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Effects of the maize-mucuna agroecosystem on soil properties, weed dynamics and maize yield, in traditional farming systems in the Tulijá Valley, Mexico.

Carlos Ernesto Aguilar-Jiménez [a], Alfredo Tolón-Becerra [b*], Xavier Lastra-Bravo [b]
[a] *Autonomous University of Chiapas. Agronomy Science Faculty. Campus V. Km. 7. Carretera Villaflores-Tuxtla Gutiérrez. 30470. Villaflores, México.*
[b] *University of Almería. Area of Engineering Projects. Ctra Sacramento s/n. La Cañada de San Urbano. 04120. Almería, España.*

[*] Corresponding author: Tel. +34950015902 Fax: +34950015491. E-mail addresses: atolon@ual.es

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1 SUMMARY

In the Mexican tropics, farmers use mainly the traditional *roza-tumba-quema*, or slash, fell and burn (S-F-B) farming system. This system has been the subject of criticism because of the severe degradation it has caused. To reduce its environmental impact, in the Tulijá Valley in Mexico, farmers are using the maize (*Zea mays* L.)-mucuna (*Mucuna deeringianum* Bort.) agroecosystem. This article analyzes the effects of this agroecosystem on soil properties, weed dynamics and maize yield in traditional farming systems in the Tulijá Valley in Mexico, in the autumn-winter (November-April) seasonal cycle. A completely random design was set up with three replicates, in five-year periods to find out the effect of mucuna on the ecological production relationships and compare it with its not being used. As a result, it was observed that as the period of use of mucuna increased, nitrogen, phosphorous and potassium concentrations in the soil also increased, mainly in the surface layer of the soil (0-0.15 cm). There was a relative decrease in the number of species, of individuals and of families the longer mucuna was used. Grain yield was observed to be statistically lower in the system without rotation with mucuna (1.99±0.26 t ha^{-1}) and highest in the system with mucuna for 15 years (5.72±0.51 t ha-1). In conclusion, the maize-mucuna agroecosystem increases and maintains agroecological sustainability of soils over time and favors production of maize.

2 INTRODUCTION

In the Mexican tropics, the traditional *roza-tumba-quema*, or slash, fell and burn (S-F-B) farming system, also known as the *milpa*, itinerant or migratory agroecosystem (Brady, 1996) is used. The peasants cultivate small fields for two or three years and then, when the soil is worn out and crop productivity falls, they abandon it, allowing natural vegetation to grow and return its fertility, and then they can be planted gain after a fallow period. This cultivation system comprises the most important part of the Mexican agricultural production to date (Hernández, 1985; Brady 1996; Ochoa-Gaona and González-Espinosa, 2000; Ávila-Romero, 2007). The lower productivity of crops, especially maize, beans and squash, is attributed mainly to gradual decrease in soil fertility (Hernández et al., 1995) and to the rapid growth of the weed population, phytophage insects and diseases.

To solve these problems, conventional agriculture uses fertilizers and pesticides as control strategies. But due to their high cost, danger in the mid-to-long term (risk of environmental pollution and contamination of food), and inefficient use (causing high natural resistance of organisms), alternative sustainable strategies are being sought.

Moreover, the high population density, intensification of land use (over-tilling) and reduction of its fertility are some of the problems observed in this type of agriculture (Pool-Novelo 1997; Ochoa-Gaona and González-Espinosa, 2000). These problems, along with forests and jungles being cut down, plant waste cleared and burnt, use of inadequate farming practices on land with slopes unsuitable for seasonal farming and the irrational use of agrochemicals have increased the damage caused by water erosion. In Chiapas, mainly soil, flora, fauna and water have been degraded to different degrees.

One of the alternatives traditionally used to improve soil fertility is rotation with legumes or green manure, because of the nitrogen and phosphorous contributions to the soil from their cultivation (Kaizzi et al., 2006). Therefore, the importance of legumes in conservation and improvement of soils is an indubitable fact, more so in the humid tropics where the smaller farmer usually lacks financial and technical resources for industrial alternatives. But soil fertility needs to be improved not only for the following crop, but also for its long-term productivity. Therefore, its quality must be improved before nitrogen availability, because organic matter added to the soil in the form of green manure is very labile, and can affect the soil's reaction and the microbiological processes nitrogen is included in. The high level of organic matter in the soil impacts largely on the availability of nutrients (Perry 1994; Szott et al. 1994).

Mucuna (*Mucuna deeringiana* Bort.), *Nescafé*, velvet bean or bean manure, is one of the legumes most commonly used as green manure in the tropics, mainly because it develops well on poor tropical soils and does not show difficulties for development in rocky mountain zones. Louis (1996) showed that mucuna biomass is of great agronomic interest for the conservation and improvement of soils in mountain tropics. This crop positively affects weed control, contribution of organic matter from biomass, and the amount of nitrogen fixed biologically by the symbiosis established by the legume with bacteria of the *Rhizobium* genus. Kaizzi et al. (2006) observed that rotation with mucuna is profitable and productive, regardless of the type of soil. But care should be taken that it does not crowd out the maize. Maize yield is directly related to the availability of macro and micronutrients present in the soil (Pool *et al.*, 1998), which is facilitated by growing legumes.

Given the importance of the maize-mucuna agroecosystem in Chiapas, this article analyzes the effects of this agroecosystem on soil properties, weed dynamics and maize yield in traditional farming systems in the Tulijá Valley in Mexico.

3 MATERIALS AND METHODS

3.1 Study site: This research was done in the Francisco I. Madero, Santa María and Tiemopá communities in the Tulijá Valley, municipality of Salto de Agua, Selva Socioeconomic Region, State of Chiapas. It is located between 17°10' and 17°30'N and 92°00' and 92°25'W at an average height of 100 m a.s.l. Its climate is AF(m), warm humid, with an average annual precipitation of 3 000 mm (constant rains all year long) and a mean annual temperature of 26.7ºC (INEGI, 2000). The topography is precipitous and the soils are predominantly lithosols with associated rendzinas and chromic luvisols, according to the FAO/UNESCO classification (1968) (INEGI, 2000). It has fertile, moderately developed soils to a depth of less than 60 cm, good drainage, slightly acid, alluvial, and is made up of unconsolidated terrigenous deposits, with a granulometry varying from coarse sand and gravel at the foot of the mountains, to silt and clay toward less sloping land (INEGI, 1990). Its profile is wet practically all year long, and its mechanization is limited by the geodesy of the land and the frequent limestone rocks. The Tulijá Valley has the characteristics typical of humid mountain tropics. The main crops are seasonal maize and beans. The farming cycles in the region are spring-summer and autumn-winter. The maize-mucuna agroecosystem is used in the area, with endemic maize genotypes managed using traditional technology (S-F-B) in the spring-summer cycle. Mucuna is used mainly as a source of soil fertilization in the autumn-winter cycle. The territory is inhabited by the Mayan Cho'l ethnic group.

3.2 Experimental design: A completely random design was set up with three replicates per microregion in 1-hectare fields belonging to different producers. The study was done during the autumn-winter cycle known as "*tornamil*" (November-April). Four strata or evaluation systems were set up by uninterrupted period of use of the maize-mucuna agroecosystem: 0 years (S1), 5 years (S2), 10 years (S3) and 15 years (S4). S1 Periods of five years were used in order to find out the effect of mucuna on the ecological production relationships compared to not using it (S1 – traditional maize). All of the systems have two degrees of freedom. The simple classification design was used to study soil, weeds, seed bank, maize production indicators and maize-mucuna agroecosystem management factors. Maize and mucuna were sown as done traditionally by local natives, using an *espeque* (planting stick). Four maize seeds were sown (November) per sowing point with 1.2 m between rows and plants for a population density of approximately 27 000 plants/ha^{-1}. The growing cycle of the Creole maize genotypes is about 130 days. Traditionally, no outside intermediate products are used, and weeding is practically the only cultivating practice (December-March). Mucuna was sown 50 days after maize (December-January) in between the rows and 2 m^2 apart, at a rate of 2 seeds per sowing point, with a population density of 5 000 plants/ha^{-1}. Due to the uncontrolled growth of mucuna, it climbs up the maize plants. Maize is harvested 100 days after sowing the mucuna (April-May), that is, 150 days after planting (April-May). Harvesting is manual, leaving the dry plants standing to serve as a guide for the mucuna. Mucuna development is complete 250 days after planting. As the environment is humid tropical, ground cover of mucuna foliage is 100%. The mucuna is left until the following growing cycle (October), when it is again manually incorporated (with a machete) to allow the maize to be planted (November).

3.3. Sampling and analysis: For the physicochemical soil analysis, sampling was done using a systematic sampling plan (five-point-centered) at the beginning and at the end of the growing cycle. Samples were taken at 0-0.15 m and 0.15-0.30 m to find out the effect of the mucuna on soil fertility at levels where the maize root system has different behavior and requirements due to species characteristics. In each field, between the first and second sampling, five sampling sites were set up to reduce variability in soil characteristics. The five subsamples were combined in one compound sample per field. A total of 48 soil samples were collected: four systems, three replicates, two sampling times and two depths. The methods used to determine the main agronomic properties were: the Bouyoucos hydrometer method (Bouyoucos, 1927) for texture, excavation for apparent density (ϱ), conductimetry, soil-water ratio 1:5, potentiometer for electric conductivity (EC), soil-water ratio 1:5, pH meter for pH, for organic matter the Walkley and Black (Walkley and Black, 1934) oxidation method (OM), the Kjeldahl Macro method for total nitrogen (N), diphenylamine method (Morgan extraction solution) for NO_3, Olsen method for phosphorous (P) extractable cations with Morgan solution for potassium (K), and Versenato method for calcium (Ca) and magnesium (Mg). N was interpreted using the Moreno classification (1978) for OM, K, Ca and Mg, the Letelier classification (1967) for pH and the texture classification was based on the proportion of sand, silt and clay (López, 1996). Weed sampling was done by the point-centered quarter method (Krebs, 1985) within a 0.25 m^2 area (0.50 x 0.50 m). The quadrat was thrown out at random and in zigzag in each field, taking three samples in each. The samples were taken before weeding (30 days after sowing maize), during flowering (70 days after sowing) and during the maize physiological maturity stage (100 days after sowing). Each time the quadrat was thrown, the total number of individuals per species inside it was counted. Later, they were grouped by species and placed in paper bags for their identification and dried for 72 hours. The dry plants were weighed with a top loading balance.

Diversity, density and floristic similarity of weeds were determined to find out the effect of mucuna on the emerging flora. The diversity of weeds was found using the Shannon-Weaver Index (1949).

$$H' = -\sum_{i=1}^{S} \pi_i * \log(\pi_i)$$

Where *H'* is the diversity index, π_i is the proportion of individuals of the species *i* (n_i) out of the total individuals of all species (*N*). The similarity between communities was determined by the Sörensen index (Krebs, 1985):

$$I_{SS} = \frac{2c}{a+b} * 100$$

Where *a* is the number of species in Community or Sample 1, *b* in Community or Sample 3, and *c* the total number of species in both communities or samples.

The Importance Value Index (IVI_i) assesses the overall significance of a species since it takes into account several properties of the species in the vegetation (Curtis y McIntosh, 1950, 1951; Finol 1971; Mueller-Dombois and Ellenberg 1974; Matteuci and Colma 1982; Lamprecht, 1990; Kent and Coker 1994). It was used to assign the structural importance of a species within a stand of mixed species:

$$IVI = DR_i(\%) + FR_i(\%) + CR_i(\%)$$

where DR_i is the relative density or ratio of the number of individuals of species *X* to the total number of individuals of all species, FR_i is the relative frequency of species *X* divided by the sum of the frequencies of all of the species, and CR_i is the relative predominance found by calculating the percentage of total biomass of one species over the total biomass of all of the species.

The growing tray or germination method (Mariaca et al., 1995) was used for the repository or seed bank analysis. Compound samples were taken from soil in each of the fields at 0-0.15 m. The 12 samples collected were placed in different 0.20 m wide by 0.40 cm long and 0.20 m deep wooden trays. The trays were placed under covers made of regional vegetal materials, allowing sunlight to enter to keep seeds from being contaminated by the wind (anemochory), by animals (zoochory) or by water (hydrochory). During the whole experiment, they were watered every three days to keep the soil moist and facilitate emergence of the weeds. To find out how much the weeds were sprouting, they were examined eight days after the first sampling. Every 30 days, they were again examined to observe the development of the species that sprouted. At the end of the experiment, in the fourth and last sampling (at four months), the number of individuals in each species was counted, identified by family and species, and classified by type and number of species with wide or narrow leaves.

For the yield component analysis, the López et al. (1993) method was used because the study was done in fields under production. Five points per field were sampled in zigzag where 10 plants in a row were taken to determine the agronomic variables: number of rows per ear, ears per plant, ear weight and plants harvested. The Lafitte (1994) method was used to estimate grain yield.

3.4 Statistical analysis : The data were analyzed using PASW Statistics 18 version 18.0.0 (2009) for analysis of variance, t-tests with 0.05 probability level ($P<0.05$) for maize yield components, according to the criteria of Cochran and Cox (1999), Castillo (2000) and García-Villalpando *et al.*, (2001). Due to the nature of the study and the uniformity of the experimental sites, the analysis was done using the simple classification model (Dixon and Massey, 1972). The Pearson's correlation analysis was used to find out correlation and determination of maize variables.

3 RESULTS

3.1 Soils: In the statistical analysis of the soil variables, no significant differences were observed in treatments, but systems S2, S3 and S4 (use of mucuna) tended in general to a higher concentration of nutrients (Figure 1). The soil texture in S1 at both depths analyzed is clay loam and silty loam. Soils in S2 had a variable texture in the replicates, silty loam, loam, clay loam and clay. In S4, the predominant texture class is loam with small variations of silt and clay. S4 was found to have sandy loam, silty loam and clay textures. Concerning macroelements, the lowest amount of N was observed in S1 (0.15±0.03%), and the highest in S2 (0.20±0.05%). The other two systems were similar to S2. Significant differences were observed for S3 in the first sampling (P=0.04; 0.24±0.02%) and in S1 in the second (P=0.03; 0.14±0.01%), at a depth of 0-0.15 m. In the surface layer of soil (0-0.15 m), N concentration was higher (0.22±0.06%) than at 0.15-0.30 m (0.15±0.04%). In the first sampling, it was highest in S2 (0.21±0.05%), and in the second, in S3 (0.22±0.10%). The highest concentration of P was found in S2 and S4 (11.9±6.7

and 10.8±3.0 ppm, respectively), and slightly lower in S3 and S1 (9.8±3.9 and 9.7±7.7 ppm, respectively). Significant differences were observed in the first sampling in S1, both at 0-015 m and at 0.15-0.30 m (*P*=0.02; 6.1±1.2 ppm and *P*=0.01; 4.9±1.0 ppm, respectively). Like N, the P concentration is higher in the surface layer of the soil (12.0±6.3 ppm vs. 9.0±4.4 ppm). In the second sampling period, it was generally higher (12.3±5.7 ppm vs 8.7 vs. 4.8 ppm). K was higher in S2 (192.6±88.5 ppm), diminishing with increased use of mucuna (147.0±69.6 ppm and 114.2±51.1 ppm, for S3 and S4). It was medium in S1 (139.0±44.4 ppm). Significant differences were observed S2 in the first sampling (*P*=0.03; 300±43.3 ppm) at a depth of 0-0.15 m and in S4 in the second (*P*=0.04; 80.2±23.0 ppm) at 0.15-0.30 m. The K concentration was higher at a depth of 0-0.15 m (182.4±77.1 ppm vs. 114.1±39.3 ppm).

OM concentration was higher at a depth of 0-0.15 m (5.9±1.8%), and slightly lower at 0.15-0.30 m (4.0±1.9%). Of all the systems, S1 soils are the richest in OM (6.9±1.5%), and similar among treatments with mucuna (4.3±1.5, 4.3±1.8 and 4.3±2.3%, for S2, S3 and S4, respectively). Significant differences were observed in S2 (2.4±0.5%) and S3 (2.6±0.3%) at 0.15-0.30 m depth (*P*=0.01). At the end of the growing cycle, in the second sampling, the OM concentration was slightly higher (5.1±2.0%) than in the first (4.7±2.2%). NO_3 was higher the longer mucuna was used (78.1±62.8, 59.3±51.5 and 46.3±39.0 ppm, for S4, S3 and S1). It was the lowest in S1 (38.4±46.9 ppm). Statistical differences were observed for S1, S2 and S3 in the second sampling period at 0.15-0.30 m depth (*P*=0.005, *P*=0.001 and *P*=0.03, respectively) and for S2 at 0-0.15 m (*P*=0.02). The NO_3 concentration was higher at 0-0.15 m (69.4±56.1 ppm) and at the beginning of the growing cycle (84.6±53.4 ppm). Soils had high concentrations of Ca, especially in S3 and S4 (24447.8±18721.0 and 14991.011±5348.714 ppm). At 0.15-0.30 m depth, the Ca concentration was slightly higher (13774.614±13856.414 ppm) than observed at 0-0.15 m (11961.813±10710.012 ppm). Slight differences were observed between sampling periods. Significant differences were observed for S1 (*P*=0.03) and S2 (*P*=0.001) at 0-0.15 m and for S2 (*P*=0.02) at 0.15-0.30 m in the first sampling period, and for S1 at both depths and S2 at 0-0.0.15 m (*P*=0.02), in the second. High concentrations of Mg were also observed, mainly in S3 (1206.310±810.9 ppm) at 0.15-0.30 m depth (1053.0±767.4 ppm). No statistical differences were observed between fields.

Soils in S1 and S2 had an acid pH (6.242±0.641 and 5.8±0.8, respectively) and as mucuna was used longer, the soils became slightly more alkaline (7.2±1.141 and 7.7±0.542 for S3 and S4). No differences in pH were observed at different depths or in different sampling periods. EC also increased the longer mucuna was used (0.08±0.05 dS/m for S1, 0.08±0.04 dS/m for S2, 0.13±0.08 dS/m for S3 and 0.13±0.06 dS/m). EC was observed to be higher at 0-0.15 m depth in the first sampling period. ϱ was only measured at 0-0.15 m depth, where it was highest in S3 (1.15±0.08 g cm^{-3}).

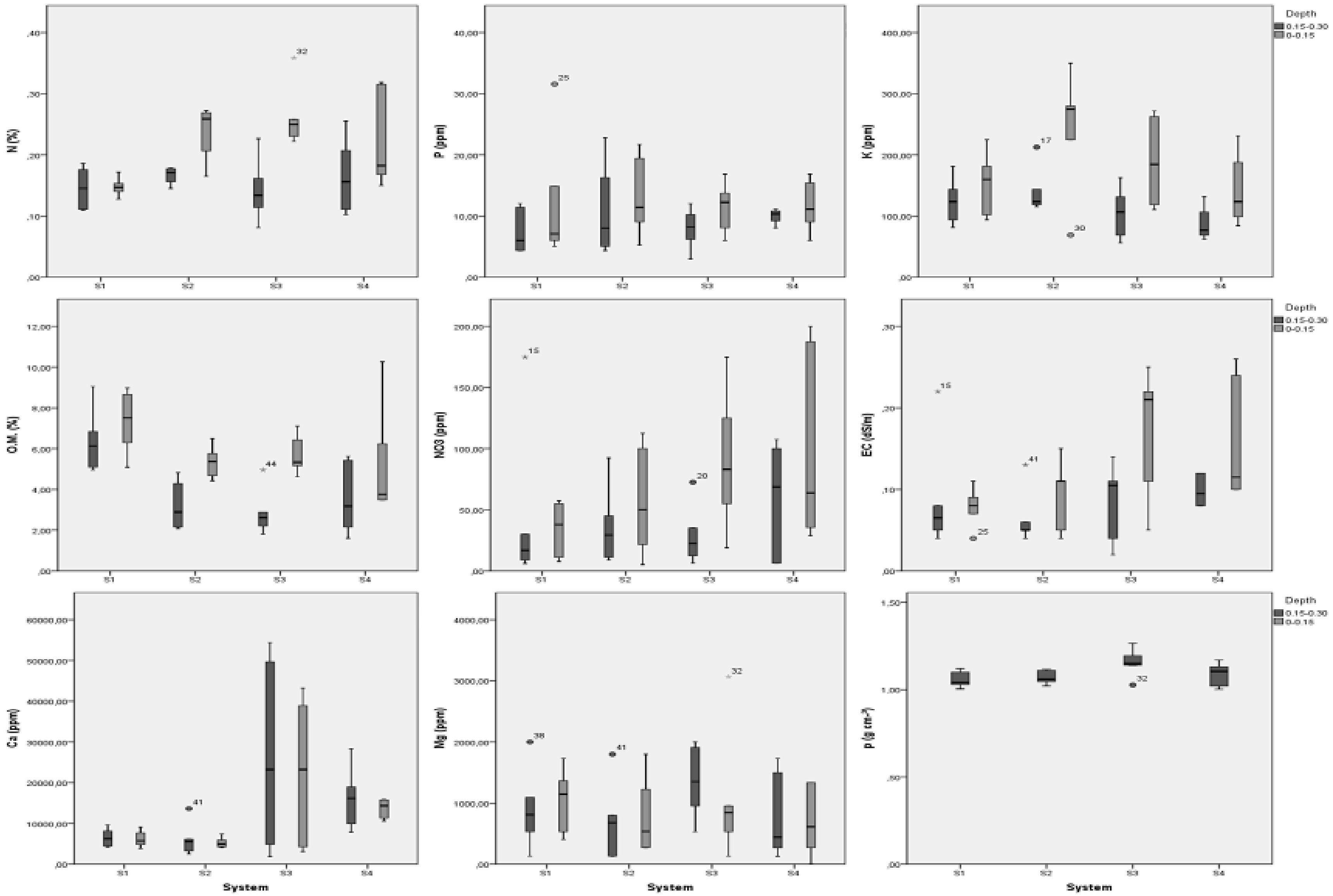

Figure 1: Boxplot showing averages and quartiles of soil variables for the various systems.

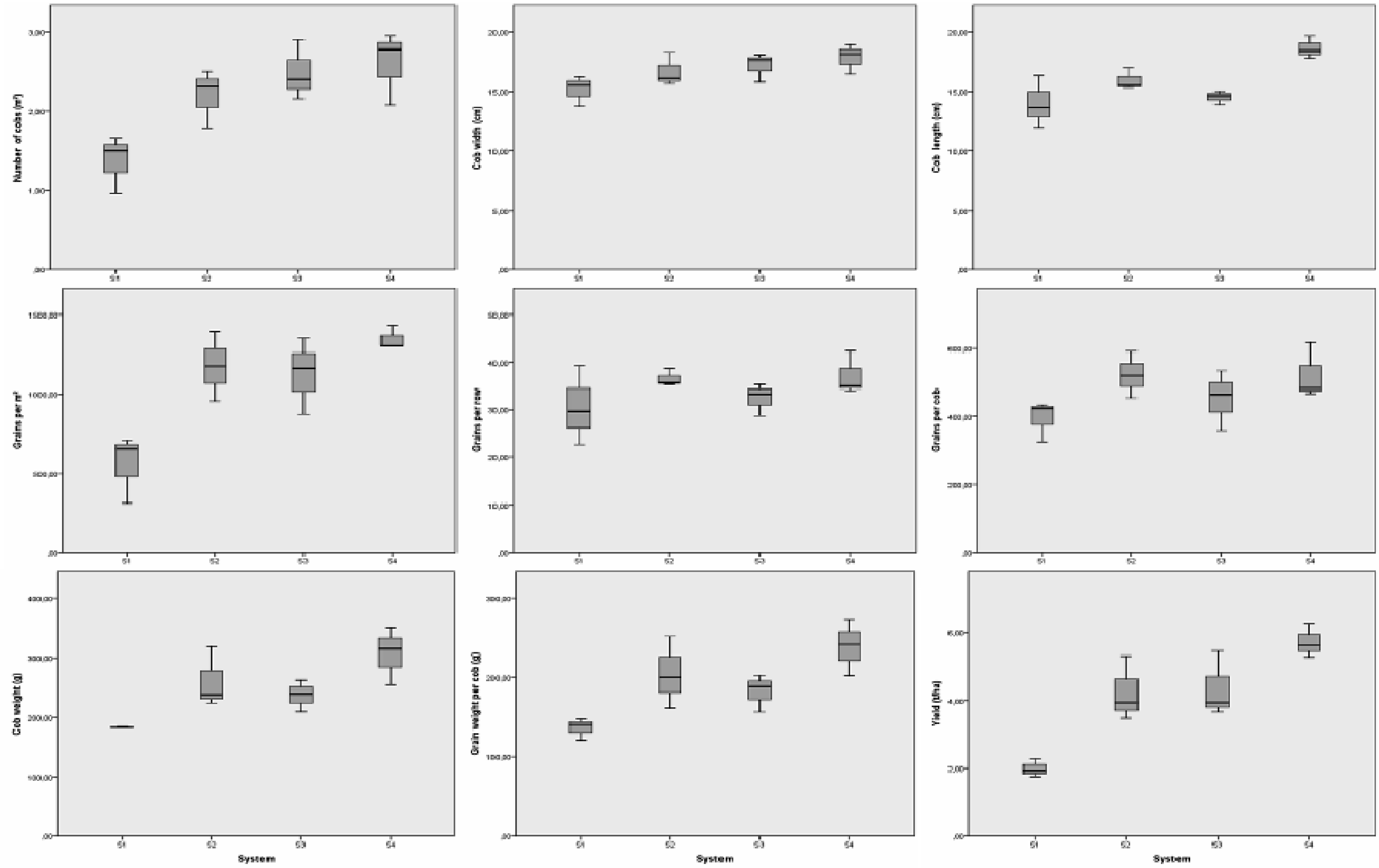

Figure 2: Boxplot showing averages and quartiles of the agronomic variables and maize yield components.

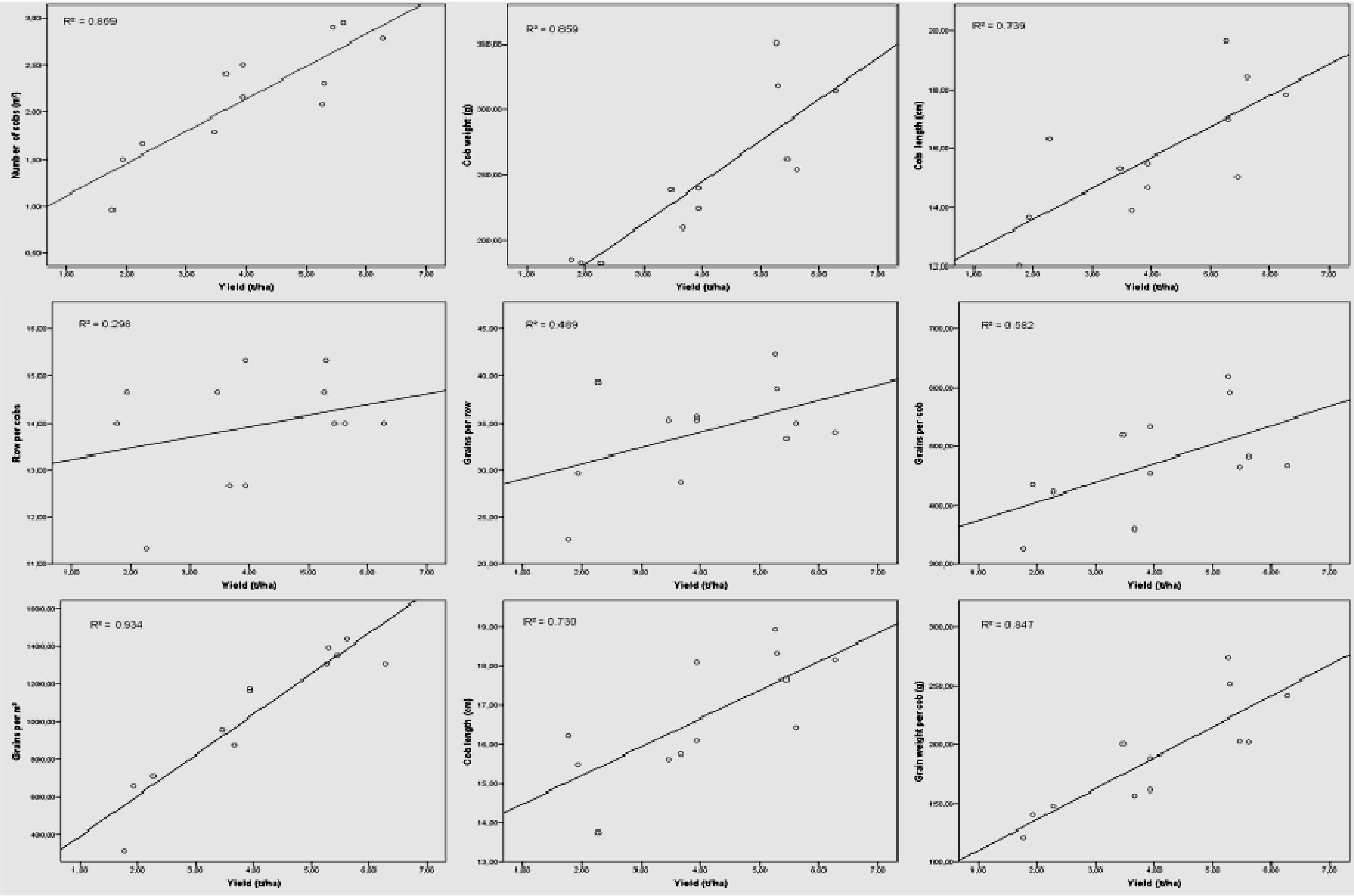

Figure 3. Pearson's correlation analysis of yield components.

3.2 Weeds: The *H'* found in each system was 1.5 (S1), 1.3 (S2), 1.2 (S3) and 0.9 (S4). In the analysis of weed similarity among systems, I_{ss} was 64.4% for S1 and S2, 58.3% for S1 and S3, 50.0% for S1 and S4, 63.0% for S2 and S3, 51.9 for S2 and S4, and 60.9% for S3 and S4. Table 1 shows the total number of species and family found in each of the systems studied. It also shows the 10 species with the highest *IVI*, their number and frequency. The highest *H'* in the soil seed bank was found in S1 and S2 (1.03and 1.2, respectively). It was 0.8 in S3 and 0.6 in S4. I_{ss} between systems was 51.2% (S1 and S2), 51.6% (S1 and S3), 38.5% (S1 and S4), 47.6% (S2 and S3), 32.4% (S2 and S4), and 32.0% (S3 and S4). 16 species were counted for S1, 27 for S2, 15 for S3 and 10 for S4.

3.3 Yield components and grain yield: In the t-tests (Table 2), statistically significant differences were found between treatments in the yield components: length of ear (S4, 18.6±0.9 cm), kernels per m^2 (S4, 1346.4±75.2), ear weight (S1, 182.9±1.4 g), weight of kernels per ear (S1, 136.5±13.7 g) and grain yield (S1, 2.0±0.3; S4, 5.7±0.5 t ha^{-1}). Most of the components improved in the systems with mucuna, S2, S3 and S4 (Table 3). S1 had the lowest number of ears per m^2 (1.4±0.6), much lower than the mean (2.2±0.6). The systems with mucuna were above the mean. The thickness of the ear varied slightly among systems. It was slightly below the mean in S1 and S2 (16.7±1.5 cm), and slightly above it in S3 and S4. The length of ear in S1 and S3 were slightly below the mean (15.8±2.2 cm). As in the previous components, ear weight was lowest in S1 (182.9±1.4). It was slightly below the mean in S3 (246.7±56.5 g), and it was above the mean in S2 and S4 (260.4±50.8, 306.5±48.9 respectively), although no significant differences were observed. The number of rows per ear varied slightly with regard to the mean (13.9±1.2). They were highest in S2 and S4 (14.2±1.4, 14.2±0.4 respectively). As in the previous component, the number of kernels per row was highest in S2 and S4 (36.6±1.8, 37.1±4.6 respectively), but with no significant differences from the mean (34.2±5.3). S1 had slightly fewer kernels per ear (394.7±59.7) compared to other systems evaluated and the mean (473.3±85.3), but there were no statistically significant differences. The number of kernels per m^2 in S1 (556.6 ±215.6) was much lower than the mean (1051.1±353.6) and the other systems, where it was higher. The mean weight of kernels per year was 190.8±47.5 g, observing much higher weights in S4, slightly higher in S2, slightly lower in S3 and much lower in S1. Grain yield was statistically lower in S1 (2.0±0.3 t ha^{-1}). Although all mucuna treatments had yields above the mean (4.1±1.5 t ha^{-1}), differences in S4 were statistically significant. In S2 and S3 yields were similar (4.2±1.0, 4.4±1.0 t ha^{-1}, respectively). The Pearson's correlation analysis provided six variables determining maize yield: kernels per m^2, number of ears per m^2, ear weight, weight of kernels per ear, length of ear and thickness of ear (Figure 3).

Table 1: Total number of species and families by system, and species with highest *IVI*.

	Species	**Families**	**Family**	**Species**	**#**	**Frequency**	***IVI***
S1	61	29	Musaceae	*Heliconia latispatha*	40	11	47.51
			Amaranthaceae	*Iresine celosia*	47	7	18.36
			Asteraceae	*Sclerocarpus dentatus*	19	3	15.11
			Poaceae	*Paspalum sp*	28	8	14.54
			Commelinaceae	N.I.	15	2	12.78
			Cyperaceae	*Cyperus sp*	49	1	11.40
			Passifloraceae	*Passiflora faetida*	29	3	10.29
			Poaceae	N.I.	36	2	9.73
			Fabaceae	*Desmodium cannum*	26	3	8.11
			Asteraceae	*Tithonia diversifolia*	14	1	6.85
S2	51	23	Poaceae	*Paspalum sp*	83	6	44.52
			Poaceae	N.I.	130	2	26.64
			Cucurbitaceae	*Cucurbita moschata*	8	8	20.63
			Commelinaceae	*Commelina sp*	48	1	17.11
			Poaceae	*Paspalum paniculatum*	76	3	16.70

			Convolvulaceae	*Ipomoea sp*	9	4	15.71
			Piperaceae	*Piper auritum*	16	5	14.08
			Amaranthaceae	*Iresine celosia*	18	7	13.48
			Euphorbiaceae	*Caperonia palustris*	45	3	10.96
			Fabaceae	*Stizolobium deeringianum*	5	4	7.04
S3	40	21	Cucurbitaceae	*Momordica charantia*	117	2	39.70
			Poaceae	*Paspalum sp*	64	6	28.41
			Cucurbitaceae	*Cucurbita moschata*	9	7	25.71
			Fabaceae	*Mucuna deeringianum*	7	6	16.64
			Euphorbiaceae	*Croton lobatus*	52	1	12.74
			Poaceae	*Digitaria horizontalis*	29	1	11.38
			Amaranthaceae	*Iresine celosia*	17	3	11.32
			Piperaceae	*Piper sp*	6	4	11.21
			Poaceae	N.I.	30	3	10.77
			Asteraceae	*Tithonia diversifolia*	29	1	10.44
S4	31	18	Poaceae	N.I.	325	2	65.92
			Poaceae	*Paspalum sp*	26	4	16.73
			Passifloraceae	*Passiflora nelsonii*	10	3	16.26
			Fabaceae	*Mucuna deeringianum*	5	4	16.21
			Poaceae	*Paspalum paniculatum*	40	4	14.96
			Convolvulaceae	*Ipomoea quinqueifolia*	17	5	13.73
			Asteraceae	*Melanthera nivea*	16	3	11.54
			Poaceae	*Digitaria sp*	10	1	9.67
			Euphorbiaceae	*Caperonia palustris*	13	3	9.46
			Bignoniaceae	*Cydista heterophylla*	2	1	9.31

N.I. = Not identified

Table 2: P-values of maize yield components ($P<0.05$).

	Number of cobs (m^2)	**Cob width (cm)**	**Cob length (cm)**	**Row per cobs**	**Grains per row**	**Grains per cob**	**Grains per m^2**	**Cob weight (g)**	**Grain weight per cob (g)**	**Yield (t/ha)**
S1	0.06	0.17	0.29	0.61	0.53	0.15	0.06	0.0002	0.02	0.01
S2	0.89	0.97	0.78	0.76	0.15	0.34	0.43	0.69	0.65	0.79
S3	0.28	0.59	0.06	0.95	0.48	0.73	0.64	0.59	0.61	0.67
S4	0.24	0.27	0.03	0.33	0.38	0.41	0.02	0.17	0.15	0.03

Table 3: Analysis of maize yield components (P<0.05).

																S.E.D.				
	NC	**CW**	**CL**	**RC**	**GR**	**NC**	**CW**	**CL**	**RC**	**GR**	**NC**	**CW**	**CL**	**RC**	**GR**	**NC**	**CW**	**CL**	**RC**	**GR**
S1	1.5	15.5	13.7	14.7	29.7	1.7	13.8	16.3	11.3	39.3	1.0	16.2	12.0	14.0	22.7	0.6	2.2	3.8	3.1	14.5
S2	2.5	16.1	15.5	12.7	35.7	1.8	15.6	15.3	14.7	35.3	2.3	18.3	17.0	15.3	38.7	0.6	2.5	1.6	2.4	3.2
S3	2.4	15.8	13.9	12.7	28.7	2.2	18.1	14.7	15.3	35.3	2.9	17.7	15.0	14.0	33.3	0.7	2.2	1.0	2.3	5.9
S4	3.0	16.4	18.4	14.0	35.0	2.1	18.9	19.7	14.7	42.3	2.8	18.2	17.8	14.0	34.0	0.8	2.2	1.6	0.7	7.9
S.E.D.	0.9	0.6	3.3	1.5	5.4	0.4	3.5	3.3	2.7	5.1	1.3	1.4	3.9	1.0	10.1					

																S.E.D.				
	GC	**GM**	**CW**	**GW**	**Y**	**GC**	**GM**	**CW**	**GW**	**Y**	**GC**	**GM**	**CW**	**GW**	**Y**	**GC**	**GM**	**CW**	**GW**	**Y**
S1	434.7	652.9	182.2	140.4	1.9	423.3	707.2	181.9	147.7	2.3	326.0	309.6	184.5	121.3	1.8	103.4	373.2	2.5	23.6	0.4
S2	454.7	1175.4	224.3	161.6	3.9	520.0	954.6	238.3	200.5	3.5	592.0	1392.2	318.5	252.0	5.3	118.9	378.7	88.0	78.5	1.6
S3	360.0	870.6	209.5	156.8	3.7	534.7	1160.7	239.3	188.6	3.9	465.3	1351.2	262.4	202.5	5.4	152.2	418.9	45.9	40.6	1.7
S4	482.7	1433.2	254.1	202.0	5.6	618.0	1302.9	350.9	273.9	5.3	468.0	1303.0	314.6	241.7	6.3	143.1	130.2	84.6	62.3	0.9
S.E.D	78.7	513.0	44.9	39.2	2.3	119.6	388.4	106.2	78.8	1.9	162.9	780.8	93.7	89.0	3.0					

NC. Number of cobs; CW. cob width; CL. cob length; RC. row per cobs; GR. grains per row;
GC. Grains per cob; GM. grains per m^2; CW. cob weight; GW. Grain weight per cob; Y. yield.

4 DISCUSSION

Soil characterization from chemical analyses at the beginning and at the end of the maize growing cycle demonstrated that the soils in the Tulijá Valley have a high nutrient content. and therefore. are adequate for farming. It was also found that soil texture analyzed is adequate for growing maize. More so when in Mexico maize is widely distributed over a wide variety of soil textures. mainly in seasonal agriculture (Ochse et al.. 1976; Contreras-Benítez et al.. 2002). The soils analyzed also favor cultivation and use of green manures in the humid tropics (Miranda. 1985).

It was observed that the longer the green manure (mucuna) was in use. the more the N concentration in the soil also increased. Although after five years from its establishment. only small variations in N level were observed. Furthermore. this macroelement is concentrated mainly in the surface layer of soil (0-0.15 m). diminishing slightly at greater depth (0-15-0.30 m). These results show the fertilizing effect of mucuna. which as a green manure (legume) favors N fixation in soil. The characteristics of slash and fell in the region (with a fallow period of about three years) also favor fixation of this macroelement. as shown by the concentration of N in S1. Biomass from the fallow period is incorporated directly into the soil at the beginning of the growing cycle (no burn). and favors the accumulation of nutrients. In this respect. Sánchez (1981) believes that burning volatizes most of the nutrients present in the vegetation. such as C. S and N. although other studies on tropical agrosystems suggest that burning and ash do not affect N content in soil in the short-term.

According to the Moreno (1978) classification. P in the soil is high or medium in all of the systems evaluated. increasing in the systems with mucuna. Triomphe (1995) also found higher amounts of P in cultivation systems including mucuna on the Honduras coast over a 10-year period. The increase in levels of P is correlated positively with years associated with mucuna. According to Contreras-Benítez et al. (2002). soils in Mexico are naturally high in P content. which is due to the characteristics typical of this tropical region. such as the nature of the soil. pH and high electrical conductivity. as well as agronomic management. The origin of the soils (luvisols. acrisols. regosols and nitosols) also impacts on the high P content. Like N. the traditional slash-fell management system favored accumulation of P. A significant amount of available soluble P is contributed by the ash and by mineralization of the fresh humified organic matter. this can be fixed by the oxides in the soil during cultivation (Juo and Manu. 1996). Sánchez (1981) mentions that there is no evidence of P deficiency in itinerant agricultural systems in humid tropical regions. and therefore. the small amounts of P that circulate in the closed nutrient cycle are apparently sufficient to prevent deficiencies under natural conditions.

The presence of high organic matter content in the soil. both at the beginning and at the end of the maize growing cycle at both depths analyzed is due to the traditional cultivation system. Higher content in soils where mucuna was not used (S1) was due to the characteristics of the autumn-winter production system (slash-fell. no burn). By not burning. fast growth of vegetation is favored and degradation of the soil is avoided. Growth of vegetation also is favored by the two-to-five year fallow period in fields used only in the autumn-winter production cycle. The vegetation incorporated into the soil by slashing when the ground is prepared for sowing. along with the high precipitation and temperatures. and the type of vegetation predominant. cause rapid. dynamic and systematic decomposition of plant waste (organic matter). The high content of organic matter impacts significantly on the values found for other soil characteristics. More so when productivity in itinerant agriculture is strongly linked to the release of nutrients by vegetation cut down (Perry 1994; Szott. et al.. 1994). In this sense. greater agrobiodiversity of soil strengthens characteristics such as resistance to stress and control of ecological processes (pest control. nutrient cycles. etc.) (Brussaard. et al.. 2007; Jackson. et al.. 2007; Rossi. et al. 2010).

The concentration of NO_3 was higher in soils under systems using mucuna. Both the higher content in N and NO_3 were quantified and stabilized in systems with use of mucuna for at least five years. this demonstrates the agroecological sustainability of the agricultural practice under evaluation. In general. soils were very rich in Ca and Mg. The pH. EC and *p* were slightly higher in systems with mucuna. The pH tendency toward acidity is due to the geographic location (humid tropics) and environmental conditions (Núñez. 1985).

It should be noted that as farm size increases. production intensifies and the period of fallow is shortened. thereby losing the equilibrium in the nutrient cycle in the S-F-B systems (Juo & Manu. 1996). Furthermore. the conditions reigning in the humid tropics cause N. a highly mobile element. to be lost from leaching and volatilization. especially in light-textured soils. Therefore. it is important to constantly incorporate organic matter into the soil using legumes as green manure. which is a highly viable alternative for developing sustainable agriculture. García-Barrios & Gonzalez-Espinosa (2004) think that the reduction in fertility of soils is due to shorter periods of fallow. changes in composition and floristic structure. and to regeneration of forested areas. By fertilizing the soil ecologically with mucuna. fertility levels remain adequate and stable. and it is possible to carry out annual growing cycles sustainably on the same land.

According to the Shannon-Weaver Index results. there is wider diversity in S1. gradually decreasing in the systems with use of mucuna. The allelopathic effects of this legume explain the decrease in *H'* as its period of use is lengthened. The same behavior is observed in I_{ss} because there is a natural selection of species. whereby those that develop a greater capacity for adaptation or coevolution with the legume survive. In S3. mucuna had a high *IVI*. demonstrating the presence of this green manure. especially in the final stages of the maize growing cycle. where its growth begins to take on importance for the purposes it was established. given its growing habits. The mucuna also had a significant *IVI* in S4. In the seed bank. *H'* was less equitable. Yield components were higher in the systems with use of mucuna. showing the positive effects of this legume. Specially because the biomass from mucuna is of great agricultural interest for conservation and soil improvement in the mountain tropics (Louis 1996; Bernardino-Hernández. 2006; Serrano-Altamirano & Cano-García. 2007; Ayala-Sánchez et al.. 2009). The system where mucuna had been in use for 15 years had the highest yield. and in general had the highest yield components as well. These results contrast with those found by Kaizzi et al. (2006) who found lower yields in maize associated with mucuna. due to the stronger competition for resources between the two crops and differences in managing mucuna. The relative uniformity of the sowing patterns and crop management in the study area helped reduce these sources of variability in this study. Furthermore. the results corroborate that the legumes help fix N and improve soil N economy (Cheruiyot et al. 2003). Moreover. the synthesis and accumulation of the major elements. mainly N. is influenced by seasonal dynamics. which affect the growth of Mucuna. Our results also contrast with those of Adiku et al. (2009). who did not find any significant increase in the maize yield in rotation with mucuna. The quality of the soils and high nutrient content. product of the decomposition of organic matter from the plant waste during the fallow period. also favored higher maize yields in the systems with mucuna (approximately 50% more than in the system without mucuna).

5 CONCLUSIONS

Based on the results found. it may be said that the maize-mucuna system constitutes an ecological management strategy for the soil in the Selva de Chiapas. This system increases and maintains the agroecological sustainability of soils in the region over time. This is further backed by over 30 years of adaptation and use of this practice by the native Choles in the Tulijá Valley. Chiapas. The positive effects observed on the concentration of N (increase of up to 50% over system without use of mucuna). and the rest of the nutrients were excellent. although no direct relationship between the concentration of nutrients and years of use of rotation with mucuna could be determined. The period of use of mucuna also favored the floristic diversity of weeds. while it had the contrary effect on the similarity of species. High floristic similarity was observed among the species in the seed bank. The maize yield was favored by the maize-mucuna system. and was positively correlated to it.

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