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Modelling agroforestry systems of cacao (*Theobroma cacao*) with laurel (*Cordia alliodora*) and poro (*Erythrina poeppigiana*) in Costa Rica
I. Inventory of organic matter and nutrients

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Abstract. The agroforestry systems of cacao (*Theobroma cacao*) under laurel (*Cordia alliodora*) and cacao under poro (*Erythrina poeppigiana*) were studied at CATIE, Turrialba, Costa Rica. An inventory was taken of the organic matter and nutrients (N, P, K, Ca, and Mg) separating the species into their compartments (leaves, branches, trunks and roots). Studies of the litter and of the mineral soil (0–45 cm) yielded these results:

	Theobroma under *Cordia alliodora*		*Theobroma* under *Erythrina poeppigiana*	
	Vegetation + Litter	Soil	Vegetation + Litter	Soil
Organic matter ($t \cdot ha^{-1}$)	50.3	168.3	39.2	198.4
Nitrogen ($kg \cdot ha^{-1}$)	446.4	7991	498.8	9555
Phosphorous ($kg \cdot ha^{-1}$)	50.3	3594	46.9	3243
Potassium ($kg \cdot ha^{-1}$)	373.4	577	315.9	713
Calcium ($kg \cdot ha^{-1}$)	473.0	2410	433.5	3082
Magnesium ($kg \cdot ha^{-1}$)	157.4	551	118.4	651

Patterns of nutrient accumulation are discussed in relation to the characteristics of these agroforestry systems.

Introduction

Considerable attention has been given to agroforestry systems during the last decade [6, 7, 13, 20, 21, 24]. According to Combe and Budowski [7], an important number of combinations of agricultural crops interplanted with timber trees, used as high shade and/or soil improvers, fall within the field of agroforestry techniques. There are multiple interactions between the species involved in a given production system, especially relating to climatic conditions (solar radiation, temperature, relative humidity, rainfall, wind), soils (organic matter, nutrients, water), plant health (diseases, pests) and bioecology (symbiosis, alotropia, alleopathy, parasitism) [4, 8, 15].

The utilization of shade trees with Cacao (*Theobroma cacao*) is widespread in Latin America. Some of the following permanent shade tree species may be found [7, 11, 19, 20, 24]:

– Fruits: Coconut (*Cocus nucifera*); Citrus (*Citrus spp.*); Avocado, palta, (*Persea americana*); Guayaba (*Pesidium guajava*); Plantain, banana (*Musa spp.*); Papaya (*Carica papaya*); Mamay (*Cucuma mamosa*); Cashew (*Anacardium occidentalis*); Zapote (*Mamonosum alocarpus*); Pear Chestnut (*Bartholetia excelsa*); Pejibaye, Pupunha, (*Bactris gasipaes*).

– Timber: Cedar (*Cedrella odorata*); Laurel (*Cordia alliodora*); Higuerón (*Ficus spp.*); Oak (*Tabebuja spp.*); Sea Almond (*Terminalia catappa*).

– Legumes: Guaba, guama, (*Inga spp.*); Poró, Bucare, Anauco, Cachimbo, (*Erythrina spp.*); Madero Negro (*Gliricidia sepium*); Albizia (*Albizia spp.*); Acacia (*Acacia spp.*).

The utilization of these agroforestry systems varies widely within regions and countries [11]. The different species usually have multiple uses (food fruit, firewood, timber, windbreaks, etc.).

The use of mathematical models for describing the behaviour of natural ecosystems and of production systems has increased markedly in recent years [2, 8, 14, 15, 16, 17, 22, 25, 26]. In order to formulate models for organic matter and nutrients, it is necessary to take an inventory of the reserves and to describe the flows between parts or compartments of the system.

Figure 1 represents a model for the organic matter and nutrient cycles for *T. cacao* under shade trees [2, 8, 15, 16]. The system's components are described according to their compartments (leaves, branches, trunks, roots, fruits, flowers). The flows between the system's components include the depositing of plant residues and the pruning of the shade trees. The inputs to the system include photosynthesis, rainfall (water and dissolved elements), fertilization and the microbial fixation of nitrogen. The outputs from the system include the water responsible for the leaching of nutrients, and the harvests of fruit and timber.

Models of this type have rarely been applied to agroforestry systems. There are, however, partial studies of organic matter and nutrient cycles in association with *T. cacao* [2, 3, 8, 15, 16, 22, 28]. Based on work done at CATIE, Turrialba, Costa Rica, models have been devised for the agroforestry associations of *T. cacao* under *C. alliodora* and under *E. poeppigiana*. These models will be presented in this series of publications.

Materials and methods

The experimental site

The studies were carried out at the Central Experiment of the Department of Crop Production at CATIE in Turrialba, Costa Rica. Of the 18 original

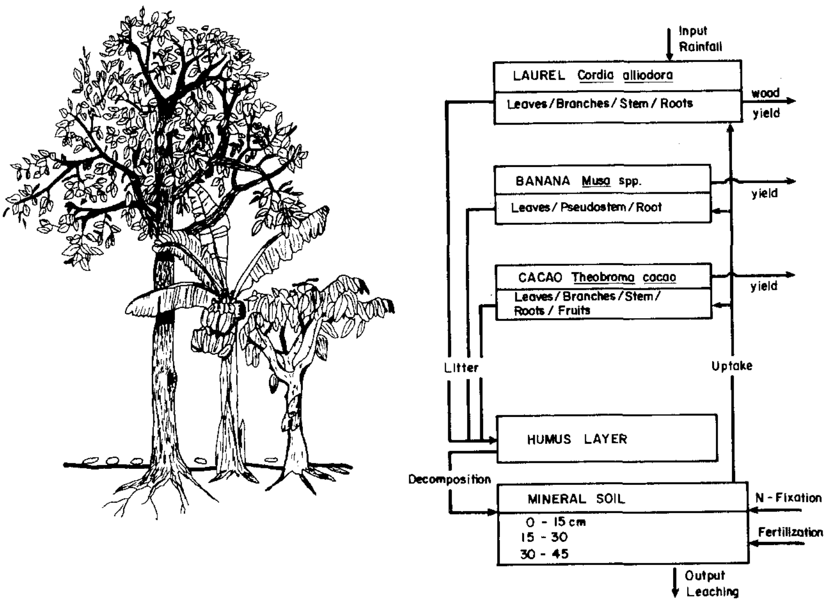

Figure 1. Schematic representations of an agroforestry system of cacao in association with shade trees and the model for organic matter and nutrients.

treatments considered [10], the following were chosen for the present study:

- *T. cacao* under *C. alliodora*
- *T. cacao* under *E. peoppigiana*

The Turrialba region is located at 9°53′N and 88°38′W and has an altitude of between 600–650 m above sea level.

The soil of the experimental site belongs to the normal Institute series. It is classified as typic Dystropepts, fine, mixed isohyperthermic [1]. The texture is clay loam. The soil has level topography, poor drainage, and is of fluvial-lacustrine origin. See Table 1 for soil analysis.

The annual average temperature (23 years) is 22.3°C; the minimum and maximum temperatures reach 17.7 °C and 27.0 °C respectively. The average annual rainfall (38 years) is 2648 mm with an average of 246 days of rain per year. Average monthly rainfall of under 100 mm was recorded only in the month of March (70 mm). The monthly average relative humidity is 87.6%.

In August 1977 *T. cacao* hybrids (Catongo x Pound) were planted at 3 x 3 meter spacing (1111 trees.ha-1) with shade trees *C. alliodora* and *E. poeppigiana* interplanted at 6 x 6 meter spacing (278 trees.ha-1) in plots measuring 18 x 18 meters with four repetitions in random blocks.

An initial application of fertilizer (13.9 kg N.ha-1, 18.2 kg P.ha-1, 11.5 kg K.ha-1) was given to the *T. cacao* and *C. alliodora*. The *E. poeppigiana* was not fertilized. Beginning in 1978 the *T. cacao* was fertilized annually with 18–10–6–5 (0.15 kg. plant which is equivalent to 120 kg N,

Table 1. Physical and chemical characteristics of the soil of the *T. cacao* and *E. poeppigiana* system

cm	Apparent density $g.cm^{-3}$	Sand %	Silt %	Clay %	pH X	pH ±	Humus %	Humus ±	N-total %	N-total ±
0–15	1.15	29	32	38	3.80	0.08	4.76	0.58	0.22	0.02
15–30	1.29	32	31	37	3.88	0.09	3.87	0.32	0.19	0.01
30–45	1.24	26	31	43	4.12	0.22	2.23	0.29	0.11	0.01
cm	P total $mg.kg^{-1}$	±	K $meq.100^{-1}$ g	±	Ca $meq.100^{-1}$ g	±	Mg $meq.100^{-1}$	±		
0.15	583	49	0.57	0.20	2.40	0.23	0.95	0.13		
15–30	616	68	0.27	0.04	2.65	0.21	0.98	0.05		
30–45	559	57	0.17	0.06	3.27	0.30	1.03	0.05		

29.3 kg P, 33.0 kg K and 20.0 kg Mg . ha-1). The *T. cacao* bushes were pruned to remove suckers and occasionally to remove dead wood. The *E. poeppigiana* were pruned for the first time in 1981 and from then on, annually or semi-annually.

Measurement of organic reserves

Measurement of *T. cacao* yields began in June 1979 [10]. The growth of the *C. alliodora* was recorded by measuring the height and the breast height diameter [10, 22]. Beginning in November 1981 measurements were made of the production of plant residues [22].

Measurement of the *T.cacao* and *E. poeppigiana* biomass was made in March 1982, when the plantations were 4½ years old, and of the *C. alliodora* biomass in November 1982. (5 years old).

In order to measure the biomass of *T. cacao,* 16 trees were chosen per system (i.e., 4 per plot) from the plot's central rows. The heights and diameters of the trunks and branches were measured. The volume was then multiplied by the specific weight of the wood (0.33 g cm^{-3}, estimated from samples taken with a Pressler borer). The number of leaves per tree were counted. From ten samples of 10 leaves, the moisture content was determined (using a forced ventilation oven at 70 °C for 24 h). Thus the dry above ground biomass of each hectare was calculated.

The data for the *E. poeppigiana* biomass was based on the volume measurement of all the trunks in the plot, and the specific weight of the wood (0.24 g cm^{-3}, estimated from samples taken with a Pressler borer). The biomass of branches and leaves is based on the material from the pruning of 8 trees (2 trees per plot) in March and September 1982 in which all of the material above 2.6 m was cut. The fresh weight of the leaves and branches was recorded. Sixteen samples were oven-dried and the moisture content was measured, and the dry weight per hectare calculated.

The biomass of the *C. alliodora* trunks was calculated from the heights and diameters of all of the trees and the specific weight of the wood (0.44 g cm^{-3}). Eight trees were cut down in order to determine the biomass of the leaves and branches. The branches and leaves were weighed and with the data of moisture content from 16 samples, the organic reserves per hectare were calculated.

To determine the biomass of fine roots ($\leqq$ 20 mm in diameter), a metal ring (27.4 cm in diameter and 15 cm in height) was introduced into the soil at depths of 0–15, 15–30, and 30–45 cm with 16 repetitions per treatment. The roots were separated from the soil with water at normal pressure and were classified into two groups: smaller than 5 mm; and between 5 and $\leqq$ 20 mm. The samples were dried and their dry weight per hectare calculated.

The organic matter from the litter layer was sampled with wooden sampling squares (0.25 m^2), 16 repetitions per treatment. The samples of decomposing organic matter were dried and weighed so as to calculate their weight per hectare.

Mineral soil samples were taken with 5 cores per plot at depths of 0–15, 15–30 and 30–45 cm and their humus content was analyzed [9]. For each depth the mean values were calculated. The apparent density at the depths cited were measured using cylinders of 250 cm^3 volume with eight samples per depth. Based on this data, the organic matter per hectare was calculated.

Measurement of mineral reserves

The plant samples, separated by species (*T. cacao, C. alliodora* and *E. poeppigiana*) were dried and prepared for chemical analysis by passing them through a Willey mill with a 40 mesh. Litter samples were treated in the same way. The following analysis methods [9] were utilized:

- Nitrogen was determined by the Kjehldal method, digested with sulphuric acid and titrated with boric acid.
- Phosphorus, digested with a mixture of nitric acid and perchoric acids, and determined by the sulphur-molybdenum-blue complex.
- Potassium, calcium and magnesium determined by atomic absorption spectrophotometry on the solution from the nitroperchloric digestion.

The soil samples were analyzed in the same way for total nitrogen (Kjehldal), total phosphorus (nitroperchloric digestion); potassium, calcium and magnesium exchangeable with ammonium acetate (pH 7.0) and pH in $CaCl_2$. The soil moniture was determined using the Bouyucos method [9].

Results and discussion

Physical and chemical characteristics of the soil

Table 1 presents the results from the soil analysis of the plots of *T. cacao* under the *E. poeppigiana* at the beginning of the experiment (1977). The pH values are homogeneous and acid. The content of organic mater is high and decreases normally with soil depth. These characteristics are similar for total nitrogen and phosphorus. The values of the exchangeable bases are uniformly high, especially of potassium.

The coefficients of variation of all of the findings are high, ranging between 10 and 50 percent. This leads to difficulties in interpreting the chemical changes of the soil as a function of time.

Organic matter reserves

The total dry biomass in each system is shown in Table 2.

The total biomass is higher in the *C. alliodora* system. The coefficients of variation obtained for the different compartments, including the soil, range between 6 and 40% and are considered normal.

Practically no difference exists in the production of aerial biomass of cacao under the two shade trees. This leads one to think that under these experimental conditions, the different types of shade have the same effect.

Table 2. Dry biomass and soil organic matter ($t.ha^{-1}$) in the systems studied

	T.cacao	*C.alliodora*	*T.cacao*	*E.poeppigiana*
Leaves	2.97	3.41	2.83	3.27
Branches	4.04	4.75	3.03	9.31
Trunks	2.80	23.71	2.51	9.32
Fine roots	4.19		1.78	
Litter	4.45		7.06	
Subtotal				
Vegetation	50.32		39.11	
Mineral soil	168.31		198.38	
Total in the system	218.63		237.49	

However, this conclusion may he verified only by recording and comparing microclimatic data: e.g., air temperatures. In the other hand, it seems a little contradictory that the biomass production of *T. cacao* under *C. alliodora* is slightly greater than the biomass produced under *E. poeppigiana* if one considers that the initial pruning of *E. poeppigiana* would allow the *T. cacao* to receive more light and consequently reach higher production. It should be pointed out that the *T. cacao* was pruned several times during the experiment and this data was not recorded. Likewise, note that the greater part of the aerial biomass (70%) is concentrated in the branches and leaves of the *T. cacao* produced under *C. alliodora* and these are precisely the organs which are the object of pruning.

It is difficult to compare the data of dry biomass from this study with other data since few studies exist and those which are reported refer to plantations having widely different conditions of climate, soil management, age, density and shade cover. For example, Boyer [3] reports on a study done in the Cameroons with 30 year old plantations having an average density of 1000 *T. cacao* trees . ha^{-1}, which had a total dry biomass production of trunks and branches of 10 t . ha^{-1} under conditions of moderate shade and of 15 t . ha^{-1} without shade. Aranguren, Escalante and Herrera [2] report that in 30 year old Venezuelan plantations having a density of 977 *T. cacao* trees.ha^{-1} and with a shade density of 566 trees.ha^{-1}, (mainly *Erythrina* spp., *Castilloa elástica* and *Artocarpus elástica*), the total biomass accumulation of leaves, trunks and branches is 17.1 t . ha^{-1}. Finally, Thong and Ng [29] working in Malaysia with *T. cacao* under 30% shade conditions, indicate an average value of reserves accumulated in leaves, trunks and branches of 5 years old *T. cacao* of 36.1 kg per tree. This value is 4.5 times greater than the value observed in this study for *T. cacao* under *C. alliodora* (8.8 kg . $tree^{-1}$) and for cacao under *E. poeppigiana* (7.53 kg . $tree^{-1}$).

With respect to the total biomass of *C. alliodora,* no comparable data could be found. At the age of five years old the laurel has a height of 11.2 m and an average diameter of 21.8 cm with a volume of 54 m^3.ha^{-1}. The biomass production of *C. alliodora* greatly exceeds that of *E. poeppigiana.* However, it is interesting to note that the distribution of biomass is completely different according to the species; whereas *C. alliodora* accumulates

Table 3. Determination of nutrient element content in the vegetation components of *T. cacao* under *C. alliodora* and *T. cacao* with *E. poeppigiana* (percent)

	T. cacao (1) – *C. alliodora* (2)								*T. cacao* (3) – *E. poeppigiana* (4)							
	Leaves		Branches		Trunks		Roots	Litter	Leaves		Branches		Trunks		Roots	Litter
System	1	2	1	2	1	2			3	4	3	4	3	4		
N	1.88	2.79	0.61	0.91	0.37	0.40	0.92	1.71	2.08	3.10	1.04	1.19	0.50	0.54	1.23	1.58
P	0.12	0.24	0.13	0.19	0.13	0 05	0.10	0.11	0.12	0.24	0.13	0.14	0.10	0.06	0.13	0.12
K	1.01	2.28	1.14	1.18	0.78	0.46	0.51	0.22	0.56	1.30	0.64	1.33	0.56	0.76	0.99	0.17
Ca	1.40	1.72	1.16	0.46	0.40	0.54	1.06	1.90	1.28	1.63	1.26	1.24	0.84	0.72	1.08	1.18
Mg	0.54	0.82	0.32	0.26	0.46	0.17	0.33	0.48	0.34	0.49	0.20	0.42	0.32	0.24	0.26	0.18

Table 4. Nitrogen accumulation in the systems *Cordia alliodora – theobroma cacao* and *Erythrina poeppigiana – Theobroma cacao* in Turrialba (this study) and in the system *Theobroma cacao* with legume shade trees in Caracas, Venezuela (2) (kg $N.ha^{-1}$)

	T.cacao		*C. alliodora*	*T.cacao*		*E. poeppigiana*	*T.cacao* (2)
Leaves	55.8		95.1	58.8		101.4	45
Branches	32.7		43.1	31.5		110.8	149
Trunks	10.3		94.8	12.5		50.3	
Fine roots		38.5			22.0		88
Litter		76.1			111.5		37
Subtotal Vegetation		446.4			498.8		302
Soil		7991			9555		34520
System total		8437.4			10053.8		34822

the greater part of its biomass in trunks the *E. poeppigiana* biomass is distributed equally between trunks and branches. On the other hand, *E. poeppigiana* exceeds *C. alliodora* in the production of biomass of its branches and leaves. The measurement of the biomass of the leaves and branches of *E. poeppigiana* is based on the total of two pruning techniques. Data of the total biomass of *E. poeppigiana* in *T. cacao* plantations has not yet been published. However, the value obtained here ($12.6\,t.ha^{-1}$) may be considered normal. It will be necessary to continue to measure the biomass from prunings in subsequent years in order to obtain a clearer idea of the variation of this important parameter.

It should be noted that the system with *C. alliodora* has a greater root biomasss than the system with *E. poeppigiana.* Also in both systems measurements of roots with diameters less than 5 mm have a lower coefficient of variation (between 14 and 16%) than measurements of roots with diameters of 5 to 20 mm whose coefficient of variation is 87%. In addition, roots having a diameter of less than 5 mm represent 63% of the total root biomass of *C. alliodora* and 66% of that of *E. poeppigiana.*

Another factor limiting the conclusions which may be drawn is the depth at which the root samples were taken. For example, Cadima and Alvim [5] observed in Bahía, Brasil, in *T. cacao* planted at 4 x 4 m spacings with *E. fusca* shade at 16 x 16 m spacings, that the *T. cacao* near the *E. fusca* were able to extend their fine root systems down to a depth of 90 cm. This allows for the possibility that with a sample taken at a greater depth, the root biomass may be greater with *E. poeppigiana* than with *C. alliodora.* It is difficult to make comparisons of root biomass with other studies since this parameter varies greatly according to species, soil type, plantation age, density, and above all, depth of the sample. Thus, Ewell [12], studying 2.5 year old *T. cacao* under *C. alliodora,* found a root biomass of $2.71\,t.ha^{-1}$ for diameters of up to 20 mm and at a sample depth of 25 cm. On the other hand, Kummerow and Alvim [23] report from Bahía, Brasil, that in 11

Table 5. P accumulation in the studied systems (kg $P.ha^{-1}$)

	T.cacao		*C.alliodora*	*T.cacao*		*E. poeppigiana*
Leaves	3.5		8.1	3.4		7.8
Branches	5.2		9.0	3.9		13.0
Trunks	3.6		11.8	2.5		5.5
Fine roots		4.2			2.3	
Litter		4.9			8.5	
Subtotal						
Vegetation		50.3			46.9	
Soil		3594			3243	
System total		3644.3			3289.9	

years old *T. cacao* planted at 3 x 3 m spacing under *E. fusca* at 24 x 24 m spacings, the root biomass was 10 t.ha^{-1} for *T. cacao* roots up to 20 mm in diameter and to a sample depth of 10 cm.

The value of dry biomass of the litter layer is greater in the assocation with *E. poeppigiana* than with *C. alliodora.* It should be noted that the data correspond to a particular time of the year and therefore only partially reflects the litter dynamics which depend on a variety of factors; e.g., phenology of the species, time of pruning of the *T. cacao* and *E. poeppigiana* etc. However, the data do partially take into account these changes as the measurement was done at the beginning of September 1981, almost a month and a half after the *E. poeppigiana* was pruned thus adding considerable amounts of organic matter. Values of the litter layer which might serve as comparisons for this study have not yet been published.

Finally, the reserves in the mineral soil are greater for *E. poeppigiana* (84%) than for *C. alliodora* (77%) which provides stability to the systems.

Mineral content

The nutrient content of the different components decreases in the following order: leaves, roots, branches, trunks (Table 3). The value for the litter are intermediate between that for the leaves and the other organs.

The N and P values found in most organs of *E. poeppigiana* are higher than those of *C. alliodora.* The *C. alliodora* leaves have higher K, Ca and Mg values; concentrations found in the roots of *T. cacao* under *E. poeppigiana* are higher than in *T. cacao* under *C. alliodora.*

Nitrogen accumulation

A notable difference does not exist between systems (Table 4). Including the litter layer, the association of *T. cacao* under *C. alliodora* accumulated 446.4 kg N.ha^{-1} in comparison with 498.8 kg N.ha^{-1} accumulated in the system *T. cacao* under *E. poeppigiana.*

The reserves in the shade trees were higher in the latter association.

Table 6. Potassium accumulation in the systems *Cordia alliodora* – *Theobroma cacao* and *Erythrina poeppigiana* – *T. cacao* (kg k . ha^{-1})

	T. cacao		*C. alliodora*	*T. cacao*		*E. poeppigiana*
Leaves	30.9		77.7	15.8		42.5
Branches	46.1		56.0	19.3		123.8
Trunks	21.8		109.7	14.0		70.8
Roots		21.4			17.7	
Litter		9.8			12.0	
Subtotal		372.7			315.9	
Soil		577			713	
System total		949.7			1028.9	

The litter layer is a transitory reserve of nutrients. The plant residues are in the process of mineralization and humification. The N values found depend on the time of the measurement and the phenology of the plants. In this case the litter N in the *T. cacao–E. poeppigiana* system (111.5 kg . ha^{-1}).

The N reserves in the mineral soil are high, representing 95% for the system with *C. alliodora* and 92% with *E. poeppigiana.* The absolute amounts of N in the soil differ notably between associations (*C. alliodora* 7991 kg N . ha^{-1} and *E. poeppigiana* 9555 kg N . ha^{-1}) due to different soil management before the experiment.

By way of comparison, the only available data in the literature (Aranguren et al.) in Venezuela is given in Table 4. These values notably exceed those of this study due to plantation age, density, etc.

Phosphorus accumulation

The amounts of accumulated P in the vegetation (Table 5) are small in comparison with other elements, e.g. nitrogen or potassium. The *C. alliodora–T. cacao* system exceeds slightly the *E. poeppigiana–T. cacao* system (50.3 versus 46.9 kg P . ha^{-1}).

Total amounts of P accumulated in live and dead biomass reaches only some 1–2% of the amount in the soil.

Potassium reserves in the systems

Table 6 shows the amounts of potassium found in the two systems (kg k . ha^{-1}).

The relative amounts of K found in the soils (*T. cacao–C. alliodora,* 61%; *T. cacao–E. poeppigiana,* 60% of the total) are low in comparison with other elements. This is because the exchangeable K is only a fraction of the total K in the soil. The K accumulated in the vegetation of the *T. cacao–C. alliodora* system is found mainly in the trunks of the shade trees and the total exceeds that of *T. cacao–E. poeppigiana* system where it is found especially in the branches of the *E. poeppigiana.*

Table 7. Accumulation of calcium and magnesium in the systems of *Cordia alliodora* – *Theobroma cacao* and *Erythrina poeppigiana* – *T. cacao* (kg.ha^{-1})
+

	Ca						Mg					
	T. *cacao*	under	*C.* *alliodora*	*T.* *cacao*	under	*E.* *poeppigiana*	*T.* *cacao*	under	*C.* *alliodora*	*T.* *cacao*	under	*E.* *poeppigiana*
Leaves	41.6		58.6	36.1		53.3	16.0		27.9	9.6		16.0
Branches	46.9		21.8	38.1		115.4	12.9		12.3	6.0		39.1
Trunks	11.2		128.0	21.0		67.0	12.9		40.3	8.0		22.3
Roots		44.4			19.3			13.8			4.7	
Litter		84.5			83.3			21.3			12.7	
Sub total Vegetation		437.0			433.5			157.4			118.4	
Soil		2410			3082			551			651	
Total		2847			3515.3			708.4			769.4	

Table 8. The percentage distribution of elements in the systems of *Cordia alliodora* – *Theobroma cacao* and *Erythrina poeppigiana* – *T. cacao*

	T.cacao	*C.alliodora*	Litter	Roots	Total vegetation (kg.ha^{-1})	% in soil of total in the system
N	22	52	17	9	446.4	95
P	25	57	10	8	50.3	99
K	26	65	3	6	372.7	61
Ca	23	48	19	10	437	85
Mg	27	51	13	9	157.4	78
	T.cacao	*E.poeppigiana*	Litter	Roots	Total vegetation (kg.ha^{-1})	% in soil of total in the system
N	21	53	22	4	498.8	92
P	21	56	18	5	46.9	99
K	15	75	4	6	315.9	69
Ca	22	54	19	5	433.5	88
Mg	20	65	11	4	118.4	85

Ca and Mg reserves in the systems

The reserves of Ca in the *T. cacao* under *C. alliodora* (99.7 kg Ca . ha^{-1}) is comparable to those under *E. poeppigiana* (95.2 kg Ca . ha^{-1}). *C. alliodora* stores more Ca than *E. poeppigiana* (235.7 kg Ca . ha^{-1} versus 208.4 kg Ca . ha^{-1} respectively). The roots of *T. cacao–C. alliodora* system have a higher amount of Ca than those of the *T. cacao-E. poeppigiana* (Table 7).

Greater amounts of magnesium are found in all compartments of the *T. cacao–C. alliodora* system than in the *T. cacao–E. poeppigiana* system, wih the exception of the branches of the shade trees (Table 7).

Discussion

The data reported here do not include the cacao flowers and fruits. This compartment is dynamic and will be included in the transference processes (harvest) in corresponding models [16]. Measurements were not taken for large roots (> 20 mm diameter) so as not to destroy the experiment in progress.

The distribution of the elements (Table 8) indicates in general the following:

a) The elements are retained first by the shade species *E. poeppigiana* and *C. alliodora* in percentages that range between 48 and 75% according to the element; second by *T. cacao* with percentages of between 15 and 27% and third and fourth by the litter and roots respectively.
b) With respect to management, a considerable part of the elements retained

by the tree species in branches and leaves are put in circulation by means of pruning. While this is the rule for *E. poeppigiana,* it is not true for *C. alliodora.* Pruning of *T. cacao* also puts elements in circulation; however, the magnitude is unknown.

c) The *T. cacao* of both systems presents no notable differences with respect to the accumulation of N, P and Ca. However, for K and Mg *T. cacao* under *C. alliodora* exceeds *T. cacao* under *E. poeppigiana.*

d) The elements N, P, K, Ca and Mg are found in the following relations in the aerial biomass of *T. cacao* under *C. alliodora:* 8:1:8:8:3.4 and 10.5: 1:5:9.7:2.4 under *E. poeppigiana.* With the exception of K, these relations are much like those found by Thong and Ng [29] in Malaysia who report a relation of 9:1:13:8:3 for 5 years old *T. cacao* including roots.

e) In both associations the elements are accumulated in the following order: N > Ca > K > Mg > P.

f) The data indicates that under the same plant densities *E. poeppigiana* only slightly exceeds *C. alliodora* in reserves of N and Ca while for the other elements, the reserves are almost identical.

The inventory presented should not be interpreted in isolation, but rather as part of the total cycle of organic matter and nutrients, including the transference process [22] in corresponding models [16] which will be discussed in subsequent publications.

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