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ASSOCIATIONS BETWEEN CACAO (Theobroma cacao) AND SHADE TREES IN SOUTHERN BAHIA, BRAZIL

P. Cabala Rosand*
M. Santana*
A. Cadima Zevallos*

SUMMARY

A review is made of the information on Theobroma - shade tree combinations in the south of Bahía, Brazil. Following a description of the climatic and soil characteristics of the area, the principal shade tree species are presented. Data on biomass production and nutrient cycling for the association of T. cacao - Erythrina spp. are discussed. Practical inferences for the management of T. cacao plantations are deduced from the consideration of nutrient cycling models, and a newly recommended fertilization system is presented.

INTRODUCTION

Originating from the basins of the Amazon and Orinoco rivers, the cacao tree (Theobroma cacao) was introduced into the southern part of Bahia around 1850 (2) and found favourable edapho-climatic conditions as well as the absence of some natural enemies which occur in its original habitat, which facilitated the expansion of the crop. In the last decade this crop has spread to different areas of the Brazilian Amazon, but most of the plantations and production of seeds are found in the southern part of Bahia where more than 600,000 ha exist nowadays (37).

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* Cocoa Research Center, Ilhéus, Bahia, Brazil.

As *T. cacao* is a component of an intermediary stratum of the forest in its original habitat, the "Cabruca" method, which consists of the partial cutting of trees or thinning of the native forest, was adopted as a traditional method for the establishment of new plantations. A variable number of trees are maintained as definite shade. This method permits irregular spacing between plants and very often more than one plant per hole is found due to the use of several seeds during the direct planting. For protection during the development phase the new *T. cacao* trees are generally associated with banana (*Musa* cvs.) or cassava (*Manihot esculenta*).

In accordance to what happened in the productive regions of Western Africa (Ghana and Nigeria), the *T. cacao* in southern Bahia have been predominantly established on soils of medium to high natural fertility indicating the greater demand of this crop in relation to other perennial crops of the tropics, such as the Africa oil palm (*Elaeis guineensis*) and the rubber tree (*Hevea brasiliensis*).

In the past 15 to 18 years new production systems have been developed to increase productivity. These systems include fertilization associated with the removal of excess shade, as well as the use of adapted germplasm for new *T. cacao* plantations. In these new plantations, spacings between *T. cacao* trees have been reduced, and leguminous trees of the *Erythrina* spp. genus are being used as a definite shade.

This paper presents some results of experiments made in Southern Bahia, which examined the advantages of the use of the *T. cacao* - shade tree associations, particularly with respect to nutrient conservation in the agroecosystem, and criteria for fertilizer recommendations.

ENVIRONMENTAL CONDITIONS

The *T. cacao* region, located in the southern part of Bahia, in the northeast part of Brazil, is situated between the coast line and Long. 41º 30'W and between 13º and 18º 30' Lat. S (Fig. 1).

Climate and vegetation

Similarly to most tropical regions, the temperature is relatively uniform during the year with an average of 24ºC (average 26ºC during the summer and never below 18ºC during the winter months) (36). The distribution of rains, which constitutes the main parameter used to differentiate tropical climates for agricultural purposes, permits the distinction of two sub-regions. One is near

the coast with precipitations over 1000 mm well distributed during the year and defining an Udic hydric soil regime (28). The other sub-region which begins between 40 to 60 km from the coast, has a pronounced difference between humid and dry periods with annual precipitations below 750 mm. In these circumstances the Ustic type of soils prevail (28, 36).

Although 10 different types of vegetation have been described in this area, there is a predominance of the *Higrofila perenifolia* (rain forest) and *Tropofila* forest which shows a close correlation with the rainfall distribution as has been described for other tropical regions (28).

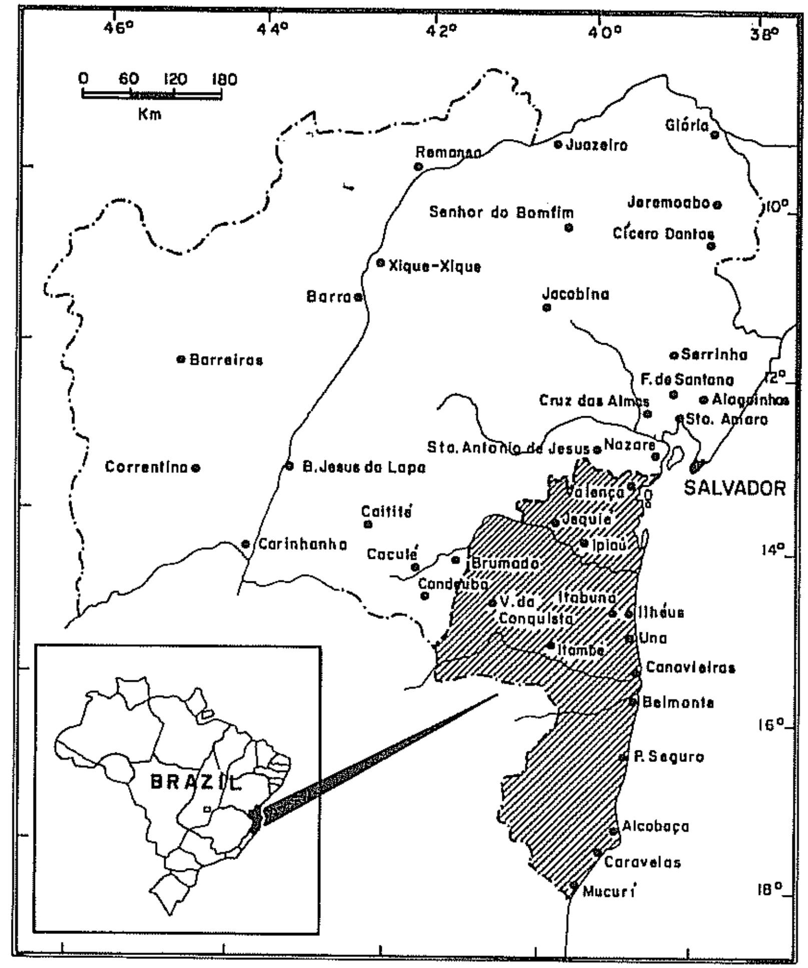

Fig. I. Location of the Cacao Region in Southern State of Bahia, Brazil

Soils and land use

There exists a great variability of soil types including nine of the orders considered in the classification system of the United States Department of Agriculture (35). Among these soils, units classified as Alfisols, Inceptisols and Ultisols (Table 1), with base saturation greater than 30%, have been traditionally used for T. cacao cultivation. Generally these soils are derived from intermediary and basic rocks and present medium to high fertility.

Table 1. Traditional soils used for *Theobroma cacao* in Southern Bahía, Brazil (35)

Order	Suborder	Group	Subgroup	Regional name
Alfisol	Udalf	Tropudalf	Typic Tropudalf	CEPEC modal
Alfisol	Udalf	Tropudalf	Typic Tropudalf	Itabuna modal
Alfisol	Udalf	Tropudalf	Lithic Tropudalf	CEPEC raso diaclasado
Alfisol	Udalf	Tropudalf	Lithic Tropudalf	CEPEC fase rochosa
Alfisol	Udalf	Tropudalf	Oxic Tropudalf	Vargito eutrófico
Alfisol	Ustalf	Haplustalf		Sao Paulinho
Alfisol	Ustalf	Paleustalf	Oxic Paleustalf	Sao Paulinho
Alfisol	Udult	Tropudult	Typic Tropudult	Vargito distrófico
Ultisol	Udult	Tropudult	Orthoxic Tropudult	Nazaré, Itabuna, Morro Redondo, Vargito distrófico
Inceptisol	Tropept	Dystropept	Oxic Dystropept	Rio Branco
Inceptisol	Tropept	Dystropept	Fluventic Dystropept	Aluvial argiloso

Soils of the Oxisol and Ultisol orders with base saturation below 30%, and low natural fertility, have special importance because they cover vast areas in southern Bahia and present a big potential for an increase of the agricultural production in this region.

Large areas (28.5%) of these soils are used as pastures for cattle on an extensive and semi-extensive scale, and a considerable part (55%) includes secondary and remnant primary forests where itinerant agriculture is used on a small scale to produce *M. esculenta*, corn (*Zea mays*) and beans (*Phaseolus* spp.) (24).

The factors which limit the fertility in Alfisols, Ultisols, and Oxisols are represented in the polygonal graphics of Figure 2. The "a" soil **(Typic Tropudalf)**

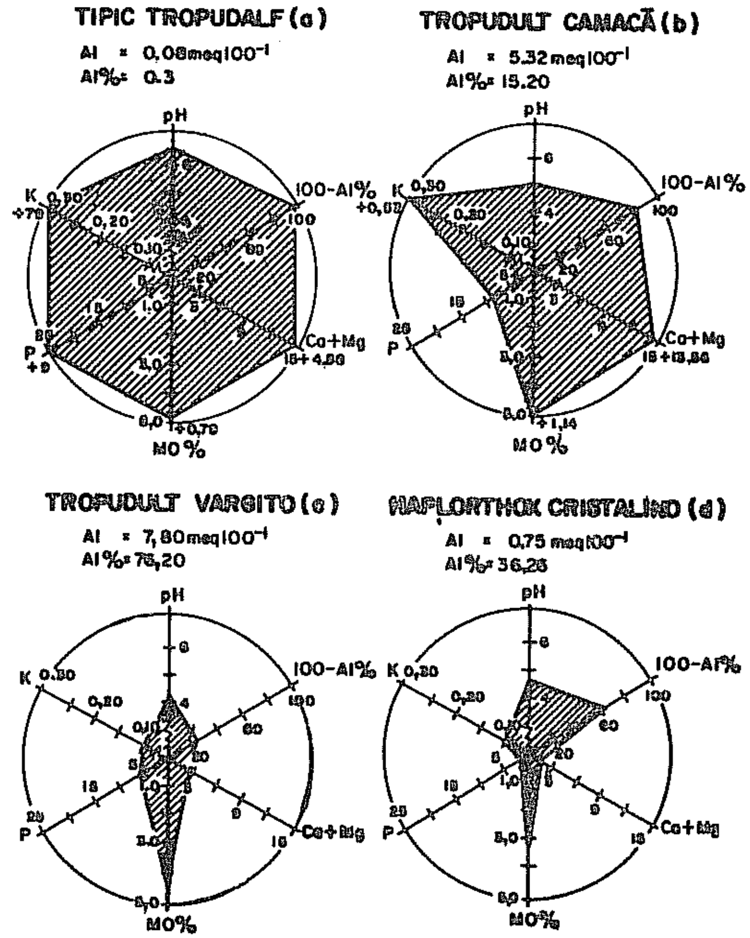

Fig. 2. Comparative fertility of soils of Southern Bahia, Brazil. a) and b) high fertility soils c) low fertility soil with high levels of exchangeable Al and d) low fertility soil presenting low contents of Al (9)

is of high fertility, and does not present chemical limitations. The "b" soil (**Tropudult Camaca**) is more acid, has low levels of P, and although the absolute levels of Al in the exchange complex are high, the percentage of saturation of that element is low because of the high exchangeable quantities of divalent bases. The "c" soil (**Tropudult Vargito**), which represents an acid soil poor in Ca and Mg and with high proportions of exchangeable Al, requires large quantities of dolomitic limestone, not only to attenuate the harmful acidity but also to elevate the levels of exchangeable bases. The "d" soil (**Haplorthox cristalino**) also represents an acid soil, with low buffering power and 1 to 2 meq.100 g^{-1} of Al. In this case the use of liming is more related to the supply of Ca and Mg than to acidity reduction.

T. cacao SHADING

In a survey of 61 plantations of T. cacao under "Cabruca", distributed among 30 southern Bahia municipalities, a relation of 1: 9.5 was found between shade trees and T. cacao, corresponding respectively to 76 ± 0.1 and 724 ± 0.3 trees. ha^{-1} (1). An excess of shade trees, and the necessity to gradually remove some of them, was suggested in order to provide better response to fertilizer additions (8). The shade tree species which occur more frequently in the T. cacao plantations are presented in Table 2 along with data on their heights and the diameter of their canopies (34).

Nevertheless, the need for and the influence of shading have been intensively studied since the pioneer experiments in Trinidad by McDonald (25) and Hardy (19), later repeated under artificial shade conditions by Murray (26, 27). Experiments have also been realized in Ghana, Nigeria (14, 40) and in Brazil (8) where greater productivity was obtained when fertilizers were applied in the absence of shade trees. Cunningham and Burridge also determined a faster growth with greater luminosity if fertilizers were applied, and problems, such as lack of water, air turbulence, weeds, pests and diseases were solved respectively by irrigation, wind breaks and use of pesticides (13).

These experimental results are related to a higher photosynthetic activity, intensification of the metabolic processes and greater consumption of nutrients under high light intensities (3) with a remarkable influence on flowering, flushing, number of leaves and fruits (5, 21).

Although greater flowering and higher productivity is obtained under higher light intensities, the shade trees offer other advantages such as protection of T. cacao from wind and direct insolation damage, as well as soil enrichment and conservation (18). The shade factor must be considered in each locality with respect to the climatic conditions and the soil physical properties as well as nutritional status (18).

Table 2. Canopy diameter and height of native trees of Southern Bahia, used as definitive shade for Theobroma cacao (34)

Common name	Scientific name	Total height (m)	Canopy diameter (m)
Imbiricu	Bombax macrophyllum K. Schum.	30.4	15.7
Pequi preto	Caryocar edule Casarreto C. Barnier	27.2	16.6
Sapucaia	Lecythis pisonis Cambess.	29.0	12.8
Arapacu	Sclerolobium chrysophyllum peopp. Gendl.	26.6	15.3
Massaranduba	Manilka elata	28.2	13.3
Juerana branca	Pithecolobium pedicellare	22.9	15.3
Bacumixa	Sideroxilon vastium Fr. Allem.	27.8	11.9
Faveira	Pterodon rubescens Benth.	20.6	12.9
Mucitaiba	Zollernia aff. mocytaiba Fr. Allem.	27.4	11.4
Bomba d'agua	Hydrogaster trinerve Khlim.	27.6	10.1
Ipé amarelo	Tabebuia serratifolia (Vahl.) Nichols.	23.3	11.3
Louro d'agua	Vochysia sp.	27.3	10.3
Massaranduba paraju	Manilkara coreaceae Miq.	22.7	12.1
Jatobá peloso	Hymenaea aurea Lee & Langenheim	28.7	12.8
Araçá vermelho	Psidium guineense Sw.	25.0	8.6
Oleo copaíba	Copaifera sp.	27.4	12.8
Bicuíba vermelha	Virola gardneri (A.DC.) Warb.	27.4	10.5
Bapeba preta	Chrysophyllum sp.	25.7	8.2
Aderno	Emmotum nitens (Benth.) Miers.	25.1	9.4
Cajazeira	Spondias lutea L.	18.8	11.4
Putumuju gigante	Centrolobium robustum (Vell.) Mart.	28.8	8.0
Arapati	Arapatiella psilophylla (Harms) Cowan	26.2	7.8

The T. cacao - Erythrina spp. associations

Cadima and Alvim observed, in a T. cacao germplasm plot grown on an hydromorphic soil of the Central Experimental Station of Urucuca, that the T. cacao plants located closer to the Erythrina shade trees produced more than those further away (12). To explain this behaviour these authors characterized the root distribution of the T. cacao, near to and far from these leguminous shade trees, establishing that in the former situation the tap-root goes as deep as 90 cm, whereas the tap-root of the more distant plants does not reach 60 cm (Figure 3). The number of roots of different diameters per sample square (30 x 30 cm) also established this difference, since there was a larger number of thin T. cacao roots (0-2 mm) in the 0-30 cm layer close to the Erythrina, than at more distant points. It was also verified that the soil was richer in nutrients, namely total N and exchangeable bases, near to the leguminous trees than at more distant poin

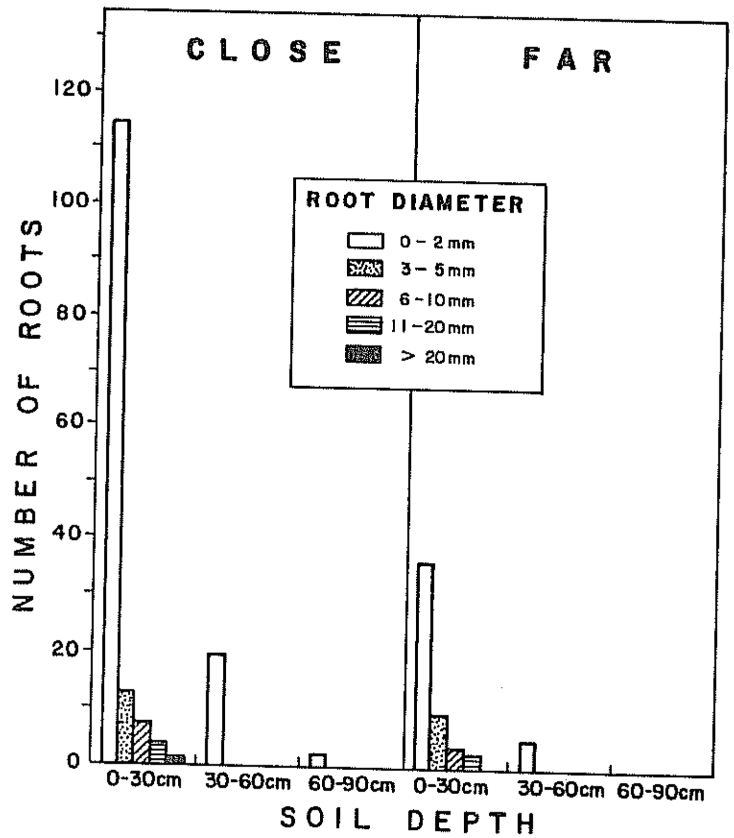

Fig. 3. Number of roots of different diameters found in 30x30cm sample squares close to and far from Erythrina trees in a Theobroma cacao plantation (12)

Santana and Cabala investigated the influence of Erythrina on the percentage of N in the soil, by taking samples at 3 to 9 m from the tree trunks (29). The total amount of N began to drop at a distance of 4.5 m. The Erythrina, apart from presenting a deeper root system than that of adult T. cacao, extends its superficial roots for more than 10 m. Therefore, with the spacings generally used in southern Bahia, a large proportion of the plantations are influenced by the canopy and the root systems of these shade trees.

The leaf fall which generally occurs from July until September, is associated with the sensitivity of Erythrina to photoperiod and thermoperiod which prevail during short days (4). In this period litterfall can be 2t (dry mass) ha^{-1} (29).

Recently, in a "Catongo" T. cacao plantation (**Typic Tropudalf**), shaded with Erythrina fusca, the litterfall and the rain water gathered under the trees were analysed for N, P, K and Mg, according to the methodology described by Santana & Cabala (30). During the first year (July 12, 1981 until July 12, 1982) there was a continuous fall of leaves and branches of both species with seasonal peaks in September, October and June for the leaves of the T. cacao. The largest litter contributions from the Erythrina occurred in July-September and January-March. The greatest leaf fall took place at the end of the dry period confirming the results obtained by Boyer (6). The input from the T. cacao flowers was more intense from December to May, whereas the input from the Erythrina flowers was limited to the period of August to September (31).

The chemical analysis of the residues showed that a large part of the N transferred to the system (143 kg), came from the T. cacao and Erythrina leaves, which represented respectively 49 and 33% of the 8146 $kg.ha^{-1}$ of the residues deposited during the experimental period. In Cameroun, it was estimated that 55 kgN ha^{-1} would be returned to the soil from the T. cacao leaves (6). Generally the Erythrina residues are richer in N than those of the T. cacao and this leguminous tree has a high production of nodules (29).

The rate of litter decomposition in T. cacao plantations varies according to the type of the residue, the species and the environmental conditions (30). Generally the residues of Erythrina decompose faster than those of T. cacao. However, most of the components of both species contained only half of their initial weight after 6-9 months (Figure 4). It is believed that in natural conditions, where the residues remain in a more direct contact with the decomposing agents and the soil organic fraction, that the process of decomposition must be faster.

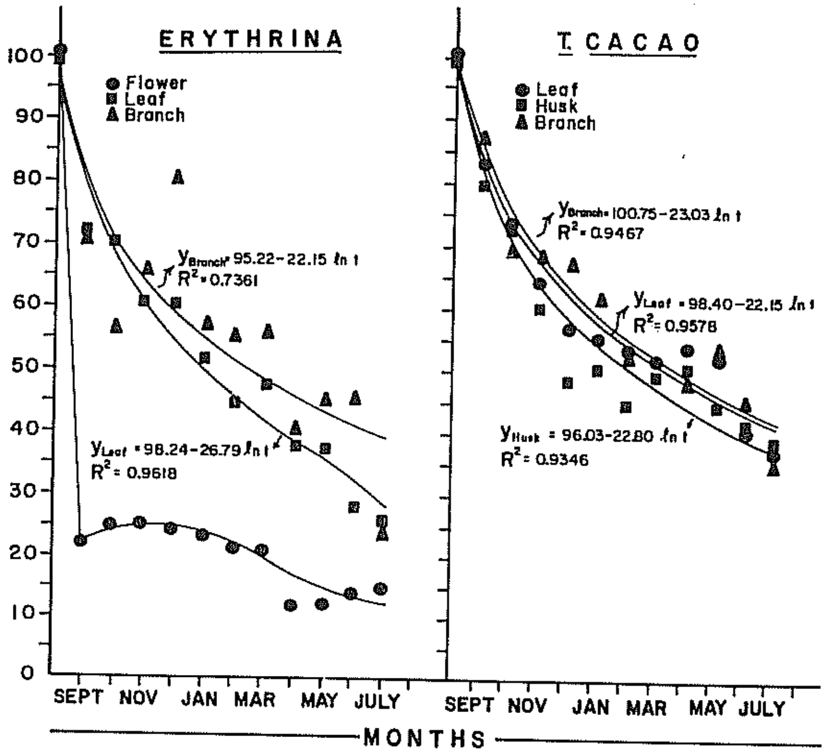

Fig. 4. Rate of decomposition and regressions for Erythrina and Theobroma cacao residues (30). t = time (months).

The nutrient content of the residues represents an important contribution to the T. cacao-Erythrina association especially in respect to N, Ca and Mg (Table 3) (31). The amount of K in T. cacao husks is high, showing the advantage of leaving them in the growing area. Important contributions of N, K, Ca and Mg were also observed in the rain water collected in the plantation, which results from the washing of the leaves. The quantities of nutrients removed from the system in the T. cacao seeds, and lost through leaching, are inferior to the inputs (litter and rain) and, depending on the mineralization rate, they could almost satisfy the total needs of the T. cacao plantation in the productive stage (31). The litterfall during the second and third year of investigation showed a decrease in relation to the first year due to the death of some T. cacao, resulting apparently from the rehabilitation of adjacent T. cacao areas and over-production caused by manual pollinization.

Table 3. Partial balance of nutrients in a 'Catongo' Theobroma cacao plantation shaded with Erythrina ($kg.ha^{-1}$) (31)

	INPUT				LOSSES	
	Litter residues* 1st. year	Litter residues* 2nd year	Husks**	Rain drip	Harvest**	Leaching
N	143.0	81.0	10 - 12	22.9	22	18.2***
P	13.0	13.9	5	2.8	5	0.5
K	34.4	17.4	40 - 42	21.4	10	2.2
Ca	180.7	142.5	1	17.9	1	53.6
Mg	63.2	42.3	3	11.7	3	37.6

* Corresponding to litterfall of 8,146 and 5,994 $kg.ha^{-1}$ in the first and second years respectively.
** Relative to 1,000 kg of dry matter.
*** As NO_3 and NH_4.

PRACTICAL INFERENCES

The development of organic material and nutrient cycling models for the interpretation of the functioning of an ecosystem, as an extension of forest ecosystem studies, is an aspect of growing interest for modern ecology (16). The organic and mineral reserves are located in the phytomass of the forest, sub-forest, epiphytes, litter and in the soil (16). The transference processes occur through rain and the production of residues which after decomposition release nutrients. In this scheme the participation of all living organisms and an appropriate management should be considered. In forest ecosystems developed on poor soils, as occurs in the Amazon Region, most of the mineral reserves are concentrated in the phytomass, in the litter and in the organic fraction of the soil (22). This type of vegetation has developed efficient mechanisms for nutrient utilization and conservation, to limit leaching through the soil profile.

The application of these models to T. cacao shade tree associations is still unclear on some aspects (17). Apart from the CATIE experiments in Turrialba, Costa Rica, studies have mainly been realized in existing T. cacao plantations. An understanding of the reserves and the transferences, beginning with the establishment phase, would be extremely useful for plantation management purposes as well as from the conservation point of view. Different technological options such as greater or lesser degrees of shading could be contrasted.

An estimate of the nutrient needs of T. cacao in different stages of development, based on the analyses of the different parts of the plant, was presented by Thong and Ng (Table 4) (38). P and Mg were absorbed in relatively small quantities whilst K needs were practically equivalent to those for N and Ca. These authors also verified, during the nursing period and the development stages, that the leaf is the most important component for nutrient storage. However, in the productive stage, leaves accumulate nearly the same quantity of nutrients as branches plus stem, with the exception of the K and Zn which predominate in the branches.

Table 4. Estimated quantities of nutrients ($kg.ha^{-1}$) absorbed by Theobroma cacao at different stages of development (38)

Stage of development	Plant age (months)	Average nutrient requirements						
		N	P	K	Ca	Mg	Mn	Zn
Nursery	5 - 12	2.4	0.6	2.4	2.3	1.1	0.04	0.01
Juvenile	28	136	14	151	113	47	3.9	0.5
Adult	50 - 87	438	48	633	373	129	6.1	1.5

It is still not known if these quantities of nutrients would be easily available in an agroecosystem of T. cacao, taking into consideration the efficiency of the root system of T. cacao and the competition which exists from the provisional shade species and the weeds. In this context, information must be obtained about the available reserves in the soil, and also about its capacity to supply nutrients to the plants during the establishment of the agroecosystem. In an experiment realized for this purpose, on three soils of southern Bahia, a clear difference was observed in the soil's capacity to release nutrients (Table 5). The **Tropudalf** soil presented a high capacity to release nutrients in comparison to the **Haplorthox** and the **Haplusthox** soils, in which P was the most deficient nutrient. This is consistent with earlier results obtained for all the southern regions of Bahia (7).

In the initial pre-production stage of T. cacao growth, split applications of the nutrients will surely contribute to a better development of the plantation

Table 5. Successive nutrient extractions ($kg.ha^{-1}$) by NH_4NO_3 of three soils of Southern Bahia (dilution 1:10 soil:water)

Extraction Nº	Soil	P (cm)		K		Ca		Mg	
		0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
1	CEPEC*	58	80	1,141	346	670	278	4,007	4,270
	UNA**	21	20	71	60	16	4	82	50
	AGUA SUMIDA***	13	13	126	77	57	22	214	119
2	CEPEC	31	54	482	40	73	40	1,900	930
	UNA	6	4	11	8	2	0	15	7
	AGUA SUMIDA	3	3	23	21	7	3	38	34
3	CEPEC	10	20	296	342	8	5	404	559
	UNA	0	0	4	2	0	0	6	8
	AGUA SUMIDA	0	0	4	5	0	0	16	16
4	CEPEC	0	0	192	251	0	0	291	374
	UNA	0	0	0	0	0	0	3	2
	AGUA SUMIDA	0	0	0	0	0	0	6	6
5	CEPEC	0	0	71	83	0	0	172	223
	UNA	0	0	0	0	0	0	0	0
	AGUA SUMIDA	0	0	0	0	0	0	0	0
6	CEPEC	0	0	29	30	0	0	87	121
	UNA	0	0	0	0	0	0	0	0
	AGUA SUMIDA	0	0	0	0	0	0	0	0
7	CEPEC	0	0	18	16	0	0	37	58
	UNA	0	0	0	0	0	0	0	0
	AGUA SUMIDA	0	0	0	0	0	0	0	0
8	CEPEC	0	0	10	7	0	0	13	24
	UNA	0	0	0	0	0	0	0	0
	AGUA SUMIDA	0	0	0	0	0	0	0	0
TOTAL	CEPEC	99	154	2,239	1,516	751	423	6,912	6,559
	UNA	27	24	86	70	18	4	106	67
	AGUA SUMIDA	16	17	153	103	65	25	273	175

* Tropudalf ** Haplorthox *** Haplusthox

until the soil surface is completely covered. In the production stage, depending on the plantation management system, the production levels and the losses which occur from the agroecosystem, maintenance fertilization may be recommended. Santana and Cabala (31) compiled information from various authors on the nutrient content in the seeds and husks of the T. cacao fruits (Table 6) (32). Even allowing for the large variation of the data reported, this gives an idea of the amount of nutrients extracted along with the production of seeds. However, the husks do generally remain in the growing area.

Table 6. Nutrient contents (kg) of dry Theobroma cacao beans and husks (32)

	N	P_2O_5	K_2O	CaO	MgO	Reference
Dry Beans*	20.0	9.6	12.6	3.0	5.0	(15)
	24.0	12.0	19.0	-	-	(39)
	20.0	15.8	21.3	2.0	11.0	(23)
	20.4	8.3	12.6	1.5	4.5	(38)
	22.0	11.7	12.1	1.5	5.1	***
	20.0	5.0	53.0	-	-	(20)
Husks**	10.6	3.0	52.0	5.3	4.2	(38)
	12.0	2.5	46.6	7.4	5.9	***
	10.4	1.7	38.5	2.6	3.5	(23)

* 1,000 kg
** Cacao husks per 1,000 kg of dry beans
*** Santana and Cabala, unpublished data

This type of information, together with data on the reserves in agroecosystems shaded with leguminous trees of the Erythrina genus, has been taken into account in the presently recommended fertilization system (Table 7) (10).

Table 7. New fertilizer recommendations, and criteria to apply lime to Theobroma cacao plantations in Southern Bahía, Brazil (10)

a) LIMING

	Ca + Mg (meq.100 cm^{-3})	Al% (100 Al/Al+S)	Limestone requirement ($t.ha^{-1}$)
Oxisols	<3.0	-	3.0 - meq. (Ca+Mg)
Ultisols (Tropudult)	-	>30	[meq.Al(Al%-30)/Al%] x1.5

b) FERTILIZATION

Soil level	Available P ($ug.cm^{-3}$)	N *	N **	P_2O_5	K_2O ***	K_2O ****	K_2O *****
Very low	0 - 4	00	30	90	00	30	60
Low	5 - 8	00	30	60	00	30	60
Medium	9 - 16	00	30	30	00	30	60
High	17 - 30	00	30	00	00	30	60
Very high	> 30	00	30	00	00	30	60

* Plantation with Erythrina shading (30 - 40 $trees.ha^{-1}$).
** Plantation with heterogeneous shading.
*** Traditional soils with high level of K.
**** Soils with medium level of K.
***** Soils poor in K.

It is also believed that the use of T. cacao cultivars which absorb nutrients (mainly P) more effeciently (11) will permit a better utilization of the nutrient reserves in the agroecosystem and an exploitation requiring minor inputs. In this respect, the investigations of mycorrhizae associations, the tolerance of T. cacao cultivars to adverse environments such as soil acidity (33) and water limitations, assume an important role.

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NUTRIENT CYCLING IN AGROFORESTRY SYSTEMS OF COFFEE (Coffea arabica) WITH SHADE TREES IN THE CENTRAL EXPERIMENT OF CATIE*

H.W. Fassbender**

SUMMARY

A description is given of the N, P and K cycles in shaded coffee (Coffea arabica) plantations of the Central Experiment of CATIE. The N cycle of the coffee-poró (Erythrina poeppigiana) association is characterized by a total absorbtion after 5 years of 912 kg $N.ha^{-1}$, which is much higher than that in the coffee-laurel (Cordia alliodora) association where the total absorbtion reached 605 kg $N.ha^{-1}$. The rate of N fixation was hence estimated as 60 kg $N.ha^{-1}.a^{-1}$. N fertilization of these agroforestry systems is subsequently discussed.

The accumulation of P was also greater below E. poeppigiana than below C. alliodora (16.1 and 12.4 kg $P.ha^{-1}.a^{-1}$, respectively). The interpretation of the P cycle is difficult due to the fixation of P in the soil. The losses of exchangeable K, Ca and Mg from the soil are notable. This is possibly due to acidification resulting from the mineralization of organic material.

INTRODUCTION

The nutrient cycles of agroforestry systems are complex since they not only present multiple interactions of soil processes but also spatial and temporal fluctuations of the crops involved (1, 5, 11). In order to develop adequate research methodologies, the implications of specific cases should be derived and generalized.

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* Translated from the Spanish by M. Major.

** Faculty of Forestry Techniques, Goettingen, Federal Republic of Germany.