information is available; and most writers fail to distinguish between medium and heavy textured Yellow Latosols (Falesi, 1972a; UNESCO, 1971). The Brazilian Ministry of Agriculture schematic soils map (1966) on a scale of 1:5,000,000 of the North, Middle-North, and Central-West regions of Brazil, an area of 6,000,000 km^2 including the 5,000,000 km^2 region comprising the Brazilian Amazon (Falesi, 1972a), provides some information about the occurrence of the different soil groups. The map (Ministerio de Agricultura,

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1. continued

Falesi, and Oliveira Filho (1967) in their soil survey of the Bragantina region. See Figure 1

TABLE 7

Characteristics of Para State and Percent Contributions of Different Region to the Characteristics

	Regional Contribution (%) - Except for Population Density								
	Total	Amazon and Xingus Basins	Marajo Island	Tocantins Valley	Guajarina	Salgado	Bragantina	Belem	Viseu
Population, persons[1]	2,161,676	16	10	15	9	7	11	30	2
Area (km^2)[1]	1,227,530	66.7	11.4	13	6.5	0.5	1.0	0.1	0.8
Population Density[1] (persons/km)	1.76[4]	0.42[4]	1.51[4]	2.02[4]	2.40[4]	23.08[4]	20.49[4]	473.44[4]	3.75[4]
Raw Rice Production[2] (metric tons)	88,398	15	11	18	36	5	10	---	5
Beans and Cowpeas[2] (metric tons)	7,309	29	10	4	27	7	22	---	1
Maize[2] (metric tons)	47,423	26	4	9	33	8	12	1	7
Manioc-Fresh Roots[2] (metric tons)	1,013,675	18	8	24	11	9	27	1	3

Table 7, Continued

	Regional Contribution (%) - Except for Population Density								
	Total	Amazon and Xingu Basins	Marajo Island	Tocantins Valley	Guajarina	Salgado	Bragantina	Belem	Viseu
Tobacco Leaves[2] (metric tons)	1,327	14	--	2	55	--	29	--	--
Jute[2] (metric tons)	15,210	100							
Black Pepper[2] (metric tons)	23,150	1	--	3	51	10	34	1	--

1. IBGE, 1970a
2. IBGE, 1974
3. SUDAM, 1970
4. Inhabitants/km^2

1966) defines two mapping units LA 4 and LA 5, as Yellow Latosols of loamy texture occupying more than 50% of the mapped area with Red and Yellow Quartz Sands occupying more than 20% of the mapped area. From this map, the author has determined the area occupied by these two units, LA 4 and LA 5, as 28,950 km^2 and 40,525 km^2 respectively, or a total of 69,475 km^2, which of course, includes the Bragantina region (mapped as LA 4 on the Ministry of Agriculture map). The other Yellow Latosols on the Ministry of Agriculture map are classified as being of clayey or undifferentiated texture and hence are not comparable to those of Bragantina region.

As was pointed out earlier, some of the soils on the Tracuateua Experiment Station are classified as Red and Yellow Quartz Sands (Rodrigues et al., 1974). The Red and Yellow Quartz Sands are broken down into fourteen mapping units in the Ministry of Agriculture map, of which six occur within the 5,000,000 km^2 area considered to comprise the Brazilian Amazon. These are units AV 6, AV 7, AV 8, AV 11, AV 13, and AV 14 on the Ministry of Agriculture map. A description of these units and their areas estimated by the author from the Ministry of Agriculture map follow:

Unit	Description	Area km^2
AV 6	More than 50% of area Red and Yellow Quartz Sands; 20-50% of area dystrophic Red Yellow Latosols of loamy texture	94,325

AV 7	Red and Yellow Quartz Sands associated with Yellow Latosols and Ground Water Laterites (No mapping unit occupying more than 50% of area)	183,600
AV 8	More than 50% of area Red and Yellow Quartz Sands; 20-50% of area dystrophic Red Yellow Podzolic soils	5,850
AV 11	More than 50% of area Red and Yellow Quartz Sands; 20-50% of area dystrophic Dark Red Latosols	24,400
AV 13	More than 50% of area Red and Yellow Quartz Sands; 20-50% of area dystrophic Red Yellow Latosols of clayey and loamy texture	60,900
AV 14	More than 50% of area Red and Yellow Quartz Sands; no associated soils occupying more than 20% of area	3,700
	Total	372,775

The calculations made by the author therefore indicate that there are 372,775 km^2 of Red and Yellow Quartz Sands associated with the dystrophic Latosols and Red Yellow Podzolic soils in the Brazilian Amazon, accounting for 7.4% of the area of the region. It should be clear from the preceding descriptions that 20-50% of the soils of these areas are of heavier texture than sands. As an estimate of the area of Red and

Yellow Quartz Sands in the Brazilian Amazon, the figure of 372,775 km^2 should be reduced by about 35%.

Another unit on the Ministry of Agriculture map consisting of light-textured soils is LV 15, dystrophic Red Yellow Latosols codominant[1] with Red and Yellow Quartz Sands. From these calculations based on the 1966 Ministry of Agriculture map, the following areas light-textured soils can be distinguished in the Brazilian Amazon:

Map Unit	Soils	Area km^2
LV 4, LV 5	Yellow Latosols of loamy texture	69,475
AV 6, AV 7, AV 8, AV 11, AV 13, AV 14	Red and Yellow Quartz Sands associated with dystrophic Latosols and Red Yellow Podzolic soils	372,775
LV 15	Red and Yellow Latosols codominant with Red and Yellow Quartz Sands	82,250
	Total light-textured soils	524,505

Thus, about 10% of the Brazilian Amazon consists of light-textured soils of low fertility. It should be noted that these are the soils most commonly used for agriculture in the region, not only for subsistence crops grown under shifting cultivation, but also for black pepper, the region's chief

1. Codominance means that each soil occupies from 25-50% of the area mapped.

cash crop (Vieira *et al.*, 1967; Valverde, 1967; Sombroek, 1966).

A further estimate of the occurrence of light-textured soils in the Brazilian Amazon can be derived from a consideration of the soil survey carried out along the Transamazon highway from Estreito to Itaituba, a distance of 1180 km. (See Figure 1.) The breakdown of soils along the 877 km mapped is as follows (calculated by author from Falesi (1972b)):

Soil Type	Extent (km)	Percent
Structured Terra Roxa	85	9.7
Dystrophic Red and Yellow Podzolic soils	319	36.2
Yellow Latosols (mostly heavy textured)	135	14.3
Concretionary Latosols	72	8.2
Red and Yellow Quartz Sands	139	15.8
Eutrophic Red Yellow Podzolic Soils	94	10.4
Others	33	3.4
Total	877	100.0

Thus it can be seen that the occurrence of sandy soils along the Transamazon highway is even greater than one would expect from the estimate made from the map of the whole region. The two methods of estimation of the extent of sandy soils in the Brazilian Amazon give surprisingly close agreement.

3.3. The observations of Sombroek

The most detailed study to date of soils of the Amazon has been carried out by Sombroek (1966), who does not give estimates of the extent of the soil types but does make various observations concerning their occurrence and association. He also gives more analytical information about the soils than do other surveys. The areas surveyed by Sombroek are shown in Figure 2. The soils occurring on the Tracuateua Experiment Station would be called Kaolinitic Latosols and Kaolinitic Latosolic Sands by Sombroek, the distinction again being made on the basis of texture. The Kaolinitic Latosols have more than 15% clay in some subhorizon of the B; the Kaolinitic Latosolic Sands have less. Kaolinitic Latosols having less than 35% clay in the B horizon are considered to be medium textured; those with more are considered to be heavy textured (Sombroek, 1966). Descriptions of these soils taken from Sombroek are presented in Appendix I.

Sombroek relates the occurrence of the different soil types to geomorphological units. These are given in Figure 4.

It can be seen that the medium-textured Kaolinitic Latosols and Kaolinitic Latosolic Sands occur chiefly on Pleistocene Terraces, east of Manáus. Sombroek states that these soils are the predominant soils of the Bragantina region

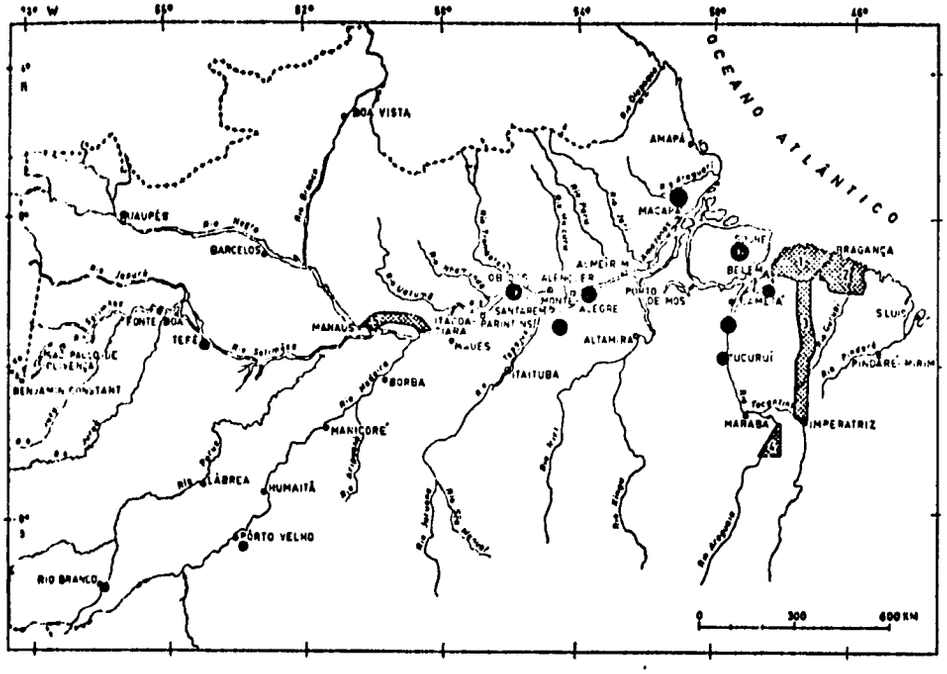


Figure 2. Areas covered in soil surveys utilized by Sombroek (from Sombroek, 1966).

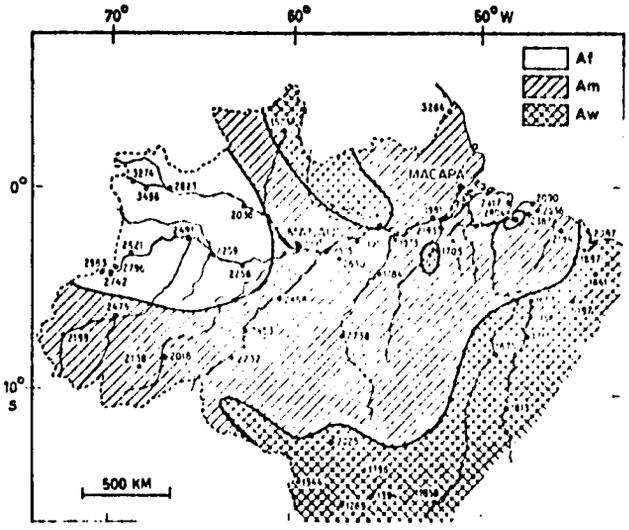
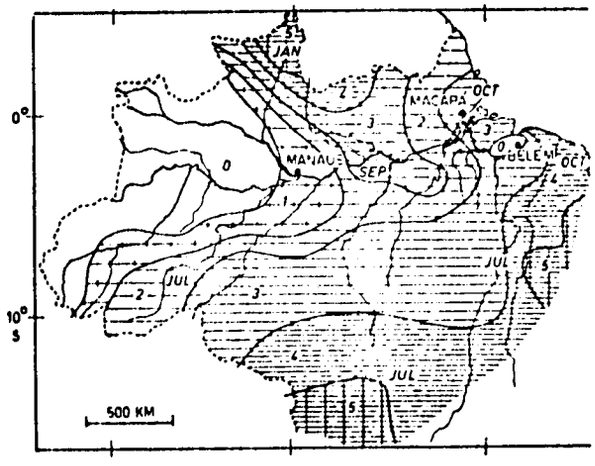
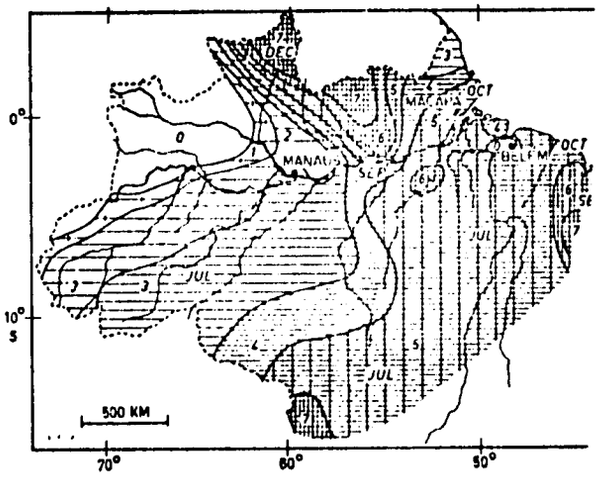


Figure 3. A. Climates of the Brazilian Amazon as per classification of Koeppen and total annual rainfall (from Sombroek, 1966).



B. Number of dry months per year and central month of dry season taking less than 50 mm rainfall as criterion for dry month (from Sombroek, 1966).



C. Number of dry months per year and central month of dry season taking less than 100 mm rainfall as criterion for dry month (from Sombroek, 1966).

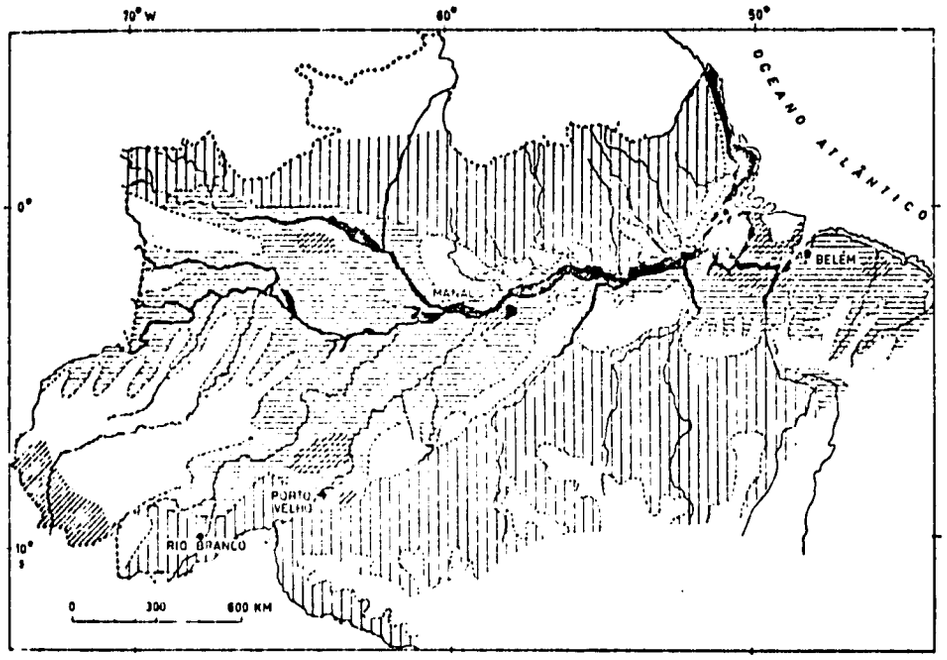


Figure 4. Main Amazon soils in relation to geomorphological units (from Sombroek, 1966).

- Holocene terrains-Saline and Alkali soils.
- Holocene terrains-Low Humic Gley and Humic Gley soils
- Ground Water Laterite soils
- Pleistocene terraces-Kaolinitic Yellow Latosols (of varying texture) and Kaolinitic Latosolic Sands
- Amazon planalto-Kaolinitic Yellow Latosols of very heavy texture (4 + 5: Planicie)
- Outcropping crystalline basement and outcropping Paleozoic, Mesozoic, and Early Tertiary deposits, as well as Early Tertiary (?) peneplanation surface-Red Yellow Latosols, Dark Red Latosols, Red Yellow Podzolic soils, Lithosols, Ground Water Laterite soils
- Cretaceous (?) peneplanation surface- Areno-Latosols

and of the Caete-Maracassumé region (immediately east of the Bragantina region-See Figure 2). The Kaolinitic Sands, he states, "are normally present near the rivers and are of frequent occurrence in the Lower Amazon region. The uplands with Kaolinitic Yellow Latosols or Kaolinitic Latosolic Sands are largely under forest." (Sombroek, 1966). It can be seen that these light-textured soils occur principally in the eastern Amazon region since Sombroek does not mention their occurrence in connection with other geomorphological units. Also, he notes that the Kaolinitic Yellow Latosols which have developed on Pleistocene terraces of the western Amazon basin are of heavier texture than those of the eastern Amazon. It must be cautioned that conclusions for the western Amazon are based on a smaller number of observations taken over a restricted area. (Sombroek, 1966).

The location of the "Cretaceous (?) peneplain surfaces" in Figure 4 should be noted since these are where most of the other sandy soils of the Amazon basin are located.

Sombroek states that the heavier-textured soils generally support a higher gross timber volume than do the lighter-textured soils. Sombroek shows that the lighter-textured soils generally have higher bulk densities and lower % pore space and (having fewer small pores) poorer moisture

availability; but moisture availability is generally low for all Yellow Kaolinitic Latosols regardless of texture. He also notes that very deep tree rooting (up to several meters) is characteristic of the medium-textured Kaolinitic Yellow Latosols and Kaolinitic Latosolic Sands, Sombroek also notes that some tree species are more frequent on the lighter-textured soils. (Sombroek, 1966).

Sombroek also discusses land use in the Bragantina region. He notes the shortage of land in the area. Although he states that there seems to be no clearly defined preference for certain soil types for agricultural purposes, he observes that the majority of shifting cultivation in the present-day Amazon is found on light and medium textured soils. Concretionary soils are also used; and the plinthitic concretions do not seem to constitute a great obstacle to their use. Heavy textured soils are little used because they are generally far from land and water transport routes. The very heavy textured soils may present some difficulties because of problems with the drinking water supply and tillage; although Sombroek states that where they are used, the yields are "comparatively very satisfactory". (Sombroek, 1966)

In summary, it may be concluded that light-textured Yellow Latosols such as those found on the Tracuateua Experi-

ment Station and tentatively classified as Quartzipsammentic Haplorthox or Orthoxic Quartzipsamment, while not constituting a very large proportion of the total land surface of the Brazilian Amazon, comprise a group of the region's most extensively used agricultural soils in spite of their low fertility.

Chapter Four

History of Settlement and Land Use of the Bragantina Region.

4.1. Present pattern of land use in the Bragantina region

The region of the state of Pará in which the Tracuateua Experiment Station is located is known as the Zona Bragantina because it was served by a railroad which connected the cities of Belém and Bragança from 1908 to 1966. The railroad provided a link between the area and the city of Belém which is still reflected in the pattern of land use in the area. A map of the Salgado and Bragantina regions, showing the route of the railroad, the date of construction of the different sections of the railroad, boundaries of the areas opened to government-sponsored colonization, and the location of the principal towns of the region is given in Figure 5. The present pattern of land use in the Bragantina region has been described by Valverde and Dias (1967) who identify ten zones as one moves out from Belém toward Bragança along the former railraod route.

These are as follows:

1.) Urban expansion
2.) Production of charcoal and fuel-wood
3.) Vegetable production
4.) Fruit production

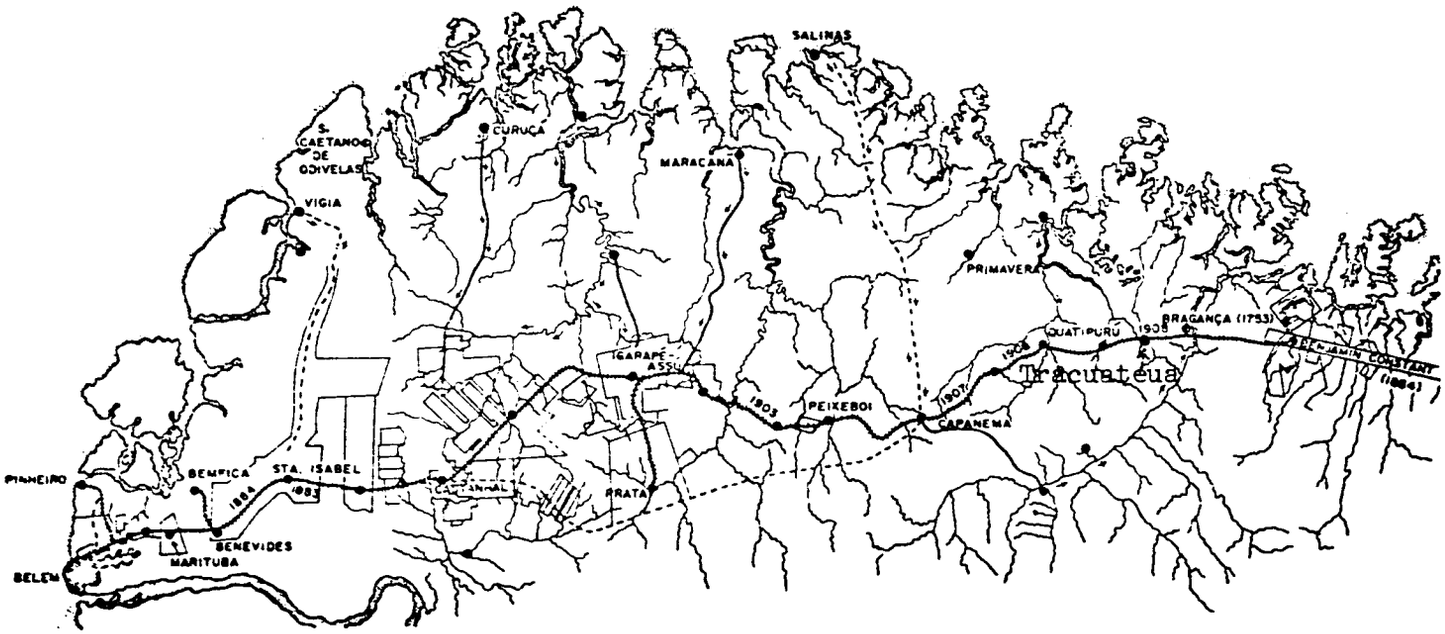


Figure 5. Map of salgado and Bragantina regions showing route of Belém-Bragança Railroad, date of construction of different sections of the railroad, boundaries of areas copened to government sponsored colonization and location of principal towns of the regions.

(from Sioli, 1973)

5.) Black pepper

6.) Economic degradation-soils completely exhausted

7.) Manioc meal production (The manioc may be grown in association with maize and/or rice)

8.) Malva[1] production (This may be associated with manioc, maize or beans.)

9.) Tobacco associated with cattle raising

10.) Extractive activities or fishing

This pattern reflects a chronological sequence in which soil fertility becomes progressively exhausted. It can be seen that of the activities listed above, only the production of malva, manioc, rice, maize, and beans (cowpeas) depend upon the native fertility of the soil. As this is exhausted, the

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1. Malva (Pavonia malacophyla) and Uacima (Urena lobata) are members of the Malvacea, in appearance similar to Kenaf (Hibiscus cannabinis) whose fibers are prepared in a manner similar to Kenaf. The plants sprout spontaneously and densely in areas of the Bragantina region following cutting and burning of the forest. The fibers are similar in quality to jute. The production of the state of Pará was worth about one million dollars in 1973.

area becomes one of economic degradation until another activity such as production of charcoal, black pepper, fruits, or vegetables, which either require a lower level of soil fertility or depend upon the use of mineral or organic fertilizers, becomes established. It should be noted that all four of these last-mentioned activities depend upon the city of Belém as either a market for the charcoal or as a source of capital for the purchase of inputs such as fertilizers necessary for the establishment of one of the other activities. (Valverde and Dias, 1967; Egler, 1961). Tobacco and cattle raising and gathering activities are important only along the coast or in the valley of the Guama River, which forms the southern boundry of the Bragantina region, where the açai palm (gathered for its fruits and for the production of hearts of palm), crabs, and fish are plentiful (Valverde and Dias, 1967). Cattle are raised in areas which flood in the rainy season and leave natural pastures when the waters recede. The cattle are confined in corrals for part of the day or year so that their manure accumulates in the corrals. The corrals, thus fertilized, are used for tobacco growing during the dry season when cattle are grazing on the lowland pastures. This system, apparently Portuguese in origin, enables areas of extremely low fertility to produce a cash crop. (Valverde and Dias, 1967; Penteado, 1967).

It can be seen that soil fertility is the dominant consideration in all of these activities. Annual crops rely on fallows of several years for restoration of fertility (Sioli, 1973); but due to population pressure, such an amount of idle land cannot be maintained and soils become rapidly exhausted. It will be seen in the following chapter that rainfall, temperature, and sunlight are adequate for most crops in all but one or two months of the year. From the preceding discussion, it can be seen that it is thoroughly possible to raise tobacco in the dry season on light soils of low moisture retaining capacity (Sombroek, 1966).

4.2. History of settlement

Although the low native fertility of the soils of the Bragantina region has been documented in the previous chapter, their low native fertility was not obvious to government officials a centry ago who regarded the exuberant tropical forest which covered the region east of Belém as evidence of fertile soils. The Vice-President of the Province of Pará suggested in 1858 that the area east of Belém be opened to colonization by preferably European immigrants who would produce foodstuffs for the city of Belém. The city, founded in 1616, was finding itself spending distressingly large amounts of its revenues from the developing rubber trade on foodstuffs imported from other parts of Brazil (Penteado, 1967).

In 1858 what is presently known as the Bragantina region was practically uninhabited except for the town of Bragança, founded by the Portuguese in 1662 and enlarged by arrival of a contingent of immigrants from the Azores in 1753 (Penteado, 1967); an Indian village[1] organized by Portuguese missionaries along the Maracana River, now a part of the Colonia de Prata (For location, see Prata in Figure 5); and a few way stations along the precarious overland route btween Belém and São Luis, the capital of the state of Maranhao (Egler, 1961). A chronology of the principal events in the history of the Amazon region is given in Appendix II.

Three factors had a long-term effect on the settlement of the colonization of the region: the rubber boom, the construction of the Belém-Braganca railroad, and the entry of persons displaced from northeast Brazil following the droughts which periodically plague this overpopulated and impoverished area (Penteado, 1967).

The rubber boom was important because it drew people out of agriculture and into rubber-gathering, precipitating the agricultural crisis which provided a stimulus for colonization,

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1. Many such "reductions" were set by Jesuits and other missionary groups throughout the Amazon from the mid-sixteenth to mid-eighteenth centuries. (See Appendix II)

and because it provided the government of Pará with the necessary revenue for financing the expensive colonization scheme, which included building the railroad and recruiting colonists in Europe. The colonization scheme ended in 1914 when the appearance of plantation rubber from Southeast Asia brought about a fall in rubber prices and demand for the inferior Brazilian product, depriving the government of the state of Pará of revenues for financing further colonization. (Penteado, 1967).

The Belém-Bragança railroad, begun in 1883, gave the Bragantina region its name, determined the pattern of settlement, and was supposed to carry the produce of the colonists to market in Belém. In realizing the necessity of good transport to the success of the colonization scheme, the planners of the Bragantina colonization in the 1870s showed more foresight than the planners of settlement along the Transamazon highway in the 1970s where inability to get produce to market contributed to the failure of that colonization scheme. However, it was only after the end of the rubber boom when the government no longer had revenues to spend on expansion on the railroad that the railroad began to be profitable. However, this period, which as we shall see followed the entry of large numbers of settlers from northeastern Brazil who planted considerable areas to foodstuffs, ended in 1926 when the railroad again began losing money. (Penteado, 1967; Egler, 1961). A paved road from Belém to Braganca, completed

in 1958, served the function formerly filled by the railroad, whose tracks were taken up in 1966, this time at the expense of the Federal government (Valverde and Dias, 1967).

The fact that settlers from northeast Brazil played an important part in the development of the Bragantina region is a further indication of how plans for the settlement of the region were not fulfilled. It was pointed out that the original plans for the colonization called for the bringing of European immigrants; and from 1875 to 1902, about 15,000 persons, mostly from Spain, but also from France, Italy, and the Azores were brought to colonize the region (Egler, 1961). However, very few of these remained for any length of time, most probably for the following reasons: the colonies were poorly administered and no useful services were provided for the colonists (Valverde and Dias, 1967; Egler, 1961); the colonists were not necessarily persons with previous experience in agriculture (Egler, 1961); the colonists came from temperate environments and did not readily accustom themselves to life in the tropics (Penteado, 1967); and there was readily available employment in the cities of Belem and Bragança, not to mention the developing urban centers in the Bragantina region itself, in services and commerce, employment created by the wealthy rubber economy.

Northeastern Brazil has been overpopulated and impoverished ever since it lost its monopoly on world sugar production in

the latter half of the seventeenth century. Only the coastal areas have sufficient rainfall for sugarcane production. In the drier inland areas, however, nomadic cattle raising had soon established itself, providing cattle for food and power for the sugar-producing areas. As the sugar industry declined, the people[1] employed in it moved into the cattle-raising areas, which increasingly took on aspects of a subsistence economy since it no longer had a market for its cattle. Thus, the Northeast experienced a peculiar phenomenon: population increase despite economic stagnation. An increase in world cotton prices in the 1860s, occasioned by the U.S. Civil War, stimulated cotton production in the drier interior areas, with the result that labor moved out of the subsistence economy based on cattle raising and into a cash economy based on cotton growing. However, a prolonged drought struck in 1877 and lasted until 1880 with the result that all of the regions' cattle and 200,000 human beings died of starvation. Masses

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1. As slavery was only abolished in Brazil in 1888, these statements apply only to free persons who could move off plantations. Most of the present poor in the sugarcane region of the Northeast are descendants of slaves who could not move into the direr interior where population pressure was already considerable by the time of abolition (1888). (Furtado, 1963).

of starving people descended on the cities of the region where federal authorities offered them free steamboat passage to the Amazon ports of Belém or Manáus. (Furtado, 1963)

Furtado (1963) estimated that 260,000 people came from northeastern Brazil to the Amazon between 1872 and 1900. Many of them became rubber collectors but some found their way to the Bragantina region since their presence was already noted at the Colony of Benevides[1] in 1878 (Penteado, 1967). Further droughts in the Northeast brought at least 9,000 persons from the Northeast to the Bragantina region by 1902 (Penteado, 1967). In 1915, when official colonization had ended and employment in rubber gathering was no longer available, another drought brought at least 30,000 persons from northeast Brazil to the Bragantine region (Sioli, 1973; Egler, 1961). Population of the state of Pará increased from 445,356 in 1900 to 983,507 in 1920 (Brazilian Census figures) which is about 130,000 more than one would expect from a 3% annual increase over a 20-year period. Certain facts about these immigrants should be noted if their effect on the Bragantina

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1. Started in 1875, the Colony of Benevides marked the beginning of government efforst to colonize the Bragantina region. One-hundred-eighty Europeans, almost half of them French, were settled there in October, 1875, but only 91 of them were still there in February, 1877. In 1878, the presence of 800 Northeasterners was already noted. (Penteado, 1967).

region is to be understood:

1.) They did not come with the intention of staying. When word of the end of the drought in the Northeast reached them, they would try to return home. As the figures show, not all of them were successful; but the fact that this element did not consider its presence in the area as permanent influenced the type of activities in which it would engage. (Penteado, 1967).

2.) The Northeasterners brough an agricultural technology developed in areas of fertile soil where rainfall was the major limiting factor to an area of excessive rainfall where soil fertility was a major limiting factor (Egler, 1961).

3.) Most of the Northeasterners had been sharecroppers or squatters in the area whence they came. Although they were given land in the Bragantina region, they tended to gravitate into land ownership relations similar to those to which they had been accustomed. Lots were often traded off permitting the development of latifundia and landless peasants. (Valverde and Dias, 1967; Penteado, 1967).

4.) Many of the migrants had little or no experience in agricultural pursuits. The government offered considerable incentives to migration, attracting all sorts of adventurers. Upon arrival, financial assistance was often given so that there was no need for settlers to immediately begin farming. (Penteado, 1967).

Hence, land was requently exploited for maximum profit

in the shortest time. Lots were quickly cleared since timber prices were attractive. There was also considerable demand for charcoal both by urban users and by the railroad. Government policy favored planting of rice and maize which quickly exhausted the soil. Later incentives were given for the planting of sugarcane for the production of raw sugar, liquor, and molasses. Manioc was planted when reasonable yields of rice and maize were no longer obtained. While there was plenty of virgin land, the colonists prospered. Enough produce was shipped into Belém to supply the needs of the city and for the railroad to produce a profit from 1916 to 1926. Thus, the area was little affected by the collapse of the rubber market since most of its products were those with the least elasticity of demand in Belém. (Egler, 1961).

What exactly caused the railroad to start losing money after 1926 is difficult to determine; but it is reasonable to assume that it was due to a reduction in the produce transported. Unfortunately, no production data for the area previous to 1939 are available. Some parameters of agricultural production, land use, employment, and population for the Bragantina region and the state of Pará for the period 1939-1969 taken from Brazilian census figures are shown in Table 8. It is clear from the table that production of rice, manioc, maize, and beans has fallen off considerably, but evidence of

Table 8

Changes in various measures of agricultural production and activity in the Bragantina region and in state of Pará 1939-1969 (IBGE, 1970a; 1960a; 1950a; 1940a; 1970b; 1960b; 1950b; 1940b; SUDAM, 1970)

A. Production of annual crops in Bragantina region

Year[2]	Rice Production (T.)	Percent of state total	Manioc roots Production (T.) fresh weight	Percent of state total	Maize Production (T.)	Percent of state total	Beans (Cowpeas) Production (T.)	Percent of state total
1939	14,635	42.0	192.681	36.4	15,554	37.9	2532	47.7
1949	17,683	40.0	229.593	38.5	16,376	40.0	3717	20.0
1969[1]	7,613	7.4	137.858	23.7	3,900	8.1	1314	22.0

Year	B. Area in annual crops (Has,)		C. Number of agricultural establishments		D. Persons employed in agriculture	
	Bragantina	Pará State	Bragantina	Pará State	Bragantina	Pará State
1949	36,015	127,596	15,055	50,615	51,368	214,255
1959	62,458	225,227	19,085	83,180	75,460	334,505
1969[1]	35,486	283,500	20,360	141,779	83,054	591.252

1. Corrected to account for changes in area of Bragantina microregion from 1960 to 1970 cenuses.
2. Agricultural census for 1960 could not be located.

Table 8, Continued

Year	E. Population of Bragantina region		F. Population of city of Belém		G. Population of state of Pará	
	Number persons	Increase over previous decade %	Number persons	Increase over previous decade %	Number persons	Increase over previous decade %
1939	131,452		206,331		944.644	
1949	160.232	28.3	260,608	26.3	1,123,273	18.9
1959	208,513	23.3	402.170	54.3	1,550,935	38.1
1969[1]	237,917	13.9	633,374	57.5	2,167,018	39.7

a decline only appeared after 1950. Sugarcane and timber were already of little importance by 1940.

It would fit very well in this account of the history of land use in the Bragantina region to attribute these declines in production of annual crops to a decline in soil fertility. However, the fact that the number of agricultural establishments and the number of persons employed in agriculture did not decline since 1950 would indicate that other factors may have been operating. Two crops, malva and black pepper, began to become important in the area after 1940 and 1950 respectively (Penteado, 1967), occupying areas previously used for annual crops. Production of annual crops became more important in the area south of the Bragantina region where soils were less exhausted. Also, with the construction of the Belém-Brasília highway (opened in 1961), rice and maize from central Brazil became available in the region, making local production of such crops less attractive. (Valverde and Dias, 1967). So, although declining soil fertility certainly played a role in the decline of annual crop production in the Bragantina region in the past twenty years, it is unlikely that it alone could have been responsible for as great decline as the figures in Table 8 indicate.

4.3. Present decadence

Every author who has written about the Bragantina region in recent years has noted the impression of decadence which the region presents (Sioli, 1973; Valverde and Dias, 1967; Penteado, 1967; Egler, 1961; de Mattos, 1958). The reasons for this impression are not hard to find: declining fertility of areas used for slash-and burn agriculture; more attractive opportunities outside of the region so that the more aggressive and ambitious elements of the population move to other areas; and a population that lacks the training and capital to move into pursuits other than the production of annual crops under shifting cultivation as is the practice in the region (Valverde and Dias, 1967; Penteado, 1967). No truly viable alternative land used have really presented themselves in the region, however. There is little prospect for expansion of malva production within the Bragantina region[1] and the pepper has been attacked by Fusarium spp. which shortens considerably the productive life of the pepper vines. Breeding resistant pepper varieties has been hampered by the lack of a trained breeder at the station of EMBRAPA in Belém and by the difficulty in obtaining material from Southeast Asia. All of the pepper plants in the Bragantina region are

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1. The most important malva producing areas are located to the south of the Bragntina region (Valverde and Dias, 1967).

of a single clone and hence very susceptible to annihilation by disease. (Personal communication, Dr. Anne. S. Prabbhu, former head of plant pathology section, state branch of EMBRAPA (formerly IPEAN and IAN), Belém, Brazil). Rubber plantations operated by Pirelli and Goodyear in the Bragantina region consume considerable resources in controlling insects and diseases with chemicals and produce little profit (Personal communication, Dr. Delmas Ryker, supervisor, Granja Marathon, Goodyear Rubber Corp., São Francisco do Pará; Brazil).

Vegetable and fruit growers, who, like the black pepper growers, are often of Japanese descent[1], find it more profitable to truck fruits and vegetables from southern Brazil to Belém than to grow them in the Bragantina region where high rainfall, low cation exchange capacity of the soils, and high temperatures necessitate considerable expenditures for fertilizer and pesticides, offsetting whatever advantage closeness to market may offer. Although some pasture grasses have performed satisfactorily in the region, the Bragantina region only had 241 establishements devoted to livestock raising in 1970, with a total of 22,939 animals or about 2%

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1. Japanese emmigrants who entered the Bragantina region after 1930, have generally prospered more than other settlers. Valverde and Dias (1967) pointed out that Japanese families had an income more than three times that of Brazilian families in one settlement of the Bragantina region.

of the total in Pará state (IBGE, 1970b). It is doubtful that expansion of this activity would provide much employment for the area's population.

Other proposals for the area include the cultivation of tree crops since they most resemble the original vegetation of the Bragantina region (Sioli, 1973). Unfortunately, a long time must elapse before such crops are productive and since tree crops are invariably cash crops, the area become dependent on foreign markets where prices tend to vary. The unpleasant social consequences of plantation agriculture are well-known.

Some sort of mixed farming operation, possibly centering on dairy cattle since there are fairly good fresh milk markets in the growing urban areas of the region, making manure available for crops, is probably the most viable prospect for the area. A much publicized effort in this direction, the Granja Imperial, where chickens and cattle were to be raised on imported feed to provide manure for annual crops (Sioli, 1973; Egler, 1961, ended in failure with the proprietor blaming the incapacity of the local population to adopt new methods (Penteado, 1967).

4.4. Simultaneous polyculture in the Bragantina region

The 1950 agricultural census (IBGE, 1950b) showed that 99% of the maize, 99% of the rice, and 67% of the manioc came from simultaneous polyculture. Such widespread practice of simultaneous polyculture was evident to the author in the

time he spent in the region in 1974 and 1975. While the value of the practice will be dealt with in other parts of this thesis, some cultural and historical reasons for simultaneous polyculture should be dealt with here. Simultaneous polyculture was almost universally practiced by the indigenous population of the Amazon (Meggers, 1973, 1971). In Table 1, the importance of the practice in northeastern Brazil, where most of the present population of the Bragantina region had its origins, was shown. Finally, Donald (1963) noted the occurrence of simultaneous polyculture in the Mediterranean region of Europe whence came most of the European colonists of the Bragantina region. Hence, whatever the environmental factors which might have favored the adaptation of simultaneous polyculture in the Bragantina region, all settlers in the region, whatever their origin, had undoubtedly been previously exposed to the practice.

4.5. Some observations by the author

The author spent fifteen months in the village of Tracuateua in the township of Bragança of the Bragantina region while carrying out the field work to be reported upon in this thesis. As this is probably longer than any of the authors who have written about the area have spent in the region, the author feels himself qualified to make some comments about the Bragantine region. The village of Tracuateua is rather strategically located in the region insofar as all of the land uses described at the beginning of this chapter could be observed

in the immediate vicinity.

One of the most striking aspects is the importance of the public sector in providing employment and services in the area. Another large segment of the population is employed in service occupations and not in agriculture. Salaries paid by the experiment station and the elementary school and the pensions paid by the federal government to retired railroad workers and to rural workers over 65, although small[1], appear to the author to be a more significant source of income in the village than any agricultural pursuits although the area is classified in the 1970 census as being over 90% rural (IBGE, 1970a). Also, in the city of Belém, government employees constitute a much larger portion of the labor force than those employed in industry. The level of services provided by the government in the village[2], while by no means adequate, is considerably more than one would expect in such an impoverished and underdeveloped area. No food aid is provided, however.

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1. A retirement pension for a rural worker was about $30 per month. School teachers without a teaching certificate received $30 per month while those with a certificate received about $60 monthly. The minimum wage for agricultural labor was set at about $1.50 per day but this was often not paid.

2. The elementary school taught the 1st through 7th grades. The state health post had two nurses and distributed some medicines. Following establishment of a branch of the rural workers' syndicate, a doctor and a dentist came to the village weekly.

The observations about the deficiencies of the human element, made by certain authors (Valverde and Dias 1967; Penteado, 1967) also seem justified. The people have little tradition of communal activity; and thinking in terms of a unit larger than one's own family is rare. Entering into a dependent relationship with a wealthy person is considered a much more secure provision of one's future well-being than becoming self-sufficient. The most aggressive and ambitious persons generally leave the area to seek opportunity elsewhere, leaving the most tradition-bound and least innovative elements of the population behind. Hence, communities in the Bragantina region seem unusually unreceptive to new ideas. Thus, even if one were to find an agronomically viable land use for the area, considerable difficulty would be encountered in getting it accepted by a large proportion of the population.

4.6. Conclusions

Piere Gourou pointed out that unlike most places where the productivity of the hinterland produces a city, the Bragantina region was produced by the city of Belem and never became particularly productive (Penteado, 1967). After its initial function, that of providing foodstuffs to the city of Belém, had exhausted its soils, the Bragantina region became reliant on capital generated in Belém to establish other productive exterprises such as pepper plantations, often established on

the vacation properties of middle and upper class city dwellers[1] (Egler, 1961). Although the closeness of the Bragantina region to Belém has prevented it from becoming hopelessly backward, its economy has characteristics more of a welfare state than of an agriculturally productive area.

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1. These persons are generally bureaucrats whose salaries are paid by the federal government from revenues generated in more productive areas of Brazil.

Chapter Five

An Experiment to Evaluate the Effect of Simultaneous Polyculture of Manioc, Maize, and Rice on Yield, Nutrient Content of Manioc, Weed Control, and Leaching of Cations

5.1. Objective

The objective of the present study was to determine if simultaneous polyculture of rice (*Oryza sativa* L.) and manioc (*Manihot esculenta* Crantz) on a Quartzipsammentic Haplorthox in the Bragantina region of the Brazilian Amazon would result in increased production, increased K content of manioc, better weed control, and reduced leaching losses of exchangeable cations. Maize was also included in the experiment in order to contrast its effect with that of rice and to reflect its frequent association with manioc in the region.

5.2. Justification

Simultaneous polyculture in the Bragantina region accounts for almost all of the production of the major food crops of the population: rice, cowpeas, manioc, and maize. It has been shown that over 99% of the rice, 99% of the maize, and 67% of the manioc produced in the area are produced by mixed cropping (Penteado, 1967). Considering the low fertility and cation exchange capacity of the sandy soils which predominate

in the area (Vieira et al., 1967; Sombroek, 1966), it is conceivable that simultaneous polyculture might provide better soil cover than a monoculture and reduce weed growth and nutrient losses occasioned by leaching as has been suggested by Miracle (1967).

The author hypothesized that the rice and manioc might complement each other since rice straw contains high levels of K (Tokunaga, 1975) and manioc generally responds to this element on sandy soils (Stephens, 1960; Djokoto and Stephens, 1961a; Ofori, 1973a) which predominate in the Bragantina region (Vieira et al., 1967; Ministerio de Agricultura, 1966). The author's observation of farmers in the region stepping on the rice straw to flatten it around the manioc plants following the rice harvest suggested that common agricultural practice in the region might be exploiting the benefits of the association.

In considering various published studies of simultaneous polyculture, only one (Dalal, 1974) has been found where the effect of the practice on soil nutrient status had been measured. Although Dalal (1974) found no significant effect of cropping system on the exchangeable Ca, Mg, and K status of the soil sixteen weeks after planting maize and pigeon peas in pure stands and in simultaneous polyculture, it should be noted that

rainfall never exceeded 100 mm per month during the course of the experiment so that considerable amounts of leaching would not be expected. Furthermore, the soils used by Dalal were of somewhat heavier texture and had a higher exchange capacity (12 me/100g) than those used in the present study. In the present study, soil samples have been taken at four month intervals to a 1 m depth so that changes in nutrient status could be determined with greater precision. An effort has also been made to obtain a measure of weed growth under the different cropping systems studied.

The choice of cropping systems to be studied has not been made without difficulty. It has been shown that most of the studies of simultaneous polyculture have included a legume among the species studied (Table 2). In the Bragantina region, the cowpea, the only legume grown to any extent[1] is not a particularly important crop although it appeared to the author to be a fairly important article of the diet (See Table 8). Because cowpeas planted during the rainy season exhibit excessive vegetative growth, are highly susceptible to diseases

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1. Among the other legumes noted by the author being grown in the Bragantina region are the yard-long bean (*Vigna sesquipedalis*) which Purseglove (1968) considers a member of the same species as the cowpea, the peanut (*Arachis hypogea L.*), the lablab bean (*Dolichos lablab*), and the pigeon pea (*Cajanus cajan*). None of these are ever anything more than backyard crops however. A large-scale scheme for peanut cultivation ended in failure in the early 1960s when the crushing facility closed.

and insects, and produce little grain yield, cowpeas can only be planted toward the end of the rainy season. Since rice and maize planted in association with manioc at the beginning of the rainy season would be ready for harvest at the end of the rainy season, it would seem convenient to follow them by cowpeas; but the manioc has by this time already formed a closed canopy. Cowpeas must either be planted in an area from which malva (See page 113) has already been harvested or in an area of one to three years' regrowth which would be relatively easy to cut and burn toward the end of the rainy season. A second planting of manioc is often planted into the cowpeas, one or two months after planting. (Penteado, 1967; Valverde and Dias, 1967). It can be seen that manioc planted at either the beginning or end of the rainy season will remain a pure stand after six months when the associated crops are harvested, probably thus accounting for the higher incidence of pure stand manioc than pure stand rice, maize, or cowpeas in agricultural census figures.

It can be seen that it would be difficult to evaluate the comparative merits of the simultaneous polyculture production systems noted above and of pure stands of the species involved and still have an experiment of manageable proportions. It has been decided therefore to restrict the present study to

cropping systems which would begin at the start of the rainy season and which would include only combination involving maize, manioc, and rice. Because pure stand rice or maize would leave the land uncropped after their harvest while the manioc is still growing, a planting of cowpeas following the pure stand of rice has been included; but simultaneous polyculture involving cowpeas has not been included because of the difficulties noted above. This solution still leaves a three month period previous to the manioc harvest in which the plots not planted to manioc are uncropped but no suitable crops for this period could be found.[1]

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1. Among the possibilities considered were peanuts, sesame, and tobacco. As consideration of Table 11 would show, the crop would have to be planted in a dry period (September or October) and harvested when rainfall was increasing (December or January)

5.3. Materials and Methods

a.) Soils of the experimental area

The experiment was carried out at the Tracuateua Experiment Station[1] of EMBRAPA, the agricultural research corporation of the Brazilian Ministry of Agriculture. The station is located at latitude 1° 04'30" south of the Equator and longitude 46° 56'00" west of Greenwich in the township of Braganca, state of Pará, Brazil (Rodrigues et al., 1974). A map of the station showing the localization of the experimental areas is given in Figure 6. The soils of the experimental area have been mapped as dystrophic Red and Yellow Quartz Sands with mottles from the surface to 60 cm and are most probably Quartzipsammentic Haplorthox, sandy, oxidic, isohypothermic in the U.S. soil taxonomy. Problems of classifying these soils are discussed in Chapter Three. A description of these soils taken from the survey of the Tracuateua Experiment Station follows. Analytic data is presented in Table 9.

Profile #1

Lithology and geologic formation: Tertiary, Pirabas formation

Original material: Sedimentary

Relief: Flat

Erosion: Slight sheet erosion

Drainage: Moderate to well drained

Vegetation: Scrub forest, approximately three years old

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1. Presently known as UePAE de Tracuateua (state level research unit) (Unidade de Pesquisa no Ambito Estadual).

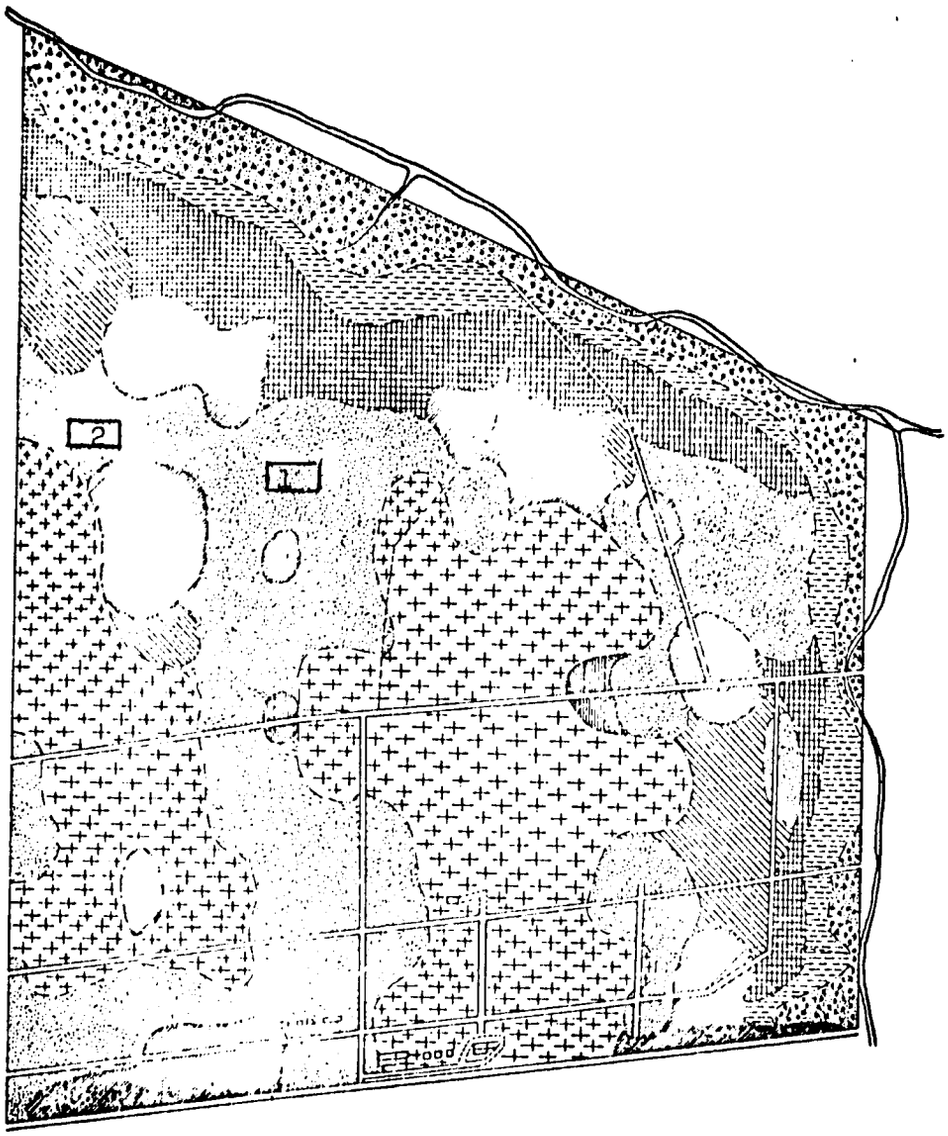

Figure 6. Map of Tracuateua Experiment Station showing location of experimental areas.

1. Area with fifteen year regrowth
2. Area with less than seven year regrowth

(from Rodrigues et al., 1974)

Red and Yellow Quartz Sands with mottles to 60 cm.

TABLE 9

Analytic data for soils in same mapping unit as experimental area (Rodrigues *et al.*, 1974)

Horizon	Depth cm	pH		Gravimetric Anal.					P_2O_5 (Bray II) mg/100g	Exchangeable Bases					Al^{+++}	C %	OM %	N %	C/N %
		H_2O	KCl	Coarse sand%	Fine Sand%	Silt%	Total clay%	Natural clay%		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Sum					
										me/100g									
										Profile #1									
Ap	0-12	4.5	3.8	53	32	6	9	2	0.36	0.57	0.14	0.05	0.05	0.81	1.01	1.33	2.29	0.08	17
A3	12-34	4.3	4.0	50	32	6	12	12	0.14	0.10		0.03	0.03	0.16	0.81	0.65	1.12	0.05	13
B21	34-70	4.2	4.1	53	29	2	16	16	0.14	0.06		0.04	0.02	0.11	0.81	0.29	0.49	0.03	10
B22	70-108	4.4	4.1	57	23	4	16	16	0.14	0.08		0.03	0.02	0.13	0.80	0.13	0.23	0.02	7
B23	108-150+	4.5	4.1	47	31	6	16	16	0.14	0.08		0.03	0.02	0.13	0.60	0.13	0.23	0.02	7
										Profile #2									
Ap	0-12	4.6	3.9	75	15	4	6		0.20	0.72	0.16	0.04	0.04	0.96	0.50	0.79	1.36	0.06	13
A3	10-26	4.2	3.8	67	19	3	11	4	0.14	0.14	0.04	0.03	0.03	0.24	1.01	0.44	0.75	0.05	9
B1	26-52	4.5	3.9	64	19	4	13	5	0.14	0.06		0.03	0.02	0.11	0.81	0.29	0.50	0.03	10
B21	52-86	4.7	3.8	66	16	6	12	6	0.14	0.08		0.03	0.02	0.13	0.81	0.18	0.32	0.02	9
B22	86-129	4.6	3.8	60	20	4	16	5	0.14	0.06		0.03	0.02	0.11	0.60	0.13	0.23	0.02	7
B23	129-150	4.7	4.0	64	17	4	15	1	0.14	0.08		0.03	0.02	0.13	0.60	0.09	0.15	0.01	6

Horizon	Depth	Description
A_p	0-12 cm	Very dark grey-brown (10 YR 3/2, moist); sandy very weak small and medium granules, breaking readily into fine earth; very friable, non-plastic, and non-sticky; many pores and channels; diffuse, smooth boundary.
A_3	12-34 cm	Dark brown (10 YR 4/3, moist) with few small and medium yellow mottles (10 YR 7/6, moist); loamy sand; weak small and medium granules, readily breaking into fine earth; many pores and channels; very friable, non-plastic and non-sticky; diffuse, smooth boundary.
B_{21}	34-70 cm	Yellowish brown (10 YR 5/6 moist) with few and distinct, strongly brown (7.5 YR 5/6 moist) small mottles; sandy laom; weak small and medium granules, readily breaking into fine earth; very friable, non-plastic, non-sticky; diffuse, smooth boundary

Profile #1, Continued

Horizon	Depth	Description
B_{22}	70-108 cm	Yellowish brown (10 YR 5/8, moist); sandy loam; weak small and medium granules, readily breaking into fine earth, many pores and channels; very friable, non-plastic and non-sticky; diffuse, smooth boundary
B_{23}	108-150+ cm	Strongly brown (7.5 YR 5/8, moist); sandy loam; weak small and medium granules; many pores and channels; very friable, non-plastic and non-sticky

Roots: fine and medium, many in the A_p and A_3; fine roots common in B_{21}, B_{22}, B_{23}; medium roots, few in B_{21}; large roots, few in A_3 and B_{21}.

Observations: Activity of organisms common throughout profile. Charcoal fragments in A_3, B_{21}, B_{23}. Few small concretions in B_{23}. Below A_3, some resistance to penetration with knife noted.

Profile #2

Lithology and Geologic formation: Tertiary, Pirabas formation

Original material: Sedimentary

Relief: Flat

Drainage: Moderate to well-drained

Vegetation: Scrub forest, approximately one year old, palms predominant

Horizon	Depth	Description
A_p	0-10 cm	Very dark, grey-brown (10 YR 3/2, moist); sand; very weak small and medium granules, readily breaking into fine earth; many pores and channels; very friable, non-plastic, and non-sticky; gradual, smooth boundary
A_3	10-26 cm	Dark grey-brown (10 YR 4/2, moist) with small and medium, common, distinct, brownish-yellow (10 YR 6/8, moist) mottles; sand; very weak small and medium granules, readily breaking into fine earth, many pores and channels; very friable, non-plastic and non-sticky; diffuse, smooth boundary
B_1	26-52 cm	Dark yellowish-brown (10 YR 4/4, moist), with small, few, prominent strongly brown (7.5 YR 5/6, moist) mottles; loamy sand; weak small and medium granules, readily breaking into fine earth; many pores and channels; very friable, non-plastic, non-sticky; diffuse smooth boundary

Profile #2, Continued

Horizon	Depth	Description
B_{21}	52-86 cm	Strongly brown (7.5 YR 5/6, moist), with small, few, distinct, brownish yellow (10 YR 6/8, moist) mottles; loamy sand; weak small and medium granules, breaking readily into fine earth; many pores and channels; very friable, non-plastic, and non-sticky; diffuse, smooth boundary
B_{22}	86-129 cm	Strongly brown (7.5 YR 5/8 moist); sandy loam; weak small and medium granules, breaking readily into fine earth; many pores and channels; very friable, non-plastic and non-sticky; diffuse, smooth boundary
B_{23}	129-150+ cm	Strongly brown (7.5 YR 5/8, moist); sandy loam; weak small and medium granules, breaking into fine earth; many pores and channels; very friable, non-plastic and non-sticky.

Roots: Fine and medium, many in the A_p and A_3, common in the B_1, B_{21} and B_{22}, few in B_{23}

Observations: Activity of organisms common throughout profile. Charcoal fragments in A_3. Some resistance to penetration with knife noted from A_3, B_{23}.

b.) Experimental design

A split-split plot experiment was desinged to compare the effects of different crop combinations on productivity and nutrient loss. Each block was split into a weeded and a non-weeded half. Each weeded or non-weeded half block was planted with one of the following crop combinations:

1.) Manioc (*Manihot esculenta* Crantz) var. Pretinha, in pure stand

2.) Rice (*Oryza sativa* L.) var. IAC 47, in pure stand followed by cowpeas (*Vigna unguiculata* (L.) Walp., var. 40 dias vermelho, in pure stand

3.) Maize (*Zea mays L.*), var. Piramex, intercropped[1] with manioc

4.) Manioc mix-cropped[1] with rice

5.) Manioc mix-cropped[1] with rice and intercropped[1] with maize

Sixty days after planting, each of these subplots was further divided, each half receiving 300 kg ha^{-1} of K_2O in the form of KCl. Half blocks measured 19.2m x 48m. Subplots measured 19.2m X 9.6m. Sub-subplots measured 9.6m X 9.6m.

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1. The terms mix-cropping and intercropping are used here according to the definitions of Ruthenberg (1971). The reader is referred to Chapter Two.

Crops were planted at the following spacings and densities:

Manioc - 1.2m X 1.2m or 6944 plants ha^{-1}. One 20 cm planting piece was used per hill, and planted horizontally.

Cowpeas - 0.5m X 0.3m with 3 seeds per hill or 66,666 plants ha^{-1} or 200,000 plants ha^{-1}

Rice - 0.3m X 0.15m with five seeds per hill, giving 222,222 hills ha^{-1} or 1,111,111 plants ha^{-1} for pure stands. When mix-cropped with manioc, three of every 32 rice hills were replaced with one manioc plant. Hence, in the rice-manioc mixed cropping treatment, there were 201,388 rice hills and 1,006,943 rice plants ha^{-1}. In the treatment with rice, maize, and manioc, an additional eight rice hills of every 32 were placed with eight hills of maize, leaving 145,833 rice hills of 729,166 rice plants ha^{-1}.

Maize- 1.2m X 0.15m with three seeds planted per hill but thinned to one plant per hill in all treatments. A population of 55,555 maize plants ha^{-1} was obtained in all treatments in which maize was planted.

The treatments thus contained the following plant populations per hectare:

	Population (plants ha^{-1})			
Treatment	Manioc plants	Maize plants	Rice plants	Cowpea plants
Manioc in pure stands	6944			

Treatment	Population (plants ha^{-1})			
	Manioc plants	Maize plants	Rice plants	Cowpea plants
Rice in pure stands followed by cowpeas in pure stands			1,111,111	200,000
Manioc intercropped with maize	6944	55,555		
Manioc mix-cropped with rice	6944		1,006,943	
Manioc mix-cropped with rice and intercropped with maize	6944	55,555	729,166	

According to the terminology of Haizel (1974), therefore, a method similar to the replacement series of Willey and Osiru (1972) was used in the treatments containing rice: fifteen rice plants were considered the equivalent of one manioc plant and five rice plants the equivalent of one maize plant when these crops were grown in association with rice. However, in the maize-manioc combinations, an additive method was adopted: populations were the same as those used in pure stands (Haizel, 1974). Hence populations of manioc and maize remained constant in all treatments.

The experiment was set out with four replications. Two of the replications were located on an area which had been in fallow for over fifteen years; the vegetation in this area consisted of trees of over 0.5m in diameter and 20m in

height. The presence of species, such as mangoes, not native to the area in the vegetation, and evidence of previous human activities such as ridges for planting tobacco indicated that the area was by no means virgin forest. The other two replications were located on an area which had lain fallow for less than seven years. The vegetation on this area consisted of palms, less than ten meters in height. Such vegetation, known as capoeira and is quite typical of the Bragantina region, where the length of fallow under shifting cultivation seldom exceeds ten years (Sioli, 1973).

Consideration of surface (0-20 cm) soil samples taken by the author revealed little difference between the two areas, however. The mean organic matter content, determined by digestion with $K_2Cr_2O_7$ for fifty cores taken in the area of fifteen year fallow was 1.2% while it was 1.0% for 50 cores taken in the area of seven year fallow. The sum of exchangeable Ca, Mg, K, and Al determined according to the methods of the soil test laboratory of North Carolina State University with Ca, Mg, and Al being determined by extraction with KCl and K by extraction with 0.05N HCl, was approximately the same for the two areas: 2.0 me /100g soil. Al accounted for about 15% of the sum of these cations in both areas. P_2O_5 as determined by Bray II was very low in both cases, averaging 7.9 ppm in

the area of 15 year fallow and 5.5 ppm in the area of seven year fallow. Greater differences appeared when the entire profile to a 1 m depth was considered as shown below:

	Characteristics of upper 1 m of soil			
	P_2O_5 ppm	Ca+Mg+K me/100g soil	Al (me per 100 g soil)	O.M. %
Area of 15 year fallow	1.42	0.76	0.80	0.88
Area of 7 year fallow	0.97	0.67	0.53	0.54

The areas were cut and burned in October, 1973. Clearing and site selection took place in mid-January, 1974 when the author arrived at the experimental area. The area was prepared according to local practice with only the largest timber being removed. The soil was not tilled in any way previous to planting. Demarcation of the experimental area took place on Jan. 28, 1974. Dates of planting, emergence, and harvest for the different crops are presented in Table 10. Because of the interval between burning and planting, initial weed growth in the area was considerable and it was decided to weed all areas on Feb. 21 and 22. Half blocks to be weeded were weeded on March 30 (area of fifteen year fallow) and April 6 (area of seven year fallow). Maize was thinned to one plant per hill on February 28.

Soil samples were taken four times during the course of the experiment: Jan. 30-Feb. 1, 1974; April 1-6, 1974;

Table 10

Dates of planting, emergence, and harvest of crops

(all dates are 1974 unless otherwise noted)

A. DATES OF PLANTING

	Replicate	Crop: Rice	Manioc	Maize	Cowpea
Area of 15 year fallow	1	Jan. 31	Jan. 29	Feb. 8	June 27
	2	Feb. 1	Jan. 29	Feb. 8	June 27
Area of 7 year fallow	3	Feb. 5	Jan. 30	Feb. 7	June 27
	4	Feb. 6-7	Jan. 30	Feb. 7	June 27

B. DATES OF EMERGENCE

	Replicate	Crop: Rice	Manioc	Maize	Cowpea
Area of 15 year fallow	1	Feb. 6	Feb. 5-12	Feb. 12	July 1
	2	Feb. 7	Feb. 5-12	Feb. 12	July 1
Area of 7 year fallow	3	Feb. 12	Feb. 5-12	Feb. 12	July 1
	4	Feb. 13	Feb. 5-12	Feb. 12	July 1

C. DATE OF HARVEST

	Replicate	Rice	Manioc (1975)	Maize	Cowpea 1st. har.	Cowpea 2nd har.
Area of 15 year fallow	1	May 18	Feb. 10	June 22	Sept. 5	Oct. 10
	2	May 22-23	Feb. 11	June 22	Sept. 5	Oct. 10
Area of 7 year fallow	3	May 27	Feb. 12	June 22	Sept. 5	Oct. 10
	4	June 2	Feb. 13	June 22	Sept. 5	Oct. 10

Aug. 8-15, 1974; and Feb. 12-19, 1975. Five separate composite samples were taken in each subplot or sub-subplot, consisting of the 0-20, 20-40, 40-60, 60-80, and 80-100 cm depths. Each composite sample was composed of five cores. For the first two samplings, taken prior to the application of potassium fertilizer, all subplots were sampled. For the last two sampling dates, all sub-subplots were sampled.

Potassium fertilization, using 4.6 kg of KCl per sub-subplot (299.48 kg K_2O ha $^{-1}$) took place on April 7, 1974. The KCl was broadcast on each plot without incorporation. Some burning of rice and maize was noted following this application but the plants recovered completely within two weeks.

Maize tasseled on April 10. Rice attained 50% flowering on May 2 (Replicates 1 and 2) and May 5 (Replicates 3 and 4). Harvest dates are given in Table 10.

Following rice and maize harvest, all cereal straw was flattened in accordance with local practice and all plots weeded. All residues were left on all plots. Since plots planted to pure stands of rice would otherwise have been idle for the remainder of the experiment, it was decided to plant cowpeas on them. No further treatments were applied to any of the plots until the time of manioc harvest.

Harvested areas were 10.08 m^2 for all crops except cowpeas for which a 24m^2 area was harvested. The experimental design allowed for the sampling of non-contiguous areas of 1.44 m^2 at monthly intervals for determination of dry matter production in each sub-subplot. Although such areas were generally harvested, drying facilities at the Tracuateua Experiment Station did not prove adequate for satisfactory drying of samples.

c.) Analytical Methods

At the time of manioc harvest, the production of manioc leaves, stems, and roots and of weeds from such 1.44 m^2 areas of each sub-subplot were taken and weighed, dried in cloth bags at 70 C and reweighed.

These samples were then ground in a Wiley No.1 Mill using a 0.5 mm screen. Drying and grinding were carried out at the Food and Forest Technology Sector (Setor de Tecnologia), of EMBRAPA in Belém, Pará, Brazil. At the service laboratory of the Department of Agronomy of Cornell University, these samples were redried and a 1 g sample taken for Mg, K, and Ca determination by the following method: The sample was dry-ashed in a silica crucible, dissolved in 3 ml conc HCl and brought to a volume of 10 ml. A 0.5% La solution was added and the determination made with a Jarrel-Ash Atomic Absorption Spectrophotometer (Jarrel-Ash Corp.; Waltham, Mass.).

Grain weights of rice, maize, and cowpeas were corrected to 14, 15, and 13% moisture respectively after determining moisture content of the grain produced by each sub-subplot with an Overton Mark V moisture tester (Seedburo Equipment Co.; Chicago, Ill.). Tiller number and 1000 grain weight of rice were determined in each sub-subplot. Cob number and weight were determined for all maize sub-subplots. Fresh weight of roots and tops, root number, and manioc meal yield produced according to local methods were determined in each sub-subplot in which manioc was grown. Manioc meal was produced by peeling, grating, pulping, squeezing, sieving, and toasting the roots. Weeds were harvested in each sub-subplot.

Soil samples were air-dried, crushed with a rolling pin on a leather covered table, and sieved with a Tyler 10 sieve (USBS 12 - 1.68 mm diameter) (RODOTEST; Telasten Ltda. Brazil). Thus, analyses were done on a <1.68 mm fraction rather than a <2 mm fraction. However, very little material failed to pass the 1.68 mm sieve. The first two samplings were analyzed by the Soils Section of the representation of EMBRAPA in Belém, Pará, using the methods described earlier in this section. However, it was decided to complete the analyses at Cornell University so all samples were shipped to Ithaca, New York where the 0-20, 20-40, and 60-80 cm samples from each sub-subplot for all four dates of sampling were analyzed for exchange-

able K and Mg, available P, and pH by the soil test laboratory of the Department of Agronomy using rapid soil test procedures (Greweling and Peech, 1965).

Statistical analyses were performed by conventional analysis of variance techniques using F-tests and t-tests at p=0.05 as criteria of significance unless otherwise stated.

As the weights of harvested protions of the different crops did not appear to be very comparable, conversion to production of kilocalories and protein production per unit area was performed using the following conversion figures (Nicholls, 1961):

	per 100g	
	kcal	protein(g)
Maize whole (11.5% moisture)	360	10.0
Rice, highly milled (60% milling yield assumed)	349	7.0
Cowpeas (10% moisture)	281	24.0
Manioc root (62% moisture)	144	0.7

Value of products was calculated using prevailing local prices in the Bragantina region in Jan., 1975, which were as follows: Maize-NCr$2 per kg; Manioc meal-NCr$2.50 per kg; Rough rice-NCr$2 per kg; Cowpeas-NCr$4 per kg. In Jan., 1975 $1.00(U.S.)=NCr$8.

5.4. Results

Precipitation data, taken at the Tracuateua Experiment Station during 1974 and those published by Penteado (1967) and Bastos (1972) are presented in Table 11. Although there appears to have been considerably more rainfall in 1974 than in the year or years[1] on which the data presented by Bastos are based, the same trends are evident: eight months with more than 100 mm of rain and four months with less. It is also evident from the data that moisture stress may only have occurred during the August-November period and would thus only have affected the cowpeas and the manioc.

The only evidence of severe insect or disease attack appeared on the cowpeas which were considerably damaged by armyworms (probably Spodoptera spp.) but since no pesticides had been applied to any other crop in the study, it was decided to use no control measure. Occasional plants of manioc showed evidence of bacterial wilt (Pseudomonas spp. or Xanthomonas manihotis) but none of these were within the area harvested for yield. Almost all plants showed symptoms of brown leaf spot, (Cercospora henningsii) but the absence of this disease would be more remarkable than its presence and is usually considered not to affect yields (Lehman, 1972). The manioc showed no other evidence of damage by insects

1. No statement is made concerning the number of years on which the data are based.

Table 11

Precipitation Data for Tracuateua

(From Different Sources)

	Precipitation (mm)		Number of Rainy Days	
Months	Bastos 1972	Observations 1974	Penteado 1967	Observations 1974
January	206	322.6	17	24
February	394	423.8	23	28
March	483	846.2	27	29
April	501	543.5	27	26
May	353	543.1	27	30
June	207	406.0	24	27
July	227	253.5	23	25
August	119	70.6	15	9
September	36	36.2	7	4
October	13	1.5	3	1
November	9	5.0	2	1
December	81	139.0	5	10
TOTAL	2629	3598.2	200	214

or diseases. The leaves of the maize showed considerable symptoms of what the plant pathologist[1] of the state representation of EMBRAPA in Belém identified as Curvularia spp. It appeared to the author that maize plants were more severely affected in the area of seven year regrowth than in the area of fifteen year regrowth although no indices of disease severity were measured. No differences in disease incidence with cropping or management treatments were obvious, however.

The leaves of almost all rice plants showed leaf spots characteristic of brown spot (Cochliobolus miyabeanus, Ito et Kuribayashi, Drechsler ex Dastur) as the disease is quite common in the Bragantina region where sandy soils of low fertility, high rainfall, and low insolation provide ideal conditions for development of the disease (Padmanabhan, 1973; Ou, 1972). Indices of disease severity based on the scale proposed by Aluko (1979) were taken in all sub-subplots. However, specks larger than 1 cm in diameter were never noted, which would correspond to R (resistant) on the scale of Aluko. Parallel studies by Dr. Prabhu in areas adjacent to the experimental area showed this variety to possess a moderate degree of resistance to brown spot although severe infection did develop on other varieties in his study. Hence, using the

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1. Dr. Anne S. Prabhu, present address: Centro Nacional de Pesquisa de Arroz e Feijão, Goiania, GO, Brazil, who informed the author that the disease is widespread among maize in the Bragantina region.

scale of Aluko, no differences could be noted in the degree of severity of the disease in the different cropping and management treatments since in all cases disease incidence was slight. The author had previously speculated that brown spot would not be a serious problem if resistant local varieties were planted at the beginning of the rainy season.

A more laborious method, that of counting the number of rice leaves in each sampling area (1.44 m^2) affected by brown spot, was also used to determine the extent of disease incidence. Counts were made 70 days after emergence of the rice. The results of these counts were as follows:

Treatment	Percent of rice leaves with symptoms of brown spot	
	Area of fifteen year fallow	Area of seven year fallow
Rice in pure stand	0.80	1.78
Rice mix-cropped with manioc	0.12	2.79
Rice mix-cropped with manioc and intercropped with maize	3.63	6.52

(Based on eight replicates)

It can be seen that more leaves were affected when rice was associated with maize and manioc than when grown in pure stand or when associated only with manioc. The increased shading provided by the maize probably provided a better environment for disease development. It should also be noted

that disease incidence was greater on the area of seven year fallow than on that of fifteen year fallow. The association of the disease with low soil fertility has frequently been noted (Ou, 1972).

No other diseases or pests were observed on the leaves or panicles of the rice.

Mean yields of the different crops from the different treatment combinations and the kilocalorie, protein, and monetary equivalents of such yields are given in Table 12. Becasue of the complexity of the tests of significance for the split-split plot design (Little and Hills, 1972), not all significant treatment differences could be indicated in the table.

In the case of rice yields, the effects of cropping system and potassium were significant. The effects of weeding and all interactions were insignificant. It can be seen that rice yields in pure stands did not differ significantly from those in the rice-manioc combination although both of these systems produced significantly more rice than the treatment in which rice, manioc, and maize were grown together. The increases in rice yield due to potassium application were only significant in the case of

Table 12

Yields of crops, production of kilocalories and protein, and value of produce produced by different cropping and management systems

(Means of four replicates)

	Rough Rice kg/ha 14% M	Maize kg/ha 13% M	Cowpea kg/ha 15% M	Manioc Roots fresh weight kg/ha	Energy Kcal/m^2	Protein g/m^2	Value NCr/ha
Manioc in pure Stand							
-K unweeded				3336	480	2.35	1475
+K unweeded				2953	425	2.05	1748
-K weeded				5421	781	3.83	3210
+K weeded				5825	839	4.10	3449
Mean				4387d	631e	3.09p	2595x
Rice in Pure Stand, Followed by Cowpea							
-K unweeded	1299		508m		446	17.71	4654
+K unweeded	1692		500m		539	19.16	5412
-K weeded	1509		209m		389	11.28	3703
+K weeded	1907		295m		504	15.16	5028
Mean	1601a		378		470f	15.83q	4699z

Table 12, Continued

	Rough Rice kg/ha 14% M	Maize kg/ha 13% M	Cowpea kg/ha 15% M	Manioc Roots fresh weight kg/ha	Energy Kcal/m^2	Protein g/m^2	Value NCr/ha
Manioc Intercropped with Maize							
-K unweeded		125k		2348	383	2.92	1642
+K unweeded		270k		3638	619	5.29	2694
-K weeded		397k		3971	741	6.19	3236
+K weeded		439k		5460	938	6.44	4121
Mean		308q		3846d	670e	5.21sp	2923rx
Rice Mix-Cropped with Manioc							
-K unweeded	1287			3110	721	7.64	4436
+K unweeded	1571			2952	763	8.73	4916
-K weeded	1490			3980	998	9.12	5827
+K weeded	1635			4850	967	10.34	5845
Mean	1495a			3723d	862n	8.96t	5256z

Table 12, Continued

	Rough Rice kg/ha 14% M	Maize kg/ha 13%	Cowpea kg/ha 15% M	Manioc Roots fresh weight kg/ha	Energy Kcal/m^2	Protein g/m^2	Value NCr/ha
Rice, Maize, Manioc Mix-Cropped							
-K unweeded	331	72j		3654	622	4.71	2976
+K unweeded	489	99j		3792	684	5.71	3481
-K weeded	763	122j		3447	707	6.33	3845
+ weeded	779	23j		4496	821	6.70	4278
Mean	589b	79h		3847d	708e	5.86s	3644r

Values followed by the same letter do not differ significantly at p=0.05 by Duncan's multiple range test. Because of the complexity of the tests of significance for the split-split plot design, not all significant differences are indicated.

pure stands, where the increases were significant in both weeded and unweeded treatments.

In the case of maize, maize intercropped with manioc yielded significantly more than maize intercropped with manioc and rice. Other factors and interactions were not significant.

With cowpeas, no factors or interactions affected yields significantly. The large negative response to weeding did not attain significance because of the small number of degrees of freedom available for the comparison.

Manioc yields are unusually low for the crop and fresh weight of roots did not show a significant response to either weeding, cropping system, or potassium. Other yield related factors have been presented in Table 13. Meal weight, root number, and root-stem ratio (determined on the basis of dry weight) did not show any significant response to any of the main effects or their interactions. However, fresh weight of above ground parts, hence referred to as fresh stem weight, showed a significant response to weeding and to potassium application. Fresh stem weight from weeded plots averaged 12,858 kg/ha as opposed to 9159 kg/ha for unweeded plots. Fresh stem weights for plots receiving potassium averaged 12,027 kg/ha as against 9991 kg/ha for unfertilized plots. There was no response to cropping system

Table 13

Fresh weight of roots, meal weight, root number, fresh weight of above **ground parts**, and mean root weight of manioc in treatments where it **was** cropped. (Means of four replications)

Treatment	Fresh Weight of Roots kg/ha	Meal Weight kg/ha	Number Roots per 10 m^2	Fresh Weight of Above Ground Parts kg/ha	Root/ Stem Ratio (Dry weight)	Mean Root Weight g
Manioc in Pure Stand						
-K Unweeded	3363	706	20.25	8593	0.5025	159.25
+K Unweeded	2977	843	19.25	9172	0.4395	158.00
-K Weeded	5465	1392	29.00	13853	0.5256	187.25
+K Weeded	5872	1470	25.75	16382	0.4821	229.50
Mean	4419	1103	23.56	12000	0.4874	183.50
Manioc Mix-Cropped with Rice						
-K Unweeded	3135	551	25.50	8480	0.4913	120.75
+K Unweeded	2976	503	19.75	9594	0.5569	149.75
-K Weeded	4806	1093	29.25	9406	0.6826	166.00
+K Weeded	4340	1134	26.25	12638	0.4793	166.25
Mean	3814	843	25.19	10029	0.5525	150.69

Table 13, Continued

	Fresh Weight of Roots kg/ha	Meal Weight kg/ha	Number Roots per 10 m^2	Fresh Weight of Above Ground	Root/ Stem Ratio (Dry weight)	Mean Root Weight g
Manioc Intercropped with Maize						
-K Unweeded	2368	822	19.75	7064	0.4348	118.00
+K Unweeded	3659	736	24.00	10268	0.4757	145.25
-K Weeded	4149	1081	27.50	11058	0.5208	152.00
+K Weeded	5505	1153	28.50	14832	0.5422	196.50
Mean	3920	948	24.94	10805	0.4934	152.94
Manioc, Intercropped with Maize and Mix-Cropped with Rice						
-K Unweeded	3684	920	26.00	9523	0.5082	140.00
+K Unweeded	3823	825	21.00	10580	0.4502	169.50
-K Weeded	3506	760	28.00	11949	0.4414	130.75
+K Weeded	4532	1018	29.25	12753	0.4904	155.25
Mean	3886	871	26.06	11201	0.4725	148.88
C.V. (%)	27.89	30.49	21.75	24.75	18.25	23.39

and none of the interactions were significant. Mean root weight, determined by dividing fresh root weight by root number in each sub-subplot, also showed a significant response to weeding and to potassium application. The interaction between weeding and cropping system was significant for both mean root weight and for total fresh weight of roots and is shown in Table 14. It can be seen that both total fresh root weight and weight per root were significantly lower for the manioc-maize-rice combination than for the pure stand manioc when weeding was practiced but there was no significant difference in the absence of weeding. Weeding appears to have improved manioc performance in pure stands as compared to where the manioc was grown in simultaneous polyculture. When weeded, mean tuber weight in pure stands was significantly higher than all other treatments although it was significantly higher than only the maize-manioc combination in the absence of weeding.

In general, it may be stated that rice and manioc both tended to produce slightly more in pure stands than when the two crops were grown together, but the difference was not significant. Hence, the combined yeild of the species in simultaneous polyculture was always greater than would have been produced by two half hectare pure stands of each crop.

TABLE 14

Weeding X cropping system interaction for fresh weight of roots and mean weight of roots (Means of eight replications)

Treatment	Fresh weight of roots kg/ha	Mean weight of roots g.
Unweeded		
Manioc in pure stand	3170 a	158.63 d
Manioc intercropped with maize	3013 a	131.63 e
Manioc mix-cropped with rice	3055 a	135.25 ed
Manioc intercropped with maize and mix-cropped with rice	3755 a	154.75 ed
Weeded		
Manioc in pure stand	5668 b	208.38 f
Manioc intercropped with maize	4826 bc	174.25 g
Manioc mix-cropped with rice	4572 bc	166.13 gh
Manioc intercropped with maize and mix-cropped with rice	4019 c	143.00 h

Values followed by same letter do not differ significantly at p=0.05 by Duncan's multiple range test.

The advantages of simultaneous polyculture was further shown by consideration of the kilocalorie, protein, and economic value of the production of the different sub-subplots. When these parameters were analyzed statistically, cropping system, potassium, and the weeding X cropping system interaction were found to be significant in all cases. These results have been summarized in Table 15. From the point of view of kilocalorie production per m^2, the superiority of the rice-manioc combination was evident. Considering protein production per m^2, pure stand rice followed by cowpeas was best, especially if no weeding is practiced. However, this was the only treatment to contain cowpeas whose protein content is more than twice that of the other species. The rice-manioc combination gave the greatest cash value, being almost equalled in this respect by pure stand rice followed by pure stand cowpeas especially if weeding were not practiced.

A similar benefit of simultaneous polyculture appeared if the total dry matter, crop dry matter, and weed dry matter were analyzed statistically. Since the measurements were only taken at the time of manioc harvest, the rice and maize stover were not included but such a procedure may be justified on the grounds that they were not removed from the plots. Also, the manioc above-ground portions were considered as part of the crop dry matter. It should be clear that both of

Table 15

Effect of cropping system, potassium fertilization, and interaction of weeding X cropping system on production of kilocalories/m^2, g protein/m^2, and value of production.

A. Cropping System	kcal/m^2	Protein g/m^2	Value NCr/ha
Manioc in pure stand	631.31 b	3.09 k	2595 s
Rice in pure stand followed by cowpeas in pure stand	469.50 c	15.82 h	4699 q
Manioc intercropped wit maize	670.12 b	5.21 jk	2923 rs
Manioc mix-cropped with rice	862.25 a	8.96 i	5256 q
Manioc intercropped with maize and mix-cropped with rice	708.43 b	5.86 j	3645 r
	-means of sixteen replicates-		
B. Effect of Potassium Fertilization			
Without potassium	626.65*	7.21*	3550**
With potassium	710.00	8.37*	4097**
	-means of thirty-two replicates-		

* differ significantly at p=0.05
**differ significantly at p=0.01

Values followed by same letter do not differ significantly at p=0.05 by Duncan's multiple range test.

Table 15, Continued

	kcal/m^2	Protein g/m^2	Value NCr/ha
C. Interaction: Weeding X System Unweeded			
Manioc in pure stand	452.75 f	2.22 c	1862 o
Rice in pure stand followed by cowpeas in pure stand	492.63 f	18.44 a	5033 m
Manioc intercropped with maize	500.88 f	4.10 c	2168 o
Manioc mix-cropped with rice	742.00 e	8.18 b	4676 m
Manioc intercropped with maize and mix-cropped with rice	652.75 ef	5.20 bc	3229 n
Weeded			
Manioc in pure stand	809.83 dg	3.96 f	3329 u
Rice in pure stand followed by cowpeas in pure stand	446.38 l	13.22 d	4365 u
Manioc intercropped with maize	839.38 dg	6.31 ef	3679 u
Manioc mix-cropped with rice	982.50 d	9.73 de	5836 t
Manioc intercropped with maize and mix-cropped with rice	764.13 g	6.51 ef	4061 u

-means of eight replicates-

these procedures should have created a bias in favor of the treatments with manioc in pure stands. Nevertheless, as shown in Table 16, the greatest crop and total dry matter were always produced by manioc mix-cropped with rice. In the case of crop dry matter, the rice-manioc combination produced significantly more crop dry matter than the pure stand manioc, once again illustrating the greater productivity of simultaneous polyculture.

It was noted that the first two replications were located on an area of fifteen year fallow and the second two on an area of seven year fallow. Some difference in soil characteristics were noted; but it was shown that the differences in organic matter content and exchangeable bases were somewhat less than might have been expected, especially in the 0-20 cm depth. It was thought of interest to see if there were any yield differences between the two areas. Rice yields and manioc stem fresh weights showed a significant effect for replications while maize and cowpea yield and manioc root fresh weight did not. The effect of replications was also insignificant for kcal/m^2, g protein/m^2, and for value of produce. These results would indicate that the effect of area on yields was not of great importance although it should be noted that those factors which varied

TABLE 16

Effect of cropping system on total dry matter production, crop dry matter production, weed dry matter production, and crop as percent of total dry matter production.

-mean of eight replicates-

Cropping System	Total Dry Matter kg/ha	Crop Dry Matter kg/ha	Weed Dry Matter kg/ha	Crop as percent of total dry matter %
Manioc in pure stand	7774	4506	3317	58.8
Rice in pure stand followed by cowpeas in pure stand	7429	1852	2898	39.8
Manioc inter-cropped with maize	7712	4924	2787	62.9
Manioc mix-cropped with rice	8880	5779	3101	65.6
Manioc inter-cropped with maize and mix-cropped with rice	8020	5008	3037	62.2
l.s.d., p=0.05	1664	1054	1507	13.1

significantly with replicates were those which were not abnormally low so that soil fertility might have been more important in these cases. In Table 17, the mean soil test values for the 0-20 cm and 0-100 cm depths together with the yields of the different crops and other measures of productivity for each replicate have been given. The first replicate was higher than the other replicates for all values but differences among the other replicates were small even though the second replicate was also located in the area of fifteen year fallow. There was nothing in the soil test values or the yields obtained from the second replicate to indicate that it differed in any way from the replicates located in the area of seven year fallow.

Since the soil test values were available for each sub-subplot, it was thought to be of value to see if any of these were correlated with the yields obtained. Linear correlations found to be significant have been presented in Table 18. Unweeded plots were separated from weeded plots because of the differences in response previously noted. Bray II available phosphorus and total base status (exchangeable Ca^{++}, Mg^{++}, and K^{+})[1] were significantly correlated with

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1. Values obtained by the soil testing laboratory of the Soils Section of the state representation of EMBRAPA were used for these correlation studies since they included values for soil organic matter and exchangeable aluminum which were not determined by the Cornell University, Department of Agronomy soil testing.

Table 17

Mean values of Bray II available P, exchangeable bases, exchangeable Al, and organic matter in soil samples from 0-20 and 0-100 cm depths and of crop yields, kilocalorie, and protein production for each replicate

A. Soil test values for 0-20 cm depth

Replicate[1]	Bray II P ppm	Exchangeable K+Mg+Ca (me/100g soil)	Exchangeable Al (me/100g soil)	Organic Matter %
1	7.90	1.72	0.30	1.21
2	5.57	1.24	0.51	1.06
3	5.78	1.57	0.16	1.11
4	5.50	1.80	0.28	1.10

B. Soil test values for 0-100 cm depth

Replicate[1]	Bray II P ppm	Exchangeable K+Mg+Ca (me/100g soil)	Exchangeable Al (me/100g soil)	Organic Matter %
1	2.84	0.76	0.80	0.88
2	1.86	0.47	0.95	0.73
3	1.98	0.50	0.64	0.81
4	2.77	0.67	0.64	1.09

C. Crop yields

Replicate	Rice grain yield kg/ha	Maize grain yield kg/ha	Cowpea grain yield kg/ha	Manioc root fresh weight kg/ha	Manioc above ground parts fresh weight kg/ha
1	1325	320	362	5188	15051
2	1453	225	552	3373	10824
3	1123	56	209	3732	8113
4	1052	140	257	3746	10047

1. Replicates 1 and 2 from area of 15 year fallow. Replicates 3 and 4 from area of seven year fallow.

Table 17, Continued

D. Production of kilocalories and protein

Replicate	protein g/m^2	kilocalories per m^2
1	9.82	845
2	9.00	637
3	5.99	593
4	6.32	596

Table 18

Significant linear correlation coefficients for soil test values[1] and measures of productivity.

Dependent variable	Independent variable	r	Probability Correlation Due to Chance	d.f
A. Unweeded Treatments				
Manioc root fr. wt.	0-20 cm P	0.867	0.0001	12
Manioc root fr. wt.	0-100 cm P	0.877	0.0001	12
Manioc root fr. wt.	0-100 cm K+Mg+Ca	0.717	0.004	12
Manioc tops fr. wt.	0-20 cm P	0.639	0.013	12
Manioc tops fr. wt.	0-100 cm P	0.653	0.011	14
Manioc tops fr. wt.	0-100 cm K+Mg+Ca	0.731	0.003	12
Weed dry wt.	0-100 cm % O.M.	0.5222	0.0315	15
Weed dry wt	0-100 cm K+Mg+Ca	0.6228	0.0076	15
Kcal m^{-2}	0-20 cm P	0.6228	0.0076	15
Kcal m^{-2}	0-100 cm P	0.655	0.0043	15
Kcal m^{-2}	0-100 cm K+Mg+Ca	0.601	0.0107	15
B. Weeded Treatments				
Maize grain yield	0-20 cm Al	0.826	0.0210	5
Weed dry wt	0-20 cm P	0.606	0.0127	14

1. At first time of sampling

yield of manioc roots and tops and with total kilocalorie production in the non-weeded treatments. No such correlations were observed for maize and rice yields. The higher correlations obtained in the non-weeded plots may have been due to greater competition for these elements in non-weeded plots. The negative correlation of maize yields with the exchangeable aluminum of the 0-20 cm depth was considered interesting in the light of the fact that Al toxicity is more frequently reported in maize than in rice or manioc (Pearson, 1975).

Various significant effects of cropping and management systems on manioc and weed composition were found. Significant effects of potassium application and cropping system on K content in manioc plant parts have been presented in Table 19. Potassium application significantly affected the K content of manioc roots, stems, and leaves and of the plant as a whole. Simultaneous polyculture of manioc with rice significantly lowered the K content of the manioc stems as compared to the pure stand manioc or the manioc intercropped with maize. Potassium content in the manioc roots showed a significant interaction of cropping system with potassium application. In the absence of potassium fertilization, there was no difference in potassium levels of the manioc roots for the different cropping systems. When potassium was applied,

Table 19

Significant main effects and interactions on K content of manioc plant parts on dry weight basis

A. Effect of potassium fertilization on K content of manioc plant parts

Treatment	Plant Parts			
	Roots %	Stems %	Leaves %	Whole Plant %
No K applied	0.641	0.569	2.098	0.718
K applied	1.009	1.109	2.702	1.241
l.s.d. p=0.05	0.107	0.161	0.210	0.115
l.s.d. p=0.01	0.156	0.233	0.305	0.169

B. Effect of cropping system on K content of manioc stems

Treatment	K content of manioc stems
Manioc in pure stand	0.8688 a
Manioc intercropped with maize	0.9838 a
Manioc mix-cropped with rice	0.6613 b
Manioc intercropped with maize and mix-cropped with rice	0.8438 ab

C. Interaction of cropping system with potassium application on K content of manioc roots

Treatment	K content of manioc roots (%)	
	without K applied	with K applied
Manioc in pure stand	0.7425 a	0.9175 ac
Manioc intercropped with maize	0.5775 a	1.2000 b
Manioc mix-cropped with rice	0.6700 a	0.8350 a
Manioc intercropped with maize and mix-cropped with rice	0.6050 a	1.0850 bc

Values followed by same letter do not differ significantly at p=0.05 by Duncan's multiple range test.

manioc intercropped with maize showed significantly higher K content in the roots than manioc grown in pure stands or in simultaneous polyculture with rice. It should also be noted that only in the manioc-maize and manioc-maize-rice combinations was the K content of the manioc roots significantly higher when potassium fertilizer was applied than when it was not applied.

The high level of potassium fertilizer applied would be expected to depress the Mg content of the manioc plant parts. As can be seen from Table 20, this was indeed the case. Only the Mg content of the manioc leaves was not affected significantly by the application of potassium fertilizer. Even the Mg content of the weeds was significantly reduced although their potassium content had not been significantly increased by the potassium application. Weeding generally increased the Mg content of the manioc plant parts but only in the case of manioc roots was this difference significant.

The Ca content of manioc roots and of weeds from plots where manioc was grown in pure stands was significantly lower than where the manioc was grown in simultaneous polyculture with maize and rice as can be seen from Table 20. The fact that Ca content of weeds was also lower may indicate that soil erosion and hence Ca losses were greater in the plots where manioc

Table 20

Mg and Ca content of manioc plant parts and weeds as affected by potassium application and cropping system respectively (dry weight basis)

A. Mg content of manioc plant parts and of weeds as affected by application of potassium fertilizer (means of sixteen replicates)

Treatment	Mg content of plant parts on dry weight basis				
	Manioc Roots %	Manioc Stems %	Manioc Leaves %	Whole Manioc Plant %	Weeds %
without K fert.	1.181	0.263	0.716	1.324	0.322
with K fert.	0.850	0.176	0.680	1.053	0.281
l.s.d. p=0.05	0.011	0.032	0.038	0.219	0.038
l.s.d. p=0.01	0.016	0.047	0.055	0.318	0.054

B. Ca content of manioc plant parts and of weeds as affected by cropping system (means of eight replicates)

	Ca content of plant parts on dry weight basis				
	Manioc Roots %	Manioc Stems %	Manioc Leaves %	Whole Manioc Plant %	Weeds %
Manioc in pure stand	0.116 c	0.463 d	1.80 e	0.441 f	0.483 g
Manioc inter-cropped with maize	0.149 a	0.516 d	1.91 e	0.492 f	0.690 h
Manioc mix-cropped with rice	0.128 bc	0.514 d	1.68 e	0.456 f	0.644 h
Manioc inter-cropped with maize and mix-cropped with rice	0.138 ab	0.475 d	1.80 e	0.489 f	0.686 h

Values followed same letter doe not differ significantly at p=0.05 by Duncan's multiple range test.

was grown in pure stand since soil cover was poorer. Hence, less Ca should have been available to plants growing in these plots. Ca is considered to be less susceptible to leaching losses than Mg or K (Bolton, 1968).

Soil test values for exchangeable Ca and Mg at four month intervals and changes in these values over each four month period were analyzed statistically. No differences due to cropping system or weeding were found in soil Mg or K levels eight and twelve months after planting nor in changes in these levels at four month intervals. Potassium application significantly affected exchangeable soil K eight and twelve months after planting (four and eight months after potassium application). Also soils recieving potassium fertilization lost significantly more potassium than the unfertilized soils during the period from four to eight months following potassium application, as can be seen in Table 21. These levels were calculated from the test values for the 0-20 cm and 20-40 cm depths and have been expressed in terms of kg ha of Mg or K per 5,000,000 kg of soil, the approximate weight of 1 hectare of soil to a 40 cm depth assuming a bulk density of 1.25 g cm^3.[1]

Although the F test for the effect of cropping systems on Mg losses during the 0-12 month period indicated no significant effect, a t test showed that Mg losses were significantly less

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1. This method is similar to that used by Djokoto and Stephens (1961b).

Table 21

Soil potassium and magnesium levels[1] at different time intervals as affected by potassium application and cropping system

A. K level in 0-40 cm depth as affected by potassium application[2]

Treatment	8 months after planting	12 months after planting	Loss from 8th to 12th month
	K (kg per 5 X 10^6 kg soil)		
Without applied K	74.1	66.5	7.6
With applied K	173.1	110.65	60.45
l.s.d. p=0.05	17.22	17.30	21.44
l.s.d. p=0.01	23.19	23.29	28.87

B. Mg level in 0-40 cm depth as affected by potassium application[2]

	8 months after planting	12 months after planting	Loss from time of planting to 12th month
	Mg (kg per 5 X 10^6 kg soil)		
Without applied K	105.73	70.775	64.775
With applied K	93.20	70.300	64.650
l.s.d. p=0.05	13.64	15.63	14.85

1. Exchangeable values as determined by rapid soil tests (See methods) (Greweling and Peech, 1965)
2. Means of 40 replicates

Table 21, Continued

C. Mg level in 0-40 cm depth as affected by cropping system[3]

	Interval (months after planting) Mg (kg per 5 X 10^6 kg soil)			
	0-12	0-4	4-8	8-12
Manioc in pure stand	91.68	34.25	39.94	42.75
Rice in pure stand followed by cowpeas in pure stand	57.19	19.31	35.81	33.12
Manioc intercropped with maize	79.81	25.38	29.44	43.31
Manioc intercropped with maize and mix-cropped with rice	59.50	36.25	26.88	42.38
l.s.d. p=0.05	45.64	42.48	31.17	21.40

3. Means of 16 replicates

for soils cropped to rice mix-cropped with manioc than for soils in which manioc was grown in pure stand. These data have also been presented in Table 21. Considering the changes at four month intervals, the rice mix-cropped with manioc occasioned significantly smaller losses of soil Mg in the 8-12 month interval following planting than all of the other systems involving manioc. However, as we have seen, in no case was the Mg recovery in the manioc affected.

5.5. Discussion

a.) Greater productivity with simultaneous polyculture

The experimental results confirm the finding of other authors with respect to the benefits of simultaneous polyculture. Using the method of Donald (1963), the mean yield of the pure stands of rice followed by cowpeas and of manioc is 3229 kg/ha while the total yield of rice and manioc from simultaneous polyculture is 5213 kg/ha although, to the author at least, adding the weight of manioc roots that of rough rice seems questionalbe. The method of Evans (1960) where the yield of the simultaneous polyculture is compared to the yield of one-half hectare pure stands is perhaps more reasonable. It can be seen that manioc when mix-cropped with rice produces 3846 kg/ha of roots compared with 2194 kg for a one-half hectare pure stand. Rice mix-cropped with the manioc gives 1495 kg/ha as compared with 801 kg for a one-half hectare pure stand, to which might be added 189 kg for a half-hectare of cowpeas in pure stand. The method of Evans has been criticized on the grounds that it is biased in favor of mixtures because one of the species of the mixture uses more than one-half of the environment so that the comparison should be made with pure stands occupying the same proportion of a hectare as they do in the pure stand

(Willey and Osiru, 1972). Thus, of the total yield of 5218 kg/ha produced by the rice-manioc mixture, 1495 kg or 28.65% is rice and 71.35% is manioc. Hence, this yield should be compared the pure stand yields of 2865 m^2 of rice and 7135 m^2 of manioc. If this is done, the pure stands would produce 459 kg of rice and 3130 kg of manioc, less for both crops than the simultaneous polyculture.

The relative yield total (RYT) method of van der Bergh (1968) may also be applied to the data of the present experiment. This has been done in Table 22 where a similar attempt has been made to combine the manioc intercropped with maize treatment with the rice pure stand treatment and compare this combination with the manioc mix-cropped with rice and intercropped with maize treatment. If, as van der Bergh states, a RYT of greater than one indicates a benefit accruing from simultaneous polyculture, it can be seen from Table 22 that simultaneous polyculture indeed brings substantial benefits. An examination of the relative yields, presented in Table 22, obtained by dividing the yield of each species in simultaneous polyculture by its yield in pure stand, will show why this is the case. In all cases, rice yield in mixtures are more than 85% of what they are in pure stands. Thus, yield reduction in rice due to simultaneous polyculture is always less than 15% which is considerably

Table 22

Relative yields[1] and relative yield totals[2] for rice-manioc and rice-manioc-maize cropping systems

A. Rice mix-cropped with manioc

Cultural Practice	Relative yield of manioc r_M	Relative yield of rice r_R	Relative yield total RYT
Unweeded, -K	0.932	0.990	1.992
Unweeded, +K	0.999	0.928	1.927
Weeded, -K	0.734	0.987	1.721
Weeded, +K	0.832	0.857	1.689

B. Manioc intercropped with maize and mix-cropped with rice

Cultural Practice	Relative yield of manioc r_m[3]	Relative yield of maize r_{Ma}[3]	Relative yield of rice r_R[4]	Relative yield total RYT
Unweeded, -K	1.556	0.576	0.254	2.386
Unweeded, +K	1.042	0.366	0.283	1.691
Weeded, -K	0.868	0.307	0.506	1.691
Weeded, -K	0.823	0.052	0.408	1.283

1. Computed by dividing yield in simultaneous polyculture treatment by yield in pure stand

2. Sum of relative yields of all crops in mixture

3. Yields in manioc-maize mixture used in place of pure stand yields

4. Yield in rice-maize-manioc mixture divided by yield in pure stand

less than that observed by Andrews (1972) for millet and sorghum. Similarly, reduction in manioc yield due to simultaneous polyculture with rice is always less than 30% and in the absence of weeding less than 10%. Hence the reductions in the pure stand yields of both rice and manioc occasioned by simultaneous polyculture are small; and it is not surprising that they never attain statistical significance in the present study. It should also be noted that the relative yield totals are greater for unweeded than for the weeded treatments indicating that simultaneous polyculture brings greater benefits in the absence of weeding.

Other methods of measuring the benefits of simultaneous polyculture such as the competition index (Donald, 1963) and the relative crowding coefficient (de Wit, 1960) cannot be applied to the present data since all of the necessary data for their application have not been obtained. As was pointed out in Chapter One, the competition index requires growing different densities of each species in pure stand in order to find the numbers of one species which should provide the same degree of competition as one individual of the associated species. The relative crowding coefficient is only applicable to sown mixtures.

b.) Reasons for low yields

The value of the present experiment is somewhat diminished by the low yields of manioc and maize obtained. The low yields of manioc may be due to poor choice of variety, low soil fertility, excessive weed growth, pests or diseases, low plant populations, or early harvest of the manioc. Manioc yields are reported as being 9013 kg/ha of fresh roots for the Bragantina region and 5950kg/ha for the Braganca township (SUDAM, 1970), yields which are not very much higher than those obtained in the experiment. Unfertilized plots in experimental studies in the literature generally yield about 10,000 kg/ha (Tan and Bertrand, 1972) but will vary with the soils concerned and much higher values are often reported (Takyi, 1974a, 1974b)

The variety used in this study, which was the only one available in sufficient quantity at the time the experiment was planted, has some undesirable characteristics. While a high yield in manioc is supposed to be associated with a root: stem ratio of 1:1 or greater (Tan and Bertrand, 1972; Enyi, 1973b), it can be seen from Table 13 that the values obtained in the experiment were generally less than 0.5:1. Indeed, had the root:stem ratio been 1:1 and the same above-ground production been obtained, the root yields would have been quite acceptable. The fact that stumps were not removed from the

area and that the area was not ploughed or harrowed, as is generally practiced in growing manioc in experimental studies, may have had some effect on root development, Ofori (1973b) reports significant yield increases in manioc as a result of ploughing a granite-derived forest ochrosol of sandy loam texture although yields in the absence of ploughing are still more than 15,000 kg fresh roots /ha. However, he reports that experimental area had previously been cropped and fertilized so the situation is not comparable to the present experiment where large tree roots were present in the soil which might have inhibited manioc root development. It can be seen from Table 13 that mean root weight in the present experiment was always less than 200g while Ofori (1973b) reports mean root weights of over 400 g. A revised version of the present experiment incorporating land preparation treatments has been set out at the Tracuateua Experiment Station;but as the author left the area in May, 1975, he has no idea of the results. However, it appears that sheet erosion is more problematic in the area when stumps are removed and the area disked.

The fact that yields of above-ground parts of the manioc are not abnormally low casts some doubt on the hypothesis that soil fertility was limiting to manioc production in the experiment. Yields of rice grown in the same area are not

abnormally low. On the other hand, yields of both manioc roots and tops are highest in the first replicate where available phosphorus was considerably higher and organic matter slightly higher than in the other replicates. Also yields of manioc roots and above-ground parts, but not rice yields, are correlated with soil phosphorus levels and with the sum of exchangeable bases in the 0-100 cm depth. But, manioc does not seem to have a very high requirement for phosphorus (Tan and Bertram, 1972) and does not seem to respond to phosphorus in field experiments (Djokoto and Stephens, 1961a; Ofori, 1973a, 1973b). In conclusion, since manioc above-ground parts showed no sign of deficiency and responded to potassium, there is little possibility of low soil fertility being responsible for the abnormally low yields.

It has been pointed out that high incidence of pests and diseases were not noted on the manioc; so it is unlikely that these were a factor in the low yields. The plant populations used (6944 plants per hectare) are probably somewhat low. Williams (1972) shows increasing yields with populations up to 25,000 plants per hectare for three Malaysian manioc cultivars; while Enyi (1972b) reports increasing yields up to 18,500 plants per hectare for two varieties but decreasing above 12,346 plants per hectare for another variety,

on a rather heavily fertilized (N-P_2O_5-K_2O:70-125-50 kg/ha) clay loam. Lower densities (about 10,000 plants per hectare) are generally recommended on poor soils, however (Tan and Bertrand, 1972). Yet, in a study of the interaction of spacing, liming, and K fertilization, carried out on a forest ochrosol which had been cropped continuously for fifteen years[1], Takyi (1972) reports a 20% yield increase as plant densities increase from 8966 plants per hectare to twice that population. The response does not vary with lime and K application.

It is likely that weed growth in the present study would have been less if higher manioc populations had been used. The fact that there was no effect of weeding on weed growth would indicate that most of the weed growth occurred after the last weeding, approximately five months after the manioc was planted. It can be seen (Table 16) that weed growth was approximately the same for all cropping treatments, even for the plots with rice in pure stands followed by cowpeas where most of the weed growth should have taken place only in the last four months of the experiment. It would probably have been better to have planted twice the population of manioc than that used in the experiment, which could have easily

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1. Soil analytical data: pH-5.5; O.M.-1.79%; available P_2O_5 (Bray and Kurtz) 41.4 lbs/A; C.E.C.-5.39 me/100g; bases me/100g): Ca-2.26; Mg-0.49; Mn-0.14; K-0.17; Na-0.15; (Takyi, 1972).

been done by using 1.2 X 0.6 m spacing, which still allows easy planting of associated crops although only intercropping, not mixed cropping would be possible with such a spacing. Such a procedure has been used in the follow-up experiment referred to above.

Although it is doubtful that leaving the manioc in the ground for a few more months would have considerably increased yields, it should be noted that Takyi (1974b) reported an increase of over 25% of the yield at twelve months by harvesting at fifteen months. The growth period for maximum yield appears to vary considerably with variety, however; and Singh, Kumar, Mandal, and Magoon (1970) report several varieties which gave maximum yield if harvested ten months after planting.

It can be concluded that the choice of variety and the low plant populations used are probably most responsible for the low manioc yields. Soil fertility is probably of secondary importance.

Maize yields, on the other hand, are probably low due to excessively high plant populations. Maize does not perform well in the Bragantina region, with mean yields being about 500 kg/ha; while the production of the Bragança township is not even listed in the most recent agricultural census

figures (SUDAM, 1970). High rainfall during tasseling, diseases, and low fertility are the most frequently cited causes of low yields; and wide spacing (approximately 20,000 plants/ha) are used by farmers to offset the effect of low fertility and possibly create a less favorable environment for disease development. As high populations in maize often lead to barren plants (Duncan, 1969), it is not surprising that many plants did not produce ears. The author also feels that local varieties perform better than the one used which is, however, recommended by the state representation of EMBRAPA.

Cowpea yields are satisfactory for treatments in which the rice was not weeded. Although this effect did not attain significance, the yield difference is considerable (Table 12). The author speculates that there were more nutrients available to the cowpeas in those treatments where the rice was needed since the rice yields were somewhat lower leaving more nutrients to be returned to the plots. It has been pointed out that the cowpeas were considerably defoliated by insects which should also have reduced yields. It should be noted that this cowpea variety, being of indeterminate habit, produces two harvests if moisture is adequate after the first harvest.

c.) Causes of benefits accruing from simultaneous polyculture

It has been proposed that in a humid tropical area where soils are of low fertility, simultaneous polyculture may be of value in producing better soil cover, reducing competition from weeds and reducing nutrient losses due to leaching and erosion (Miracle, 1967).

1. Weed control

The cropping system X weeding interaction has been shown to be significant for fresh weight of manioc roots, mean weight of manioc roots, protein and calorie production, and value produced per hectare. Consideration of these results shows that pure stands of manioc produced a greater fresh weight of roots per hectare and greater weight per tuber than simultaneous polyculture only when weeding was practiced. Simultaneous polyculture does not take the place of weeding; but in the absence of weeding, the advantages it brings are greater. This result is also shown by examination of the relative yield totals in Table 22 which are greater when weeding is not practiced.

The effect of weeding on kilocalorie production is more complex. The rice-manioc combination is superior to all other treatments except the rice-manioc-maize combination in

absence of weeding but is not statistically superior to pure stand manioc or to manioc intercropped with maize if weeding is practiced. In the case of value of produce, the situation is complicated by the fact that cowpeas did better if the rice preceding the cowpeas was not weeded with the result that the rice-manioc combination was superior to all treatments except the rice-cowpea sequence if weeding were not practiced, but superior to all other treatments if it were. Although the rice-cowpea sequence produced the most protein per m^2 because of the presence of the legume, the rice-manioc combination was superior in this regard to all treatments not containing rice in the absence of weeding but only to manioc in pure stand if weeding were practiced (Table 15).

The general superiority of the rice-manioc combination is also shown in terms of total crop dry matter (Table 16) where it is statistically superior to manioc in pure stands although total weed dry matter does not differ. Again, it can be seen that a greater proportion of the total dry matter produced is crop in the case of simultaneous polyculture than with either of the pure stand treatments although this difference does not attain statistical significance.

In summary, the evidence for better weed control with simultaneous polyculture is at best indirect because no dimunition of weed growth was obtained by simultaneous polyculture. But, since crop dry matter production is increased, the total dry matter production is greater and the proportion of the

total dry matter that is weeds is less in the case of simultaneous polyculture. Hence, simultaneous polyculture would seem to provide the farmer with a somewhat more effective means of utilizing environmental resources available especially if weeding were not practiced.

2. Reduced nutrient losses

Reduced nutrient losses have also been proposed as a reason for increased yields in simultaneous polyculture; but as was pointed out earlier, reduced soil nutrient losses may not affect yields of crops in the same season but will conserve soil fertility in the long run. The determinations made of nutrient content of the manioc plants and weeds show that manioc roots contain less potassium when grown in association with rice than when grown with maize or with rice and maize. Manioc roots and weeds contain more Ca under simultaneous polyculture than in pure manioc stands. Finally, soil losses of Mg in the 0-40 cm depth are less in sub-subplots where rice is grown in pure stands or in association with manioc.. In order to evaluate these results properly, it is necessary to make balance sheets in which the nutrients removed by the different crops and weeds are subtracted from the nutrient changes in the soil. Contents of nutrients in harvested portions of rice, maize, and cowpeas are taken

from Cooke (1967) and are as follows:

Crop	K %	Mg %
Cowpeas	1.0	0.37
Rice	0.35	0.14
Maize	0.27	0.10

Stover contents are not included since these were returned to the plots in the cases of rice, maize, and cowpeas. Manioc and weed nutrient contents are determined from harvest and analytical data. The results are presented in Table 23 as two balance sheets, one for the area of fifteen year fallow and one for the area of seven year fallow. Since crop analyses were only carried out on two replicates, one from each area, only the results from two replications can be presented.

Statistical analyses of these data show K content of crops and plants (crops plus weeds), net K loss, and K loss percentage to all have been affected by potassium application. These results are presented in Table 24. It can be seen that although plants took up more K when K was applied[1], much more K was lost to the soil (at least carried to below the 40 cm depth) than was taken up by the plants. There are

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1. Potassium applied was equal to 249 kg K/ha.

Table 23

K and Mg balance sheet for sub-subplots with different cropping systems and management

A. Area of fifteen year fallow

Treatments	K change in soil 0-40 cm 0-12 mos. kg/ha	K in plants kg/ha	K loss[1] kg/ha	Loss as percent of change	Mg change in soil 0-40 cm 0-12 mos. kg/ha	Mg in plants kg/ha	Mg loss[1] kg/ha	Loss as percent of change
Manioc in pure stand								
Unweeded -K	74	109	0	0	94	24	70	74
Unweeded +K	263	118	145	55	181	17	165	91
Weeded -K	143	72	71	50	162	23	130	86
Weeded +K	361	168	193	53	87	21	66	76
Rice in pure stand followed by cowpeas in pure stand								
Unweeded -K	93	118	0	0	150	25	125	83
Unweeded +K	235	117	119	50	63	21	42	67
Weeded -K	81	85	0	0	37	18	19	51
Weeded +K	224	115	109	49	43	13	30	70
Manioc intercropped with maize								
Unweeded -K	62	59	3	5	75	13	62	83
Unweeded +K	286	145	141	49	100	14	86	86
Weeded -K	124	69	55	45	125	30	95	76
Weeded +K	217	158	50	27	125	23	102	82
Manioc mix-cropped with rice								
Unweeded -K	50	91	0	0	12	22	0	0
Unweeded +K	292	150	142	49	112	31	81	72
Weeded -K	74	92	0	0	12	19	0	0
Weeded +K	267	117	150	56	6	17	0	0
Manioc intercropped with maize and mix-cropped with rice								
Unweeded -K	230	112	118	51	212	31	181	85
Unweeded +K	274	139	135	49	225	24	201	89
Weeded -K	62	67	0	0	62	23	39	63
Weeded =K	293	112	181	62	87	19	69	80

1. Indicates disappearance below 40 cm depth and non-recovery in plants (crops + weeds)

Table 23, Continued

B. Area of seven year fallow

Treatments	K change in soil 0-40 cm 0-12 mos. kg/ha	K in plants kg/ha	K loss[1] kg/ha	Loss as percent of change	Mg change in soil 0-40 cm 0-12 mos. kg/ha	Mg in plants kg/ha	Mg loss kg/ha	Loss as percent of change
Manioc in pure stand								
Unweeded -K	44	53	0	0	112	15	97	87
Unweeded +K	381	89	292	77	87	12	75	86
Weeded -K	63	59	4	6	1	30	0	0
Weeded +K	274	72	202	74	6	19	0	0
Rice in pure st-nd followed by cowpeas in pure stand								
Unweeded -K	63	43	20	32	44	7	37	84
Unweeded +K	299	43	256	86	12	7	5	42
Weeded -K	94	54	40	43	119	11	108	91
Weeded +K	299	45	255	85	107	8	99	93
Manioc intercropped with maize								
Unweeded -K	144	66	78	54	93	14	79	85
Unweeded +K	299	78	221	74	100	11	89	89
Weeded -K	119	56	63	53	113	18	95	81
Weeded +K	368	89	279	76	100	12	88	88
Manioc mix-cropped with rice								
Unweeded -K	119	51	68	57	88	13	75	85
Weeded +K	249	72	177	71	88	12	76	77
Weeded -K	69	39	30	43	50	19	31	62
Weeded +K	311	56	255	82	7	18	0	0
Manioc intercropped with maize and mix-cropped with rice								
Unweeded -K	188	69	119	64	113	18	95	81
Unweeded +K	386	68	318	82	116	15	101	87
Weeded -K	88	52	36	41	62	16	46	74
Weeded +K	318	80	238	75	25	13	12	48

1. Indicates disappearance below 40 cm depth and non-recovery in plants (crops and weeds)

other significant differences although K content of the crop was significantly less in the pure stand rice treatment than in the other cropping systems; but this difference is made up for in the K content of the weeds since there is no significant difference in the K content of plants (crops + weeds) for the different cropping systems.

Potassium application significantly decreases Mg content of weeds and of weeds plus crop but has no effect on crop Mg, Mg loss, or percentage Mg loss (Table 24). It can be seen that Mg loss like soil Mg levels is not significantly affected by K application. Mg losses do vary considerably for cropping systems being considerably lower for the manioc-rice combination. Thus, the effect shown on soil Mg levels also holds when the Mg content of the plants is deducted. It will be seen in Table 24, however, that this difference is only significant for the percentage Mg loss as compared with the maize-manioc combination although the differences in the soil Mg losses and percentage Mg loss between the manioc-rice treatment and the other cropping systems is considerable. The reason for the lack of significance for this difference lies in the very large coefficient of variation (C.V) which is probably the result of combining many different results, each with their own variance, to obtain these values.

Table 24

Effect of potassium application and cropping system on K and Mg balance sheets

A. Effect of potassium application on K balance sheet

(Means of 20 replications)

Treatment	K in crop kg/ha	K in weeds kg/ha	K in plants[1] kg/ha	K[3] loss kg/ha	K[2] loss %
No K application	26.90**	43.80	70.70**	35.35**	27.20**
K applied	50.70**	51.25	101.45	193.35**	64.05**

** indicates significant difference at p=0.01

B. Effect of potassium application on Mg balance sheet

Treatment	Mg in crop kg/ha	Mg in weeds kg/ha	Mg in plants[1] kg/ha	Mg[3] loss kg/ha	Mg[2] loss %
No K application	9.35	10.05**	19.40**	69.65	89.05
K applied	8.10	8.25**	16.35**	69.30	85.65

** indicates significant difference at p=0.01

-Menas of twenty replications_

Table 24, Continued

C. Effect of cropping system on K and Mg balance sheets

Treatment	K loss[3] kg/ha	K[2] loss %	Mg loss[3] kg/ha	Mg[2] loss %
Manioc in pure stand	113.38	39.38	76.38	62.50
Rice in pure stand followed by cowpeas in pure stand	99.88	43.13	58.13	72.63
Manioc intercropped with maize	112.38	47.88	87.00	83.75
Manioc mix-cropped with rice	102.75	44.75	32.88	37.00
Manioc intercropped with maize and mixed-cropped with rice	143.13	53.00	93.00	75.88
l.s.d. p=0.05	46.50	19.11	68.43	41.73
C. V. %	35.29	36.33	85.43	54.55

1. Amount in weeds plus amount in crop

2. K or Mg loss divided by change in soil level over 12 months

3. Change in soil level (0-40 cm) over 12 months minus amount in plants. In case of K, this includes 249 kg of k applied.

What these various calculations appear to show is that the simultaneous polyculture of rice and manioc is somewhat more productive as far as total dry matter production and crop dry matter production than the other cropping systems studied although it removes no more K and Mg from the soil than the other systems. However, soil losses in the 0-40 cm depth of K and especially of Mg are considerably less for simultaneous polyculture of rice and manioc than for the other cropping systems. The most likely mechanism for this result is that the Mg is taken up early in the rainy season by the rapidly growing rice when chances of nutrient loss by leaching are great. The manioc is not growing fast enough at this point to absorb much Mg. Some confirmation of this hypothesis is given in Table 21 where it can be seen that Mg losses in the 0-40 cm depth of the soil were much less in the first four months in the two cropping systems where high populations of rice prevail. In the three crop system, the rice probably does not occupy enough of the soil mass to have much effect. Later after the rice is harvested, the straw is returned to the soil. Most of the Mg is expected to be in the straw because, as we have seen the rice grain contains very little Mg. The straw then decomposes, making Mg available to other plants at a time when it is less subject

to leaching since precipitation is considerably less by this time. It must be admitted that the data presented are hardly sufficient to prove that this course of events is occurring. What is evident, however, is that about five times as much Mg is lost from the soil rooting zone as is recovered in the plants in the pure stand manioc, manioc-maize, and manioc-maize-rice treatments. About four times as much is lost in the rice-cowpea sequence, and less than three times as much in the rice-manioc combination. These relationships are summarized in Table 25.

d.) Cation balance

It has been suggested that all plants including manioc (Ngongi, 1975) maintain a cation balance, i.e. that the sum of cations as expressed in milliequivalents per 100 g remains constant (Wallace, 1948). Wallace (1948), working with alfalfa in culture solutions at different K levels, reports that this is the case although sum of cations is somewhat increased at the highest levels of K. To see if the present data conforms with this hypothesis, the Ca, Mg, and K contents of the manioc roots, stems, and leaves, and of the weeds have been converted to milliequivalents per 100 g dry matter and subjected to statistical analyses. There proves to be very little variability with the coefficients of variation being

Table 25

Total K and Mg (kg/ha) contained in crops, weeds, and soil for different cropping systems

A. K

Cropping System	K (kg/ha) Crop	Weeds	Crop plus weed	Change[1] in Soil K 0-40 cm	K[2] loss
Manioc in pure stand	46.75 c	45.75 ab	92.50 e	205.88	113.38 f
Rice in pure stand followed by cowpeas in pure stand	8.88 d	68.50 b	77.28 e	177.26	99.88 f
Manioc intercropped with maize	50.75 c	40.25 a	91.00 e	203.38	112.38 f
Manioc mix-cropped with rice	42.50 c	41.00 a	83.50 e	186.25	102.75 f
Manioc intercropped with maize and mix-cropped with rice	45.12 c	42.13 a	87.25 e	230.38	143.13 f

means of eight replicates

B. Mg

Cropping system	Mg (kg/ha) Crop	Weeds	Crops plus Weeds	Change[1] in Soil Mg 0.40 cm	Mg[2] loss
Manioc in pure stand	10.00 h	10.00 i	20.00 j	96.38	76.38 k
Rice in pure stand followed by cowpeas in pure stand	3.25 g	10.38 i	13.63 j	71.76	58.13 k
Manioc intercropped with maize	9.00 h	7.88 i	16.88 j	103.88	87.00 k
Manioc mix-cropped with rice	10.87 h	8.13 i	19.00 j	51.88	32.88 k
Manioc intercropped with maize and mix-cropped with rice	10.50 h	9.38 i	19.88	112.88	93.00 k

means of eight replicates

Values followed by same letter do not differ significantly at p=0.05 by Duncan's multiple range test.

1. Not analyzed statistically
2. Fourth column minus third column

4.22%, 8.61%, and 5.55% for the manioc roots, stems, and leaves respectively. For the weeds, a little more variability would be expected as they consist of a mixture of species and the coefficient of variation is 11.72%. Despite these low variabilities, significant effects for application are found with all manioc plant parts but not for weeds. Also the interactions of K with cropping system and K with weeding are significant for the cation sum of the manioc roots. These effects and interactions are summarized in Table 26.

It can be seen that the total cation content of the roots of the manioc intercropped with maize is significantly greater than that of the roots of the manioc in other treatments if the plots are weeded or if K is applied. Similarly the total cation content of the manioc roots is increased by K application only for manioc intercropped with maize or intercropped with maize and mix-cropped with rice. It should be remembered that the same effect has been seen for the K content of manioc roots in Table 19. There seem to be two possible explanations. Either the maize functions with respect to K in a manner similar to that proposed for rice with respect to Mg. Indeed, Tokunaga (1975) shows that maize stover can supply soils with more K than rice straw can. Another possibility is that the maize merely functions by reducing weed growth, enabling the manioc to take up more of the applied K.

Table 26

Effect of potassium application on sum of cations of manioc plants parts and of weeds.

A. Simple effect — Sum of cations (me/100g)

Treatment	Manioc roots	Manioc stems	Manioc leaves	Weeds
Without applied K	33.93**	61.93*	205.30*	93.51
With applied K	39.48**	66.76*	214.76*	94.21

* indicates significant difference at p=0.05
**indicates significant difference at p=0.01

B. Interaction: Weeding X Potassium application (Manioc roots)

Sum of cations (me/100g)

Treatment	No weeding	With weeding	
Without applied K	32.90	34.95	l.s.d. at p=0.05 for K application in same weeding treatment=1.78
With applied K	40.05	38.90	

l.s.d. at p=0.05 for weeding or for K in different weeding treatments= 38.91

C. Interactions: Weeding X cropping system and potassium application X Cropping System (Manioc roots)

Cropping System

Sum of cations (me/100g)

	Without Weeding	With Weeding	Without K	With K
Manioc in pure stands	36.67 b	34.50 b	34.75 c	36.43 dc
Manioc intercropped with maize	34.77 b	45.25 a	34.35 c	45.67 e
Manioc mix-cropped with rice	36.60 b	32.60 b	34.00 c	35.20 c
Manioc intercropped with maize and mix-cropped with rice	37.85 b	35.35 b	32.60 c	40.60 d

Values followed by same letter do not differ significantly at p=0.05 by Duncan's multiple range test.

The percentage contribution of each element to the sum of cations has been similarly analyzed. It is shown in Table 27 that potassium application always significantly increases the part of the total cations which is K and decreases the percentage which is Mg and Ca. Applied K does not, however, significantly lower the percentage Mg and Ca of the total cations of the manioc leaves.

e.) Economic analysis

Although the effect of different cropping systems on the value of produce has been presented in Tables 12 and 15, the different inputs that each cropping and management practice entails have not been enumerated. This has been done in Tables 28 and 29. The man-days required for each activity are presented in Table 28. These are converted to monetary terms and compared to the value produced by each system in Table 29. As shown in the analysis of value produced, the most profitable combinations remain rice followed by cowpeas and rice mix-cropped with manioc with the former being more profitable if the rice is not weeded and the rice-manioc simultaneous polyculture most profitable if weeding is practiced. Even without weeding, the rice-manioc combination is more profitable than all other treatments with the exception of the rice-cowpea sequence. Although K always increases the value produced, it rarely produces a greater profit than treatments without K and the percentage return on investment is always greater if

Table 27

Effect of Potassium application on cation distribution in manioc plant parts and weeds

A. Manioc roots

Cation	Percentage of Total Cation Equivalents	
	Without K	With K
Mg	28.21**	18.42**
K	49.42**	64.39**
Ca	19.85*	16.63*

B. Manioc stems

Cation	Percentage of Total Cation Equivalents	
	Without K	With K
Mg	32.04**	21.85**
K	27.42**	42.45**
Ca	40.54*	36.20*

C. Manioc leaves

Cation	Percentage of Total Cation Equivalents	
	Without K	With K
Mg	29.73	27.56
K	27.43**	32.24**
Ca	42.86	40.20

D. Weeds

Cation	Percentage of Total Cation Equivalents	
	Without K	With K
Mg	27.11**	24.12**
K	36.08**	43.88**

* indicates significant difference at p=0.05

**indicates significant difference at p=0.01

Table 28. Economic Analysis (See footnotes on following page)

Management system		Operations (Man-hours per hectare)																	
		Clear and burn[1]	Clear off wood[1]	Cut manioc[2]	Plant manioc[2]	Plant rice[7]	Plant maize[7]	Weeding[6]	Applying K[6]	Harvest manioc[2]	Harvest rice[4]	Harvest maize[5]	Prepare manioc meal[3]	Step on cereal straw[6]	Land preparation for cowpeas[6]	Plant cowpeas[7]	Weed cowpeas[6]	Harvest cowpeas[8]	Total
Manioc in pure stand	Unweeded -K	17	20	3	5					15			47						107
	Unweeded +K	17	20	3	5				2	15			56						118
	Weeded -K	17	20	3	5			10		15			93						163
	Weeded +K	17	20	3	5			10	2	15			98						170
Rice in pure stand followed by cowpea	Unweeded -K	17	20			2					19				10	2	20	17	109
	Unweeded +K	17	20			2			2		24				10	2	20	17	116
	Weeded -K	17	20			2		10			21				10	2	20	7	114
	Weeded +K	17	20			2		10	2		27				10	2	20	10	122
Manioc intercropped with maize	Unweeded -K	17	20	3	5		2			15		1	55	2					120
	Unweeded +K	17	20	3	5		2		2	15		2	49	2					117
	Weeded -K	17	20	3	5		2	10		15		2	72	2					148
	Weeded +K	17	20	3	5		2	10	2	15		2	77	2					165
Manioc mix-cropped with rice	Unweeded -K	17	20	3	5	2				15	19		37	2					120
	Unweeded +K	17	20	3	5	2			2	15	22		49	2					128
	Weeded -K	17	20	3	5	2		10		15	21		73	2					168
	Weeded +K	17	20	3	5	2		10	2	15	23		76	2					175
Manioc mix-cropped with rice and intercropped with maize	Unweeded -K	17	20	3	5	2	2			15	5	1	61	2					133
	Unweeded +K	17	20	3	5	2	2		2	15	7	1	55	2					131
	Weeded -K	17	20	3	5	2	2	10		15	11	1	51	2					139
	Weeded +K	17	20	3	5	2	2	10	2	15	11	1	68	2					158

Table 28, continued

1. Valverde and Dias, 1967
2. Krochmal, 1966
3. Wagley, 1964 (Approximately 15 kg per man-day)
4. Lima, 1956 (One man can harvest and thresh 70 kg of rough rice per day)
5. Assumed one man could harvest 200 kg per day
6. Observations of author
7. Planting estimates are for manual planter commonly used in Bragantina region. For more information, see Chapter Six. It is assumed that one man can plant a half-hectare per day with such a planter.
8. Assumed one man can harvest 30 kg of cowpeas per day.

Table 29

Cash inputs, Gross return, net return, and profit margin for cropping and man-gement systems studied

Cropping and Management System	Man Days	Labor[1] Cost NCr$[2]	Cost[4] of K fert. NCr$	Cost[5] of seed NCr$	Total[3] Cost NCr$	Value[9] of production NCr$	Net[6] Return NCr$	Net[10] %
Manioc in pure stand								
U -K[8]	107	1284			1284	1475	191	14.88
U +K[8]	118	1416	500		1916	1748	168	
W -K	163	1956			1956	3210	1254	64.11
W +K	170	2040	500		2540	3449	909	35.79
Rice in pure stand followed by cowpeas in pure stand								
U -K	109	1308		158	1466	4654	3188	217.46
U +K	116	1392	500	158	2050	5412	3362	164.00
W -K	114	1368		158	1526	3703	2177	142.66
W +K	122	1464	500	158	2122	5028	2096	136.95
Manioc intercropped with maize								
U -K	120	1440		40	1480	1642	162	10.95
U +K	117	1404	500	40	1944	2694	750	38.58
W -K	148	1776		40	1816	3236	1420	78.19
W +K	165	1980	500	40	2520	4121	1601	63.53
Manioc mix-cropped with rice								
U -K	120	1440		70	1510	4436	2926	193.77
U +K	128	1536	500	70	2106	4916	2810	133.43
W -K	168	2016		70	2086	5827	3741	179.34
W +K	175	2100	500	70	2670	5845	3175	118.91
Manioc intercropped with maize and mix-cropped with rice								
U -K	133	1596		91	1687	2976	1289	76.41
U +K	131	1572	500	91	2163	3481	1318	60.93
W -K	139	1668		91	1759	3845	2086	118.59
W +K	158	1896	500	91	2487	4278	1791	72.01

1. Calculated on basis of NCr$ 12 (U.S. $1.50) per day
2. U.S. $1.00 = NCr$ 8 or NCr$ 1 = U.S. $0.125
3. Sum of labor cost, fertilizer cost, and seed cost
4. NCr$ 1 per kg KCl
5. Calculated on same basis as value. Amounts are those needed to produce plant populations in experiment. 20 kg per ha. for beans and maize. Rice calculated on basis of 35g per 1000 grains. It is usually not necessary to purchase manioc cuttings.
6. Value of production minus total cost
7. From preceding table (Table 28)
8. U: Unweeded; W: Weeded
9. From Table 12.
10. Net return divided by total cost

K is not applied.

It may be objected that the above analysis is of little relevance to the subsistence farmer who operates outside a cash economy. It can be seen that the above analysis only had two cash inputs: seed and K fertilizer. If we deduct the amount of seed planted from that produced and omit the K fertilizzation, which such a farmer would be unlikely to practice anyway, a non-cash economic analysis can be carried out. It can be assumed that a person would require 2500 kilocalories and 50 g protein to be able to work one man-day. Also, on this basis, the number of persons who could be fed adequately with respect to protein and kilocalorie requirement can be calculated. This has been done in Table 30. No consideration of protein quality has been made although that of rice is usually considered to be superior to that of the other crops studied.

It can be seen that the manioc-rice combination maintains its general superiority, performing well with regard to both kilocalories and protein. The systems involving manioc are generally quite productive in terms of kilocalories and would be even more so if higher yields had been obtained in the experiment. The systems containing cowpeas are of course superior to all others in regard to protein productivity but markedly inferior with regard to kilocalories. Similar nutritional benefits resulting from simultaneous polyculture are reported by Pinchinat and Oelsligle (1974). Probably, the

Table 30

Analysis of yields in terms of nutritional requirements for their production

A. Kilocalories

Production System[6]	Labor kcal X 10^3/ha	Seeds[1] kcal X 10^3/ha	Total[2] kcal X 10^3/ha	Production[3] kcal X 10^3/ha	Net[4] kcal X 10^3/ha	Man-Year[5] Equiv.
Manioc in pure stands						
Unweeded	267.5	--	267.5	4800	4532.5	4.97
Weeded	407.5		407.5	7810	7402.5	8.11
Rice in pure stands followed by cowpeas in pure stand						
Unweeded	272.5	137.6	410.1	4460	4049.9	4.44
Weeded	285.0	137.6	422.6	3890	3467.4	3.80
Manioc intercropped with maize						
Unweeded	300.0	72.0	372	3830	3458	3.79
Weeded	370.0	72.0	442	7410	6968	7.64
Manioc mix-cropped with rice						
Unweeded	300.0	73.8	373.8	7210	6836.2	7.49
Weeded	420.0	73.8	493.8	9980	9486.2	10.40
Manioc intercropped with maize and mix-cropped with rice						
Unweeded	332.5	125.4	457.9	6840	6382.1	6.99
Weeded	347.5	125.4	472.9	8210	7737.1	8.48

1. Seed kilocalorie equivalents calculated on basis of kilocalorie equivalent of quantity seeded (See p. 147 and p. 154):

   20 kg maize - 72 X 10^3 kcal

   20 kg cowpeas - 56.2 X 10^3 kcal

   Rice with manioc (1,006,943 seeds): 73.8 X 10^3 kcal

   Rice with manioc and maize (729,166 seeds): 53.4 X 10^3 kcal

   Rice alone (1,111,111 seeds: 81.4 X 10^3 kcal)

2. Seeds plus labor

3. From Table 12

4. Production minus Total

5. One person is considered to require 912.5 X 10^3 kcal per year

6. Only systems without potassium application considered since no way to convert human energy into KCl could be found

B. Protein (Prot.)

Production System[6]	Labor Prot. g/ha	Seed[1] Prot. g/ha	Total[2] Prot. g/ha	Production[3] Prot. g/ha	Net[4] Prot. g/ha	Man-year[5] equiv.
Manioc in pure stands						
Unweeded	5350		5350	23500	18150	0.99
Weeded	8150		8150	38300	30150	1.65
Rice in pure stand followed by cowpea in pure stand						
Unweeded	5450	6433	11883	177100	165217	9.05
Weeded	6100	6433	12533	112800	100267	5.49
Manioc intercropped with maize						
Unweeded	6000	2000	8000	29200	21200	1.16
Weeded	7400	2000	9400	61900	52500	2.88
Manioc mix-cropped with rice						
Unweeded	6000	1480	7480	76400	68920	3.78
Weeded	8400	1480	9880	91200	81320	4.46
Manioc Intercropped with maize and mix-cropped with rice						
Unweeded	6650	3072	9722	47100	37378	2.05
Weeded	6950	3072	10022	63300	53278	2.92

1. Seed protein equivalents calculated on basis of protein equivalent of quantity seeded (See p. 147 and p. 154):

   20 kg maize - 2000g protein; 20 kg cowpeas-4800g protein

   Rice alone (1,111,111 seeds): 1633g protein

   Rice with manioc (1,006,943 seeds): 1480g protein

   Rice with maize and manioc (729,166 seeds): 1072g protein

   It is generally not necessary to purchase manioc cuttings

2. Seeds plus labor

3. From Table 12

4. Production minus total

5. One person is considered to rquire 365 X 50g or 18,250g protein per year.

6. Only systems without potassium application are considered due to difficulty in converting protein to KCl.

best solution would be a half hectare each of the rice-manioc and rice-cowpea combinations which should provide sufficient calories and protein for six persons for a year, even after discounting the protein and kilocalorie needs of the persons working to produce them.

5.6. Conclusions

Yields of manioc and maize would certainly have been higher if better adapted varieties had been planted at the proper plant populations. More information may also have been obtained as to how simultaneous polyculture functions to produce increased yields.

Although the present experiment showed the superiority of simultaneous polyculture over pure stands of rice, manioc, and cowpeas by several measures proposed to show the benefits of the system (Willey and Osiru, 1972; van der Bergh, 1968; Donald, 1963; Evans, 1960), little information has been obtained as to how this increased productivity comes about. We have seen that simultaneous polyculture appears to increase total dry matter production while not affecting weed dry matter production. Yet, simultaneous polyculture often seems to bring more benefits in the absence of weeding. So, there seems to be a relationship, though not a very clear one, between simultaneous polyculture and weed control.

Some evidence has also been presented to the effect that nutrient losses are less with simultaneous polyculture than

with pure stands. Potassium and calcium content of manioc roots is increased by association of the manioc with maize; while the rice-manioc combination appears to lessen leaching losses of soil magnesium. It has been proposed that the mechanism involved is either related to weed control by the associated cereal or to uptake of the readily leachable potassium and magnesium by the faster growing maize and rice to be released when the cereal straw decomposes at a time when rainfall is less intense. It should be noted that soil Mg and K measured by rapid soil tests is not necessarily exchangeable Mg and K and hence be more mobile than cations actually held on the exchange complex.

It should not be assumed that mechanisms not examined in the present study of simultaneous polyculture are not important. Superior light utilization, increased depth of rooting, and decreased interplant competition may all have been of considerable or even paramount importance in the increased productivity observed due to simultaneous polyculture; but no measurements of these factors have been made.

Furthermore, observations made about the crop combinations studied do not necessarily apply to simultaneous polyculture involving other crop combinations. It has already been noted that rainfall in the experimental area

is considerably higher than in other areas where studies of simultaneous polyculture have been carried on. Legumes play a less important role in the present system than in most of those studied (See Table 2). It has been noted that almost all systems do involve a fast-growing crop, usually a cereal, and a slower growing crop. Since one of the mechanisms proposed here for increased yielded in simultaneous polyculture depends on the relationship between fast and slow growing crops, it may be of considerable importance in other crop combinations.

Finally, in spite of the deficiencies in management of the present experiment, the economic analysis of the yields that were obtained show that enough kilocalories and protein could be produced to supply the needs of six persons for one year from one hectare planted with the crop combinations studied. This result should be considered in reference to present and possible future land uses of the Bragantina region. With better manioc varieties at higher plant populations, another modification in management practices, the cropping systems used in the present experiment should be able to feed an even greater number of persons.

In Chapter 2, it was stated that there are 12,906 km^2 of light textured Yellow Latosols similar to that used for

the present experiment in the Bragantina and Salgado regions (Vieira et al., 1967). If we assume that 80% of this area is available for agricultural purposes, it will be seen that this amounts to 1,032,480 hectares. As was shown in the present chapter, the yields obtained can be expected under shifting cultivation with a seven year fallow. Even allowing for a ten-year fallow as is supposedly common in the region (Sioli, 1973), 100,000 hectares would still be available each year for annual crop production and could, as we have seen, produce adequate kilocalories and protein for 600,000 persons or 150% of the present population of the Bragantina and Salgado regions.

Chapter Six

Fertilization with Simultaneous Polyculture

6.1. Objectives

Difficulty in carrying out cultural operations was listed in Chapter Two as a disadvantage of simultaneous polyculture. The previous chapter has shown that simultaneous polyculture does bring benefits but it does not obviate the necessity of maintaining soil fertility by other means. Getting farmers to incorporate practices such as the use of fertilizer into their traditional practices has received little attention from most investigators. Andrews (1972) and Willey and Osiru (1972) worked with intercropping rather than mixed cropping because it could be more easily mechanized and viewed their studies as showing a way in which simultaneous polyculture could be incorporated into intensive agriculture. Other authors have considered methods by which yields could be improved by incorporating selected inputs into traditional practices although not specifically in the context of simultaneous polyculture.

Where simultaneous polyculture is associated with shifting cultivation, it is unlikely that tilling of the soil will be practiced, thus limiting means of fertilizer application to broadcasting. Dunsmore (1970) has tried mixing rice seed with granules of monoammonium phosphate but has found that other modifications of traditional practice, such as closer spacing, would still be necessary for maximum benefit to be derived from broadcast fertilization. As fertilizer prices have increased considerably what might have shown a significant benefit three years ago may no longer be an economic practice.

Dalal (1974) has pointed out that the response curves of two associated crops are rarely the same, making it possible that a level of fertilization that would be of benefit to one crop may even depress yields of an associated crop. This is more likely to be a problem with nitrogen than with any of the other nutrients.

Pinchinat and Oelsligle (1974) report yield benefits from simultaneous polyculture of maize and beans at 0, 100, 200, and 300 kg/ha of N when 100% of the pure stand population of maize is combined with 50 or 100% of the pure stand bean population. The combination of 100% of the pure stand bean population with 50% of the pure stand maize population

is the best treatment when no N is applied but is markedly inferior to the other treatments at the higher levels of N. The authors report that all N was applied broadcast and incorporated prior to planting, which is probably not the most ideal way of meeting the requirements of the crops involved but is certainly the most convenient method. How local farmers would incorporate fertilizer has not been considered by these authors.

In another experiment, Pinchinat and Oelsligle, (1974) report that rice and climbing type beans produce a greater relative yield[1] at high fertility levels while bush-type beans, soybeans, and sweet potato produce a greater relative yield at low fertility levels. Hence, the fertility level would be expected to affect the behavior of a particular crop of variety in simultaneous polyculture as compared to pure stands. No statement concerning methods of fertilizer application is made although timing and method of application might be expected to affect the nature of the response of each crop or variety.

The method of planting cereals in the Bragantina region where a manual planter is commonly used for seeding rice, maize, and cowpeas offers some possibilities for the applica-

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1. Ratio of yield in simultaneous polyculture to yield in pure stand.

tion of fertilizer since the size of aperture of the planter can be regulated. Also the high rainfall that prevails in the area at the time in which rice is seeded may make mixing fertilizer with the seed more practical since the chance of fertilizer damaging emerging seedlings is less if moisture is high. Thus, there would seem to be a way for small farmers to apply some fertilizer in connection with rice planting. As phosphorus is the element likely to be most limiting in Yellow Latosols, to which various crops may be expected to respond and for which method of application is likely to be most critical, it was decided to concentrate on methods of application and forms of phosphorus for a preliminary experiment.

6.2. Materials and Methods

An experiment in a randomized complete block design with four replications was laid out in each of two farmers' field near the Tracuateua Experiment Station. Soils were similar to those on the experiment station but probably of somewhat lighter texture and somewhat more poorly drained. The areas had already been planted with maize and manioc about two weeks before the experiment was laid out. The maize had been planted in rows approximately 1.8 m apart and the manioc was scattered

between the rows of maize. It was decided to plant three rows of rice 30 cm apart and 60 cm from each row of maize between the rows of maize. Planting was carried out with a manual seeder (Semeadeira de Cereais e Amendoim Marilia; Industria e Comercio Sasazalei Ltda.; C. P. 196; Marilia, SP; Brazil) calibrated to put about seven seeds of rice in each hill. Hills were 15 cm apart within the row. Plots measured 9 m X 3.6 m. There were seven treatments as follows:

1.) Triple superphosphate mixed with seeds in the planter (700 g fertilizer plus 200 g seeds per plot). Planter at opening #4.
2.) Triple superphosphate applied with planter in "hills" between rows of rice. (700 g fertilizer per plot)
3.) Simple superphosphate broadcast (1.6 kg per plot)
4.) Thomas slag broadcast (4 kg per plot)
5.) Triple superphosphate broadcast (700 g per plot)
6.) Control without P
7.) Control without N or P

Quantity of fertilizer was calculated to supply 70 kg/ha of P_2O_5 in each plot receiving P. Planting was realized on Feb. 9 and 10, 1974. Broadcast applications took place on

Feb. 14. Rice emerged on Feb. 15. Fifty kg of N per hectare as sulfate of ammonia was applied broadcast to all plots except the control without N or P on March 22. One weeding was carried out on March 21. Rice was heavily attacked by the spinach leaf beetle (Disconycha eximica; Chrysomelidae; Coleoptera)[1] larvae which necessitated control with 60% Diazinon E at 750 ml/ha at each of two sprayings realized on March 22 and April 10. Original plans called for harvest of maize, rice, and manioc on all plots but the farmer harvested maize and manioc before the author was able to. Rice was harvested on June 22. Yield components were determined by method of Yoshida, Forno, and Cock (1971). Moisture content of grains was corrected to 14% moisture by use of Overton Mark V Moisture Tester (Seedburo Equipment Co., Chicago, Illinois.). Rice was of cultivar IAC 47.

The experimental area had flooded in April due to high rainfall and it was thought that production of manioc would be negligible although the farmer reported that the manioc responded surprisingly well to the fertilization despite being in a waterlogged soil for several months.

6.3. Results

The rice in one farmer's field was planted late and did not compete well with maize and manioc. This experiment was

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1. Identification made by Mr. Robert Cheaney, Especialista en arroz; CIAT; Cali, Colombia.

hence abandoned although it was noted that rice mixed with triple superphosphate had failed to emerge entirely, an occurrence which was not observed at the other site. It was thought that this difference might have been due to better drainage at the site where the rice had failed to emerge. Concentration of fertilizer near the rice should have been more problematic in the better drained soil.

Attack by Disconycha eximica was extremely heavy and led to defoliation and death of rice plants in some cases. It was found subsequently that Sevin mixed with an adhesive gave somehwat better control than Diazinon. However, in three replicates, none of the rice plants were killed so these were harvested and yield determined. These results are presented in Table 31. Rice was otherwise not damaged by other pests or diseases.

Yields are calculated on basis of whole plot and would be twice as high if only area planted to rice were included.

6.4. Discussion

The superiority of Thomas slag may be due to the other elements such as Mg or Ca which it contains or to its neutralizing power, about 60% that of calcium carbonate. Also, it contains silica which may have been extremely valuable in the present experiment in providing mechanical resistance

Table 31

Results of fertilizer application to simultaneous polyculture of rice, maize, and manioc in farmer's field in Bragantina region

(All plots received 70 kg/ha P_2O_5 and 50 kg/ha N as ammonium sulfate unless otherwise noted)

Treatment	Production of rough rice at 14% moisture (kg/ha)
Thomas slag broadcast	843 a
Triple superphosphate in "hills" between rice plants	810 ab
Triple superphosphate broadcast	661 bc
Control without nitrogen or phosphorus	621 c
Simple superphosphate broadcast	602 c
Control without phosphorus	598 c
Triple superphosphate mixed with rice seed in planter	589 c

Values followed by same letter do not differ significantly at p = 0.05 by Duncan's multiple range test.

to the insect attack. Disconycha eximica has chewing mouth parts so a higher silica content in the rice leaves due to the slag application may have reduced considerably the damage it was able to cause. A similar effect has been reported against rice stem borers.

Of the remaining treatments, only the triple superphosphate applied in the planter produced significantly better yields than the control treatments. It is not clear why the other broadcast treatments were so ineffective since the Thomas slag, also broadcast had a significant effect. The broadcast triple and simple superphosphate may have been immobilized near the soil surface where the rice roots were unable to reach. The slag may have neutralized the soil acidity to a greater depth so that the phosphorus remained soluble. The rice plants were able to make use of the triple superphosphate applied in the planter since it was in effect "banded" and would not be expected to react as quickly with the soil. The fact that the area flooded about two months after planting should have negated these effects; but this might have occurred too late to have any effect since rice absorbs most of its phosphorus requirement at early stages.

Mixing phosphorus fertilizer with the rice seed did not appear to be a recommendable procedure. Even if the seed emerges, and we have seen that in some cases it does not,

there was no increase in yield over the control.

No economic analysis was attempted because yield increases were small and fertilizer prices have varied considerably in Brazil in recent months making it difficult to decide which prices to use.

6.5. Conclusions

The experiment offered some guidelines as to how fertilization with simultaneous polyculture under shifting cultivation may be carried out. Neither mixing P with the seed nor broadcast P with the exception of slag seemed to be particularly effective. Further studies would be necessary to determine the cause of the response to slag because it was not clearly a P response. The manual planter might indeed offer a method of applying fertilizer to crops where land preparation and row cultivation are not practiced.

Chapter Seven

The Validity of the Montgomery Effect in Upland Rice Varieties Grown in the Brazilian Amazon

7.1. Objectives

Among the disadvantages listed for simultaneous polyculture was the so-called Montgomery effect (van der Bergh, 1968; de Wit, 1960) which states that varieties which compete well in pure stands do not necessarily compete well with other species. If this is indeed the case, varieties selected by a breeder working with pure stands of a particular species as is, of course, common practice might not necessarily be the varieties that would have been selected had the selection process been carried out under simultaneous polyculture with other crops.

Variety trials carried out by the state representation of EMBRAPA in the Brazilian Amazon with upland rice have always been done with pure stands of each variety tested. In 1974, it was decided to see if these results were indeed valid for rice grown in association with maize and manioc.

7.2. Materials and Methods

Three split-plot experiments with four replications at each site were set up at three different locations along

the Transamazon highway. Soil types and characteristics of the surface soils at the different sites were as follows:

Site	Soil Type	Township	pH	Bray II P_2O_5 mg/100g	K	Exch. bases me/100g Ca+Mg	Al
1.	Structured Terra Roxa (Dark Red Latosol)	Altamira	6.3	1	0.45	8.1	0.0
2.	Red Yellow Podzol (dystrophic)	Altamira	4.7	1	0.27	0.5	7.2
3.	Yellow Latosol (heavy texture)	Itaituba	4.3	3	0.18	2.3	1.2

The main plot treatment was either pure stand rice or rice grown in simultaneous polyculture with maize and manioc. The spacings and densities used for each crop were as follows:

Crop	Pure stand		Simultaneous polyculture	
	Spacing	Density (plants ha^{-1})	Spacing	Density (plants ha^{-1})
Rice	0.3 X 0.15m (5 plants/ hill)	1,111,111	0.3 X 0.15m (5 plants/ hill) 11 of every 32 hills planted with maize or manioc	729,166
Maize		55,555	1.2 X 0.15m	55,555
Manioc			1.2 X 1.2 m	6,944

Each of the main plots were divided into six subplots. In each subplot was planted one of six rice varieties with the following characteristics:

Variety	Origin	Plant type	Tillering	Maturity (days)	Grain type
IAC 1246	Campinas, Brazil	Tall	Slight	105	Extra-long, wide
IAC 47	Campinas, Brazil	Tall	Slight	105	Extra-long, wide
IR-22	IRRI	Short	Profuse	120	Long, slender
Texas Patna	U.S.	Tall	Slight	130	Long, slender
SML Apura	Surinam	Tall	Moderate	140	Extra-long slender
CICA 4	CIAT, Colombia	Short	Profuse	125	Medium, slender

The experiments were planted in February and March, 1974. Rice was harvested as it matured. Each site was analyzed separately by standard statistical techniques (Little and Hills, 1972).

7.3. Results

Yield of each variety at each site under monoculture and simultaneous polyculture is presented in Table 32. It can be seen that yields varied considerably from site to site and appear to be related to soil fertility characteristics,

Table 32

Yield of Six Rice Varieties Grown in Pure Stands and Under Simultaneous Polyculture at Three Locations in Brazilian Amazon

Variety	Altamira Structured Terra Roxa		Altamira Red Yellow Podzol		Itaituba:Yellow Latosol	
	Pure stand	Simultaneous polyculture	Pure stand	Simultaneous Polyculture	Pure stand	Simultaneous Polyculture
IAC 1246	2705 e	291 c	1580 i	1201 m	3173 p	1445 s
IAC 47	3269 d	552 a	877 j	637 n	3066 p	1215 s
IR-22	1026 h	669 a	613 jk	450 no	2802 pq	1137 s
Texas Patna	2026 f	351 c	278 kl	324 no	2097 qr	1020 s
SML- Apura	1276 g	380 bc	224 kl	240 no	1562 r	759 s
CICA 4	1240 g	524 ab	77 l	168 o	1538 r	607 s
Mean	2134 t	251 u	608 v	503 v	2373 w	1031 x

Values followed by same letter do not differ significantly at p = 0.05 by Duncan's multiple range test.

especially the available phosphorus and exchangeable aluminum.

7.4. Discussion.

The ordering of the varieties is substantially the same under monoculture or simultaneous polyculture. Only in one case, the Terra Roxa soil, do the varieties which performed best and poorest in pure stands not perform similarly under simultaneous polyculture. It can be seen that in this soil, the difference between simultaneous polyculture and pure stand yields appears to be greatest. It may be speculated that in this case, maize growth, favored by the low exchangeable Al, was greater, giving more competition to the rice in simultaneous polyculture, hence, the big contrast between rice yields under the two systems. The only problem with this argument is that the varieties which performed unexpectedly better under simultaneous polyculture are those of short stature (IR 22 and CICA 4), which one would expect to be at the greatest disadvantage under simultaneous polyculture. The relative yields of the variety IAC 47, selected for the other experimental work in this thesis should be noted.

7.5. Conclusions

There would appear to be little danger that selection of varieties under pure stand conditions would result in a gross over- or under-evaluation of a particular variety's performance under simultaneous polyculture. It should be noted that the

varieties which did perform best under simultaneous polyculture and in pure stands are of tall stature and show considerable adaptability to varying soil conditions.

Chapter Eight

General Conclusions

8.1. Simultaneous polyculture

The present experimental work does little to change the impression of the benefits of simultaneous polyculture derived from a consideration of the previously published literature. Although the present experiments were carried out with a combination of crops not used by other investigators in an area of considerably higher rainfall than in those where most other studies of simultaneous polyculture have been carred out, simultaneous polyculture of rice and manioc gave benefits similar to those obtained in studies with other crops in different climates.

Reasons for the benefits of simultaneous polyculture not considered by other authors, reduction of weed growth and leaching losses, have been examined in the present study. Weeds were found to constitute a smaller proportion of the total dry matter production with simultaneous polyculture than with pure stands. Magnesium loss to the soil appeared to be less when rice and manioc were associated than when they were

grown in pure stands. The necessity for further studies giving attention to factors in simultaneous polyculture not examined in the present study, such as light utilization, has been pointed out. It would be desirable to work with a variety of crops and crop combinations under a variety of soil conditions to obtain results that may be applicable more than specific situations. Differences among varieties of crop species should not be ignored.

Some of the disadvantages associated with simultaneous polyculture will have to be overcome if the benefits which the practice appears to confer are to be more widely obtained. Among these are the difficulties of adapting management practices such as fertilizer application and pest control measures worked out for monocultures to crop mixtures. Formulations, as well as methods and timing of application, may have to be modified for use in simultaneous polyculture.

8.2. Implications for the Bragantina region

The present study concentrated its attention on a small number of cropping systems in an area whose climatic, cultural and economic conditions are in many ways unique. Although such a study is of limited applicability to the problems of other areas, it has considerable relevance to the problems of the Bragantina region, which, it has been shown, is in considerable need of alternative land uses.

It has been shown (Table 8) that there are presently estimated to be 35,486 hectares in annual crops in the Bragantina region (IBGE, 1970b), considerably less than what was estimated as available cropland in the region and indeed considerably less than the 62,458 hectares estimated in the 1960 census (IBGE, 1960). If these areas were to be used as recommended in Chapter Five, i. e. with one-half in rice in pure stands followed by cowpeas in pure stands and one-half in rice-manioc mixtures and yields obtained were those of the experiment without potassium application, these areas could produce the following amounts of rice, cowpeas, and manioc:[1]

Area in production (ha.)	Rice from pure stand	Rice from mixture with manioc	Total rice	Cow-pea	Manioc[2]
		metric tons			
36,015	25,282	25,003	50,285	6,455	63,836
62,458	43,907	43,424	87,330	11,210	110,865

With these areas which amount to less than 5% and 10% of total available area respectively, adequate calories and protein for 216,090 and 374,749 persons respectively can be obtained under the cropping systems recommend. Thus, the Bragantina

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1. Based on average for weeded and non-weeded plots in experiment without potassium application

2. Fresh weight of roots.

region could feed itself and even have a surplus with no input other than its own labor. The production of rice and cowpeas in the above figures are considerably higher and that of manioc considerably lower than the region presently produces.[1] Thus, the land use would involve a shift in consumption from manioc to rice and cowpeas, which would have considerable nutritional benefit in any case. Somewhat more manioc production could be obtained if it were planted into the cowpeas a month or two after planting as is a frequent practice in the area.

Intensification of the present system of shifting cultivation has not, to the author's knowledge, been advocated by other studies of the Bragantina region (Egler, 1961; Penteado, 1967; Sioli, 1973). More common suggestions have involved the establishment of tree crops such as rubber, Brazil nuts, cashews, or cacau or intensive animal production based on the importation of feedstuffs (Sioli, 1973). While both of these suggestions may be ecologically sound, they ignore the present situation of the area, which is one of a completely destroyed virgin forest occupied by a population whose only experience is with simultaneous polyculture of food and fibre crops using shifting cultivation. Plantation crops and intensive animal production make the region more dependent on the fluctuating prices and demand of foreign

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1. Present per capita consumption of manioc is 100 kg of meal (approximately 500 kg fresh weight) per year.

markets. We have seen that the lack of this dependence gave the area greater economic stability than the rest of the Amazon following the collapse of the rubber market in the early part of the twentieth century.

The author does not wish to give the impression that he is opposed to modification of existing practices in the region which might lead to greater cash income for its inhabitants and would provide badly needed manures for the maintenance of soil fertility. However, such practices should be integrated with and not substituted for the production of staple food crops, which has protected the region from the alternation of periods of prosperity and scarcity which have characterized Brazilian history and which are symptomatic of excessive dependence on an export economy.

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Appendix I.

Profile Descriptions and Analytic Data on Medium Textured Kaolinitic Yellow Latosols and Kaolinitic Latosolic Sands given by Sombroek (1966)

A. Profile descriptions.

1. Profile 25. Kaolinitic Yellow Latosol (ortho), medium textured (KYLm)

Location: Along highway BR-14, km 12.7 S of Sao Miguel do Guama.

Relief and drainage: Flattop of terrace, about 55 cm above nearby river. Well-drained. Alt. 65 m.

Parent material: Pleistocene fluviatile (?) sediments

Vegetative cover: Tropical forest with medium timber volume(150 m^3/ha ca). At the spot probably once or twice attacked by fire.

O_1 6-1 cm: Undecomposed plant residues.

O_2 1-0 cm: Partly decomposed plant residues, with very fine roots.

A_{11} 0-2 cm: Loose bleached sand.

A_{12} 2-20 cm: Brown(10YR 4/3) coarse sand. Single grains and a few, weak fine crumbs. moist, loose. Not sticky and not plastic when wet. Soft when dry. Very many, mainly fine roots. Transition gradual.

A_3 20-70 cm: Yellowish brown (10 YR 4/3) light coarse sandy loam. Little coherent massive, to weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Slightly hard when dry. Slightly more resistant to penetration than other horizons. Common pores. Many roots. Some pieces of charcoal. Transition diffuse.

B_1 70-140 cm: Brownish yellow (10 YR 6/6) coarse sandy loam. Weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Slightly hard to hard when dry. Common pores. Many roots. Transition diffuse.

B_{21} 140-220 cm: Reddish yellow (7.5 YR 6/6) heavy coarse sandy loam. Little coherent massive, to weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and slightly plastic when wet. Slightly hard, to hard when dry. Common, to few pores. Few roots. Transition diffuse.

B_{22} 220-320 cm: Reddish yellow (7.5 YR 6/6) light coarse sandy loam. Little coherent massive. Moist, very friable. Not sticky and slightly plastic when wet. Hard when dry. Few pores. Very few roots.

2. Profile 32. Kaolinitic Latosolic Sand, Forest phase (KLS,F)

Location: Araguaia Mahogany area, Rio Antonino, transect 6, stake 23 (Lat 6° 21' S; Long. 48° 16' W).

Relief and drainage: Extensive flat terrace, about 10 m above level of nearby rivulet. Somewhat excessively drained, Alt. 200 m *ca*.

Parent material: Pleistocene sediments.

Vegetative cover: Primeval forest with low timber volume. Closed canopy of rather thin trees, and palms. Open undergrowth, with a few thin climbers. Open field layer of seedlings and scattered clumps of grass.

O_1 12-2 cm: Undecomposed plant residues.

O_2 2-0 cm: Partly decomposed plant residues, and fine roots. Surface smooth, with scattered outcasts of parasol ants.

A_{11} 0-0.2 cm: Loose bleached sand.

A_{12} 0.2-10 cm: Dark brown (10 YR 4/3) light loamy fine sand. Single grains,to weak, fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Soft when dry. Many, mainly fine roots. Many large, and common fine pores. Transition clear.

A_3 10-70 cm: Yellowish brown(10 YR 5/4) loamy fine sand. Little coherent porous massive, to weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Slightly hard, to hard and somewhat brittle when dry. Many roots. Many large and fine pores. Transition gradual.

B_{11} 70-140 cm: Reddish yellow(&.5 YR 6/6) loamy fine sand. Little coherent porous massive, to weak medium subangular blocky structure, Moist, very friable. Not sticky and not plastic when wet. Common roots. Common fine pores. Some krotovinas of A_3. Transition diffuse.

With Dutch auger:

B_{12} 140-220 cm: Reddish yellow (7.5-5 YR 5/8) loamy fine sand, Moist, very friable. Not sticky and not plastic when wet. Few roots. Transition diffuse.

B_2 220-290 cm:Reddish yellow (5 YR 6/8) heavy loamy fine sand. Dry. Not sticky and not plastic when wet. A few fine roots. Transition clear.

$B_{3(g)}$ 290-320+ cm: Reddish yellow (7.5 YR 6/8) light fine sandy loam, with common, medium sized,distinct mottles of very pale brown (10 YR 7/4). Moist, very friable. Not sticky and not plastic when wet.

B. Analytic data

1. Granulometric composition is given in Table A-1.
2. Results of attack of fine earth fraction of profiles described above by H_2SO_4, d=1.47, are given in Table A-2.

Table A-1

Granulometric composition of profiles described by Sombroek

Horizon	Depth	Fine earth % 2.0 mm	Coarse sand % 2.0-0.2 mm	Fine sand **	Silt ***	Clay % 0.002 mm	"Natural" clay %	Index of structure
Kaolinitic Yellow Latosol								
A_1	0-20	100	79.1	13.2	1.0	6.7	1.8	73
A_3	20-70	100	68.4	16.4	0.8	14.4	7.9	45
B_1	70-140	100	68.5	14.3	0.4	16.8	10.1	40
B_{21}	140-220	100	62.7	16.5	1.0	19.8	0	100
B^*_{22}	220-320	100	62.2	16.4	0.4	21.0	0	100
Kaolinitic Latosolic Sand, Forest phase								
A_1	0-10	100	16.9	70.6	6.4	6.1	1.4	77
A_3	10-70	100	20.4	64.0	7.7	7.9	1.8	77
B_{11}	70-140	100	12.9	70.0	8.8	8.3	2.6	69
B_{12}	140-220	100	15.5	68.1	7.9	8.5	2.0	76
B_2	220-290	100	14.6	67.2	7.3	10.9	1.2	89
$B_{3(g)}$	290-320	100	13.2	66.3	9.8	10.7	0.2	98

* 100% hyaline and lacteous quartz grains, some of the hyaline ones rolled; some of the grains are corroded, many have ferruginous vernis. Traces of dark iron concretions, turmaline and staurolite.

** % 0.2 - 0.02 mm fraction for Kaolinitic Yellow Latosol.
% 0.2 - 0.05 mm fraction for Kaolinitic Latosolic Sand

*** % 0.02 -0.002 mm fraction for Kaolinitic Yellow Latosol
% 0.05-0.002 mm fraction for Kaolinitic Latosolic Sand

Table A-2

Results of attack of fine earth fraction by H_2SO_4, d=1.47 for profiles described by Sombroek

Horizon	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	P_2O_5 %	$SiO_2:Al_2O_3$ Ki	$SiO_2:(Al_2O_3+Fe_2O_3)$ Kr
Kaolinitic Yellow Latosol							
A_1	4.11	3.80	1.21	0.34	0.03	1.84	1.52
A_3	6.95	6.29	1.72	0.57	0.03	1.88	1.60
B_1	8.62	7.77	1.72	0.67	0.03	1.89	1.65
B_{21}	9.31	8.55	1.92	0.64	0.03	1.85	1.62
B_{22}	9.44	8.69	1.82	0.64	0.03	1.85	1.63
Kaolinitic Latosolic Sand, forest phase							
A_1	2.62	2.06	0.81	0.21	0.03	2.16	1.73
A_3	3.34	3.50	0.81	0.33	0.02	1.62	1.41
B_{11}	3.54	3.54	1.21	0.36	0.02	1.70	1.39
B_{12}	3.68	3.59	0.80	0.36	0.02	1.74	1.52
B_2	4.21	4.05	1.01	0.34	0.02	1.77	1.53
$B_{3(g)}$	4.24	4.05	0.60	0.30	0.02	1.78	1.63

3. Results of chemical analyses are given in Table A-3.
4. Cation exchange data are given in Table A-4.
5. Mineralogical composition of granulometric separates of B_1 and B_{22} horizons of Kaolinitic Yellow Latosols similar to that for which other data are given is given in Table A-5.

Table A-3

Results of chemical analyses for profiles described by Sombroek

Horizon	Moisture equivalent g/100g	C org. %C	N total %N	C/N	pH H_2O	pH KCl	P_2O_5 available mg/100g Truog	P_2O_5 available mg/100g Bray
Kaolinitic Yellow Latosol								
A_1	4.8	0.88	0.06	14.7	4.6	3.9	0.4	1.1
A_3	8.3	0.42	0.03	14.0	4.6	3.9	0.4	0.6
B_1	9.4	0.25	0.03	8.3	4.5	3.8		0.2
B_{21}	9.4	0.18	0.02	9.0	4.5	3.8		0.2
B_{22}	10.1	0.13	0.02	6.5	4.5	3.8		0.1
Kaolinitic Latosolic Sand, forest phase								
A_1	6.8	0.97	0.10	9.7	4.5	3.6		1.3
A_3	6.8	0.41	0.04	10.3	5.1	4.2		0.7
B_{11}	6.4	0.21	0.02	10.5	4.9	4.2		0.3
B_{12}	6.7	0.18	0.02	9.0	5.0	4.2		0.3
B_2	6.0	0.09	0.02	4.5	5.0	4.1		0.3
$B_{3(g)}$	7.2	0.08	0.02	4.0	4.8	4.1		0.3

Table A-4

Cation exchange data for profiles described by Sombroek

(me/100g)

Horizon	exchangeable metallic cations			Sum of cations	Active acidity	pH-dependent acidity	Potential cation exchange capacity	% Base saturation
	Ca^{++} and Mg^{++}	K^{+}	Na^{+}	S	$(Al)^{+}$	H^{+}	T	V
Kaolinitic Yellow Latosol								
A_1	0.48	0.06	0.03	0.57	0.72	2.91	4.20	13.6
A_3	0.32	0.08	0.04	0.44	0.93	2.30	3.67	12.0
B_1	0.28	0.06	0.03	0.37	0.73	1.49	2.59	14.3
B_{21}	0.28	0.07	0.03	0.38	0.64	0.97	1.99	19.1
B_{22}	0.28	0.06	0.03	0.37	0.64	0.37	1.38	26.8
Kaolinitic Latosolic Sand, forest phase								
A_1	0.48	0.06	0.03	0.57	0.93	3.83	5.33	10.7
A_3	0.30	0.06	0.04	0.40	0.52	2.44	3.36	11.9
B_{11}	0.30	0.04	0.07	0.41	0.44	1.62	2.47	16.6
B_{12}	0.30	0.06	0.05	0.41	0.36	0.97	1.74	23.6
B_2	0.30	0.06	0.05	0.41	0.32	0.88	1.61	25.5
$B_{3(g)}$	0.36	0.08	0.08	0.52	0.32	0.85	1.69	30.8

Table A-5

Mineralogical composition of granulometric separates of B_1 and B_{22} horizons of Kaolinitic Yellow Latosols

Separates	Quartz %	Kaolinite %	Limonite (goethite) %	Hematite %	Hydrargillite %	Feldspar %	Percent of sample which separate forms
B_1 (70-140 cm)*							
>80 μ	88	4		8			72.3
16-80 μ	86	5		6		3	2.4
2-16 μ	73	20				7	
<2 μ	3	84	5	5	3		
B_{22}(150-250 cm)**							
>80 μ	97			3			75.9
16-80 μ	100						5.5
2-16 μ	68	14	3	3		12	
<2 μ	6	84	5		5		

* From Guama Imperatriz area

** From Belem area

Appendix II

A Brief Outline of Human Activities in the Brazilian Amazon (980 B.C. - 1975 A.D.)

980 B.C. ^{14}C date of earliest evidence of human settlement in Amazon basin(pottery from Marajo Island). Because of similarity to pottery in Andes, it is thought that these people had some contact with that region and might have planted maize.

∿900 B.C. Manioc cultivation introduced into Amazon.

1000 A.D. Amazonian pottery suggests continued contact with Andean and Caribbean coast cultures.

1494 Line of Treaty of Tordesilhas passes through Amazon mouth officially giving basin to Spain.

1500 Vicente Penzon, a Spaniard, discovers mouth of Amazon.

1536 First Portuguese attempt to settle Amazon region fails.

1542 Francisco Orellana descends Amazon by boat from Ecuador to mouth. Friar Gaspar de Carrajal who kept a journal of trip describes heavy Indian settlement of considerable cultural sophistication along river.

1594-1597 British and Dutch attempt to establish trading posts and sugar plantations in Amazon.

1612 French establish settlement at São Luis

1615 French expelled by Portuguese.

1616 Portuguese, proceding from São Luis, build fort and establish settlement at what is now Belém, at confluence of Guamá and Pará Rivers.

1621 First epidemic of smallpox, introduced by Europeans, reduces indigenous population.

1632. Portuguese make plan for establishment of four posts in Amazon at what are now Bragança, Cametá, Almerim, and confluence of Xingu and Amazon Rivers.

1635 First sugar mill in Amazon established near Cametá on Tocantins River.

1637-1639 Pedro Teixeira journeys from Belem to Quito and back.

1639 Dutch expelled from Amazon valley.

1640-1694 Slaughter, slavery, and disease eliminate most of Indians from river margins except in missionary settlements.

1644 Introduction of cattle into Amazon valley.

1653-1750 Jesuits and other missionary groups established missions throughout the region. They gathered Indians in settlements around the missions where the Indians continued to practice many local customs and enjoyed some degree of protection from slave raiders. Much of present information about lowland Indian customs comes from the records of

these missionaries. By 1751, 50,000 Indians were living in such missions

1669 Fort and settlement established at Manáus. European population of Amazon valley approximately 700.

1680-1692 First cattle ranches established on Marajo Island.

1682-1685 First African slaves brought into Amazon

1700 Export of forest products to Portugal begins: Cacau, sasparilla, cinnamon, rubber. Some attempts made at agriculture but land is found to be less fertile for sugarcane than heavier soils of northeast Brazil. Tobacco and cacau plantations attempted near Cametá.

1727 Ourem founded as post on land route between Belem and São Luis which was way for cattle to be brought from Northeast to Belem for slaughter. Coffee introduced from French Guiana.

1740 Population of Belem was 6,500 but other towns such as Cameta and Vigia already in decline

1750 Treaty of Madrid recognizes Portuguese control of Amazon basin.

1755 Marquis of Pombal assumes power in Portugal and makes sweeping reform of colonial policy: (1) commercial company established to but forest products from Indians and settlers; (2) Jesuits expelled (1759); (3) "Europeanization"of Indian villages attempted. Intermarriage of Indians

with Europeans, use of Portuguese language, and building of European style houses with tile roofs encouraged.

1755-1825 Period of relative prosperity due to reform and efforts of commercial company. Brazil nuts, turtle oil, manatee oil, cinnamon, and other essential oils and rubber exported to Europe, especially Portugal and England. Company also encouraged agriculture: sugarcane, rice, cacau, cloves, tobacco, making implements and slaves available to interested parties. 12,000 slaves were brought into region for this purpose.

1761 Carolina (white) rice introduced from U.S.

1763 Cattle ranches established on natural grasslands in middle Amazon basin.

1796 Botanical garden established in Belem to foster culture of native plants such as cacau and cinnamon.

1803 There were 226 cattle ranches on Marajó Island with 500,000 head of cattle.

1819 German naturalist, Martius, notes good quality of tobacco near Manaus and poor quality of sugar.

1822 Brazil becomes indepemdent of Portugal. Amazon region, having enjoyed considerable prosperity due to commerce with Portugal, was slow to accept independence. At this time, the Amazon region had 85,000-90,000 inhabitants. There were

46 recognized towns, all along the coast or rivers. All of these had fewer than 2,000 inhabitants with the exceptions of Belem with 24,000, Cámeta with 8,000, Espirito Santo de Moju , Macapa, and Santarem, with 2,000 inhabitants each.

1835-1840 Amazon shaken by bloody civil war, known as Cabanagem between laboring (mostly of Indian descent) and commercial(mostly European) interests. Hostilities lasted five years, leaving 40,000 dead. Similar uprisings occurred throughout Brazil in the second half of the nineteenth century. Agriculture in area was ruined: cacau and sugarcane plantations were abandoned. The population of Belém dropped to 15,000. However, increased European demand for rubber saved area from economic ruin. Most of rubber was gathered in 100-mile radius from Belém.

1853 Introduction of steam navigation on Amazon permitted gathering of rubber over wider area, further up Amazon. Rubber boom begins. Despite immigration of rubber gatherers, no labor left over for agriculture and most of food had to be imported.

1858 Governor of Pará, distressed about high imports

of foodstuffs, decides to colonize region east of Belem (Zona Bragantina) with Europeans to provide Belem with foodstuffs.

1867 200 Americans, seeking a place to continue plantation agriculture in South America after Civil War arrive in Santarem but are not successful.

1875 First agricultural colony in Zona Bragantina at Benevides by supposedly French colonists.

1876 Sir Harry Wickham secretly takes Hevea seeds from Brazil to England, which served as base of Southeast Asia rubber plantations.

1877 Drought in Northeast Brazil. Peasants whose crop failed move into cities of Northeast whence Brazilian emperor offers them free steamship passage to Belem or Manaus.

1883-1908 Construction of railroad from Belem to Bragança to facilitate access, to stimulate settlement by immigrants and to provide rapid and relaiable transportation of products.

1890-1905 Water buffalo introduced on Marajo Island.

1897 New drought in Northeast stimulates reopening of colonization effort in Zona Bragantina after recognized failure of previous effort.

1900 Rubber prices begin decline.

1903 Annexation of rich rubber producing area of Acre from Bolivia.

1905 Asian rubber enters market.

1875-1914 Period of active colonization of Zona Bragantina

1912 Bottom drops out of rubber market with large scale appearance of superior Asian product.

1915 Drought in Ceara (Northeast Brazil). 30,000 "Cearenses" settle along Bragantina railroad.

1918-1926 Brazilian government tries to use considerable coffee revenues to buy up rubber to maintain price. Also effort made to establish plantation rubber in Brazil.

1917-1930 Owners of rubber groves try planting other crops such as rice, cotton, sugarcane. Brazilnuts replace rubber as major export product of Pará.

1922 Tobacco experiment station started at Tracuateua.

1926 Henry Ford, irritated by control of rubber price by English and Dutch, secures concession for 10,000 sq. km. from Brazilian government for rubber plantation.

1929 First Japanese immigrants to Amazon introduce jute and black pepper, the latter to become major cash crop of Amazon.

1932 Ford plantation, already beset by problems due to hilliness of terrain, attacked by South American leaf blight, caused by Dothidella (Microcystis) ulei, killing many trees .

1934 Ford makes another attempt, with a larger planta-

tion at Belterra eventually having 2 million trees. Double grafting of highly productive trunks and crowns resistant to leaf blight enabled high production but cost of this operation was high.

1936 Bragantina railroad, not producing a profit since 1926, turned over to Brazilian government.

1946 With Japanese defeat, cheap rubber again available from Southeast Asia and Ford turns over plantation at Belterra to Brazilian government who consigns it to IPEAN.

1951 Founding of SPVEA to coordinate development of Amazon region

1958 First soil survey of Zona Bragantina published revealing omnipresence of soils of low fertility

1960 Construction of Belem-Brasilia highway, first overland link between Amazon and rest of Brazil, completed.

1969 SPVEA replaced by SUDAM modeled after SUDENE, development agency for northeast Brazil.

1970 INCRA (national colonization and land reform agency)founded . Later responsible for Transamazon colonization. Construction of Transamazon highway begun with plan for colonization by smallholders.

1974 Transamazon highway finished but small farmer colonization officially declared failure. Incentives to be given to large-scale enterprises.