

Assessment of the Maize (*Zea mays*)-Mucuna (*Mucuna deeringianum* Bort) Agroecosystem

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Abstract: Problem statement: In Selva de Chiapas, Mexico, the traditional farming technique of slash-fell-burn used on hillside fields has caused severe soil deterioration. Consequently, indigenous farmers reacted by developing several agroecological practices that improve the physical, chemical and biological fertility of the soils. Standing out among these techniques is the use of Mucuna (*Mucuna deeringianum* Bort.) in rotation with maize (*Zea mays* L). **Approach:** The objective of this study was to determine the effect of the maize-mucuna system on soil fertility, ecosystem diversity and maize crop yield. The study was conducted in the Tulija Valley, Chiapas, in the autumn-winter growing season (November-April). A completely random design was applied to four periods of consecutive maize-mucuna cropping (0, 5, 10 and 15 years) in order to analyze the most significant variables related to soils, weeds, seed bank and yield. **Results:** The results obtained reveal the higher nutrient concentration in the topsoil (0-15 cm) and better crop yield in the treatments with Mucuna rotation. No direct relationship was observed between nutrient content and duration of maize-mucuna system usage. However, the diversity of weeds and similarity of species both diminished where this farming method was used. **Conclusion/Recommendations:** It was determined that the use of the maize-mucuna agroecosystem helps to increase and maintain agroecological sustainability, supporting this practice that has been adapted and utilized by indigenous Choles for more than 30 years.

Key words: Sustainability, agroecosystem, tropic, indigenous systems, tulija valley, chiapas, traditional farming, mucuna deeringianum

INTRODUCTION

The natural ecosystems of the Mexican tropics have been substituted by agroecosystems know as transhumant, itinerant or slash-fell-and-burn (s-a-b) (Brady, 1996). Consequently, a significant decrease in crop productivity is observed and the land is temporarily abandoned while it ecologically recovers (Xolocotzi, 1995). The loss of productivity is primarily attributed to the gradual decrease in soil fertility (Xolocotzi, 1995) and the rapid population increase of weeds, phytophagous insects and diseases. In conventional agriculture, the strategy for controlling these elements is the use of fertilizers and pesticides. But this method is costly and dangerous over the medium- and long-term due to contamination risk of both the environment and food products. Moreover, it is inefficient since the instructions recommended by

manufacturers are widely ignored causing a high natural resistance of pests.

In Chiapas, different degrees of soil degradation and decreases in flora, fauna and water quality are caused mainly by hydric erosion, as consequence of several agricultural activities. These activities include overfarming, forests and jungles clearing, irrational use of agrochemicals, slashing and burning of plant litter and the inadequate use of agricultural techniques on terrains with slopes not appropriate for seasonal farming. Primarily basic foods (mainly maize and beans) are farmed in Tulijá Valley (Chiapas, Mexico), in seasonal conditions during two farming cycles, i.e., spring-summer (May to October) and autumn-winter (November to April). This territory is inhabited by native Mayans from the Cho'l ethnic group. Some farmers use the agroecosystem maize (*Zea mays* L.)-mucuna (*Mucuna deeringeanum* Bort.) in their farming practices.

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Native maize genotypes are cultivated with traditional techniques (s-a-b) in the spring-summer period, while mucuna is mainly used as a plant fertilizer source during the autumn-winter period (Triomphe, 1996).

Agroecology studies agricultural production methods through harmonious relationships with nature. The main purpose of this science is natural resources conservation, understood as conservation in situ, i.e. maintain food production. Whenever possible, this science seeks to maintain the genetic wealth of the native species dedicated to agricultural use and as well as protect plant and animal wildlife. Edwards (1990) believes that sustainability implies the agrosystem's capacity to maintain productivity over time as well as deal with ecological limitations, disruptions and complex pressures from its socioeconomic setting. The criterion to assess agrosystem capacity includes aspects such as soil and water conservation, genetic diversity and the proper management of resources so as to ensure stable food sources, a good standard of living in rural communities and a healthy and safe living environment.

Legumes are extremely important to the conservation and improvement of soils. This is particularly the case in the wet tropics where small farmers, in general, lack the financial and technical means to utilize industrial products. Legumes used as green manure have traditionally served as sources of nitrogen for crops and as a means of improving soil quality (Kaizzi *et al.*, 2006). However, in order to increase the productivity of soils over the long-term, improving its quality is more important than the actual presence of nitrogen. This is because the organic matter added to the soil in the form of green manure is very labile and can affect soil reactions and the microbiological processes where nitrogen is included. Mucuna, also known as *frijol nescafé*, is one of the main legumes utilized as green manure in the tropics, as it grows well in deficient tropical soils and has no difficulties growing in rocky, mountainous areas. The effects of this crop are positive as it keeps weeds under control, functions as good biomass and contains a biologically fixed amount of nitrogen due to the symbiosis with bacteria of Rhizobium genus. Crop rotations with mucuna obtain better maize yields than on land where it is not utilized. The maize yield is directly related to the availability of macro and micronutrients present in soils (Navelo *et al.*, 1998).

This study will study the effect of consecutive periods of mucuna use on soil properties and the dynamic of weeds and the grain maize yield, in the context of traditional farming systems in the Tulijá Valley. The hypothesis of this study is that the agroecological sustainability potential of the maize-

mucuna agroecosystem is favoured by the duration of its consecutive growing, in comparison with traditional maize farming which does not rotate with this composting system.

MATERIALS AND METHODS

Study site: This study was carried out in the communities of Francisco I. Madero, Santa María and Tiempópá located in the Tulijá Valley, which belongs to the municipality of Salto de Agua. This area is found in the northeast of the State of Chiapas, Mexico, between 17°10' and 17°30' N and 92°00' and 92°25' W. Its mean altitude is 100 m and its climate is AF (m) (García, 1981), warm and wet. It has year-long rainfall, (i.e. a mean annual precipitation of 3,000 mm) and a mean annual temperature of 26.7°C (INEGI, 2007). The topography of the area studied can be classified as precipitous terrain. According to the FAO (1968), classification the predominant soils are lithosols with associations of rendzinas and chromic luvisols (INEGI, 2007). They are fertile and moderately developed with a depth of less than 60 cm. They possess good drainage, are slightly acidic, alluvial and comprised of unconsolidated terrigenous deposits. Their granulometry varies from coarse sands and gravel at the base of the mountains, to lime and clays in terrain with less slope (INEGI, 1983). It is humid practically all year and due to the geodesy of the terrain and the high presence of limestone, the use of farming machinery is limited.

Experimental design: The research was carried out in the autumn-winter season known as *tornamil*. The stratification of the Choles farmers was made according to the duration of farming with the maize-mucuna agroecosystem, i.e., on the same soil or fields without interruption. Four strata or treatments were defined: 0 (T1), 5 (T2), 10 (T3) and 15 (T4) years of use of this agroecosystem. T1 includes lands where maize is grown using traditional methods (the maize-mucuna agroecosystem is not applied).

A completely random design was applied with four treatments and three replications in the same microregion on approximately 1 ha plots belonging to three different farmers. A total of 12 study plots were obtained. The treatment durations were set at 5 years with the aim of learn the effect of the legume on the ecological relationships of farming production in each of period of time and to also compare the effect of using green manure to that of not using of it. A simple classification model was utilized to study the following factors: soil, weeds, seed bank, maize farming production indicators and the use of the maize-mucuna agroecosystem.

The maize and mucuna were both planted using the traditional methods of the local natives. The work is done by hand with the help of an espeque (dibble stick). Maize is sown at the beginning of November at average distances of 1.2 m between rows and plants. Four seeds are deposited at each point, which results in a population density of approximately 27,000 plants ha⁻¹. The growing cycle of criollo maize genotypes is approximately 130 d. The entire farming process is essentially natural, that is, it does not use external inputs.

The mucuna is sown directly between the rows of maize at a distance of 2 m², 50 d after the maize planting. Two seeds are deposited at each point, which results in a population density of 5,000 plants ha⁻¹. The mucuna emerges and begins to grow. Due to its aggressive growth at this stage, it starts climbing the maize plants. The latter are harvested 100 d after the mucuna planting, i.e., 150 d after the maize planting (March and April). The harvest is done by hand, leaving the dry maize stalks standing, which serve to prop the legume. The mucuna completely develops 250 d after sowing. As this area is a wet tropical environment, the green manure's foliage cover of the ground is 100% and it remains until the following growing cycle. In October it is manually incorporated and at the beginning of November maize is planted again. This system constitutes an ecological preparation strategy for the soils in Selva de Chiapas.

Sampling and analysis:

Soils: The research used zigzag sampling at the beginning and end of the growing cycle and composite samples were obtained for the four evaluation systems. Samples were taken at depths from 0-15 cm and from 15-30 cm. This was done to determine the effect of the fertilizer on soil fertility at levels where the maize root system has different behaviours and requirements as a result of the inherent characteristics of the species. In order to reduce variability of soil characteristics between the first and second sampling, five sampling points were established on each plot of land. Subsamples were collected at these points and were combined to obtain a compound sample for each plot. This sample underwent a physical-chemical analysis to determine the properties of agronomic interest. In total, 48 soil samples were collected.

Various methods were utilized in order to determine the main properties of agronomic interest., Bouyoucos Hydrometer (Texture); Excavation (Bulk density-BD); Conductometer (EC, soil-water ratio 1:5); Potentiometer (pH, soil-water ratio 1:5); Walkley-Black oxidation (Organic Matter-M.O); Macro Kjeldahl (Total nitrogen-N); Morgan extract solution,

diphenylamine method (NO₃); Olsen (P); Extractable cations with Morgan solution (K); and Versenato Method (Ca and Mg). The following simple general considerations were used to interpret the results: the classification proposed by Tavera (1985) for N; the classification by the CSTPA (1980) for P; the classification proposed by Moreno (1978) for K, Ca, O.M. and Mg; the classification proposed by Almyda (1967) for pH and the textural classification based on the proportion of sand, limestone and clay proposed by López-Collado (1996).

Weeds: Weed sampling was conducted using the quadrat method (Krebs, 1985) to determine the floral diversity, density and similarity and to know the effect that the legume has on the growth of flora. The sampling area was 0.25 m² (0.50 x 0.50 m) and the quadrat frame was tossed randomly, continuing along a zigzag line on each study plot, taking three samples per plot. Three samplings were taken over the course of the entire growing cycle. The first was conducted before the clearing of the *milpa* (30 days after maize sowing), the second was conduction during the flowering period of maize (70 days after sowing) and the third, during the stage when maize reaches physiological maturity (i.e., 100 days after the sowing). After each random toss, the total number of each floral species inside the quadrat frame was counted. They were grouped by species and placed in paper bags to be identified and dried for approximately 72 h. When the plants were completely dried, they were weighed using a granatary scale.

In order to learn how the populations behaved, weed diversity was determined using the Shannon and Weaver (1964) (Eq. 1):

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

Where:

H' = The Shannon-Weaver Index

π_i = The proportion of the total number of individuals of species i (n_i) with respect to the total number of individuals of all species (N) and log is the abbreviation of the logarithm, in this case, with 10 as its base (decimal)

Additionally, the similarity between communities was determined using the Sørensen Index (Krebs, 1985) (Eq. 2), which is expressed by the formula:

$$I_{ss} = \frac{2c}{a+b} * 100 \quad (2)$$

where, a is the number of species in community or sample 1; b, in community or sample 2 and c, the number of species present in both communities or samples.

The Importance Value Index (IVI_i) (Eq. 3) was applied (Curtis and McIntosh, 1950, 1951; Finol, 1971; Mueller-Dombois and Ellenberg 1975; Matteuci and Colma, 1982; Lamprecht, 1990; Kent and Coker, 1994) in order to assign each species its category of importance. The IVI_i is obtained from the sum of the Relative Density (RD), the Relative Frequency (RF) and the Relative Dominance (RDom):

$$IVI = RD_i(\%) + RF_i(\%) + RDom_i(\%) \quad (3)$$

where, RD is the ratio, in percentage terms, between the number of individuals of species X and the total number of individuals of all species; RF is the frequency of species X, divided by the sum of the frequencies of all species and multiplied by 100; and RDom is obtained by calculating the percentage of total biomass of a species out of the total biomass of all species.

The tray or germination method was used to analyze the seed bank of the various treatment study plots at different periods in time. Compound samples were taken from the soils of each one of the plots at a depth of 0-15 cm. The samples were placed in recipients made of wood (trays) measuring 20×40×20 cm. There was a tray for each replication, making a total of 12 trays. In order to avoid seed contamination from the wind, from animals, or from water, the recipients were positioned under coverings made of indigenous plant materials that allowed sunlight to enter. They were watered at three-day intervals throughout the duration of the entire experiment to maintain soil moisture and facilitate the growth of the weed vegetation.

The first observation was made eight days after the first sampling. This was done to record the degree of growth of the weed species from among the different treatment locations. Observations were made every 30 days in order to record the development of the species that had emerged. At the end of the experiment, in the fourth and fifth sampling (approximately after four months), the number of individuals of each species was counted, its family and species identified and its classification made according to the type and number of broad-leaved and narrow-leaved species.

Yield components: A description of maize in terms of agronomic interest was made with the aim of learning the effect of the farming strata that used green manure. Since this study was conducted on active farming fields, the method proposed by Luna (1993) was used.

Consequently, zigzag samplings were conducted, whereby 10 consecutive plants were counted at 5 points on each study plot. The following agronomic variables were determined: number of rows per cobs, number of grains per row, number of grains per cob, cobs per plant, weight of cobs and harvested plants. The method proposed by Lafitte (1994) was used to estimate grain yield.

Statistical analysis: The results of the soils chemical analysis were subjected to an analysis of variance (ANOVA) in the SAS packet SPSS, 1999, utilizing the programme PROC ANOVA. A completely random design ($\alpha = 0.05$) was utilized, following the criteria of Cochran and Cox (1973), Marquez (2008) García-Villalpando *et al.* (2001). Subsequently, a multiple comparison of averages was carried out using the Tukey test. Procedures of ANOVA were utilized in the statistical analysis of the yield components. Due to the characteristics of the research and the homogeneity present at the study sites, the analysis was carried out using a simple classification model (Dixon and Massey, 1966), in keeping with the strata studied. In order to detect significant differences between study systems, a multiple comparison of averages was utilized, i.e., the Duncan multiple range test with a significance level of 5%, following the criteria by Cochran and Cox (1973), Marquez (2008) García-Villalpando *et al.* (2001). Subsequently, the multiple comparison of averages was carried out using the Tukey test. A Pearson correlation analysis was conducted to find the degree of correlation and determination of the variables of maize.

RESULTS

Soils: After subjecting the edaphic elements to analyzes of variance and multiple comparisons of averages in order to determine the effect of periods of mucuna use on soil properties, the results revealed no significant differences between the treatments. A tendency was observed, however, that showed higher levels of nutrients in the treatments where mucuna was grown (Table 1).

In T1, at the two depths analyzed, the soils are silt loam and clay loam. The textures vary in T2 repetitions between silt loam, loam, clay loam and clay. The dominant textural type in T3 is loam with subtle variations of silt and clay. The texture of T5 is sandy loam, silt loam and clay.

The analysis was conducted to determine the effect of periods of farming with the maize-mucuna agroecosystem on N content. It was observed that the lowest levels were in T1 and these levels increased and

remained stable, with slight variations, in the strata with mucuna use (T2, T3 and T4). Higher N content was also observed in the layer of surface soil (0-15 cm), decreasing slightly at a depth of 15-30 cm. As regards P levels, the classification applied (Moreno, 1978) indicates that the values are high and middle range in all of the study treatments. The values increase in the soils where mucuna is grown. The K analysis revealed that the soils, for the most part, contain high levels of this nutrient.

In the samplings conducted at the beginning and end of the maize growing cycle, at a depth from 0-15 cm, it is observed that the soils are extremely rich in O.M., obtaining slightly lower values at a greater depth (15-30 cm).

NO₃ content is higher in the soils where mucuna is used in contrast to the treatment where it is not. It was observed that the soils are highly rich in calcium and magnesium. The pH, EC and BD were slightly higher in the treatments with mucuna use. The pH tends to be acidic due to the geographical location and environmental conditions.

Weeds: The values obtained for the Shannon-Weaver Index were 1.54 for T1, 1.28 for T2, 1.24 for T3 and 0.86 for T4. The similarity value (Table 2) between T1

and T2 was 64.34%. When T1 is compared with T3 and T4, the values progressively diminish to 58.25% and 50.00%, respectively. The values obtained by comparing T2 with T3 and T4 were 63.04% and 51.88 %, respectively. Finally, the similarity value between T3 and T4 was 60.87 %.

The total number of species counted in T1 was 61, distributed among 29 different families. The highest importance value was found for the species *Heliconia latispatha* (47.51). Other species with high importance values in this treatment were: *Iresine celosia*, *Clerocarpus dentatus*, *Paspalum* sp. and *Cyperus* sp. with 18.36, 15.11, 14.54 and 11.40, respectively. In T2, 51 species were counted, distributed among 23 families. The highest importance value found in this treatment was for the *Paspalum* sp. and another unidentified species. They both belonged to the Poaceae family and their values were 44.22 and 26.64, respectively. The highest importance value in T3 was for the legume *Momordica charantia*, with a value of 39.70. Also important were the species *Paspalum* sp. and *Cucurbita moschata*, whose values were 25.74 and 28.41, respectively. Mucuna had a high importance value (16.64) as well. The unidentified species from the Poaceae family had the highest importance value (65.92) in T4, followed by mucuna (16.21).

Table 1: Multiple comparison of chemical and physical properties of the soil at the beginning (1) and end of the cycle (2)

Depth	Strata	pH	EC [†] (dS/m)	BD [†] (g cm ⁻³)	O.M. [†] (%)	N (%)	P (ppm)	K (ppm)	NO ₃ (ppm)	Ca (ppm)	Mg (ppm)
0-15	T1	6.56 a	0.09 a	1.07 a	7.26 a	0.15 a	6.14 a	140.41 b	46.67 a	6904 a	909.1 a
0-15	T2	5.50 a	0.12 a	1.08 a	4.96 a	0.25 a	12.51 a	300.00 a	95.83 a	4646 a	590.9 a
0-15	T3	7.00 a	0.18 a	1.19 a	5.40 a	0.24 a	9.27 a	193.750	125.00 a	22196 a	636.4 a
0-15	T4	7.50 a	0.20 a	1.07 a	5.92 a	0.23 a	10.17 a	141.25 b	149.17 a	13679 a	500.0 a
15-30	T1	5.43 a	0.12 a	*	5.78 a	0.15 a	7.92 a	109.37 a	74.17 a	7678 a	727.3 a
15-30	T2	6.56 a	0.05 a	*	2.39 b	0.16 a	10.73 a	153.12 a	60.83 a	4775 a	499.7 a
15-30	T3	7.23 a	0.10 a	*	2.59 b	0.14 a	6.48 a	110.42 a	45.83 a	27036 a	1500.0a
15-30	T4	7.93 a	0.10 a	*	3.53 ab	0.17 a	9.56 a	93.750 a	79.17 a	15131 a	795.4 a
0-15	T1	5.96 a	0.06 a	1.04 a	7.42 a	0.14 a	17.75 a	166.67 a	22.42 a	5449 a	1200.0 a
0-15	T2	6.00 a	0.07 a	1.06 a	5.74 a	0.23 a	13.58 a	191.30 a	17.17 a	5865 a	955.5 a
0-15	T3	7.27 a	0.18 a	1.12 a	5.92 a	0.29 a	13.79 a	183.75 a	55.00 a	23173 a	1488.9 a
0-15	T4	7.60 a	0.11 a	1.11 a	4.40 a	0.21 a	13.05 a	141.66 a	43.92 a	13782 a	890.6 a
15-30	T1	5.76 a	0.05 a	*	6.95 a	0.14 a	9.83 a	139.58 a	10.33 a	5321 a	1066.0 a
15-30	T2	6.07 a	0.07 a	*	3.98 a	0.17 a	10.77 a	126.04 a	11.25 a	7500 a	911.1 a
15-30	T3	7.20 a	0.08 a	*	3.10 a	0.15 a	9.49 a	100.00 a	11.25 a	25385 a	1200.0 a
15-30	T4	7.70 a	0.10 a	*	3.53 a	0.16 a	10.39 a	80.21 0a	40.00 a	17372 a	711.1 a

[†]Electrical Conductivity (EC), Bulk Density (BD), Organic Matter (M.O); [‡] Same letters show no significant difference

Table 2: Agronomic variable and components of maize (*Zea mays*) yield

Treatment	Number of Cobs (m ²)	Cob width (cm)	Cob length (cm)	Grains per m ²	Cob weight (g)	Grain weight per cob (g)	Yield (t ha ⁻¹)
T1	1.37 b	15.6 a	13.99 a	556.56 b	182.86 b	136.45 b	1.98 b
T2	2.20 ab	16.68 a	15.94 ab	1174.1 a	260.36 ab	204.70 ab	4.23 a
T3	2.48a	17.17 a	14.53 b	1127.5 a	237.06 ab	182.63 ab	4.35 a
T4	2.60a	17.84 a	18.64 a	1346.4 a	306.53 a	239.20 a	5.71 a

Table 3: Pearson correlation analysis between variables of maize (*Zea mays*) farmed using mucuna (*Mucuna deeringianum* Bort) cover

		Cobs per m ²	Cob width	Cob length	Cob per row	Grains per row	Grains per cob	Grains per m ²	Cob weight	Grains weight	Yield	Stratum
Cobs per m ²	R ²	1.0000	0.422	0.548	0.003	0.370	0.318	0.8800	0.5270	0.532	0.86900	0.7680
	α	0.0000	0.171	0.065	0.991	0.236	0.312	0.0002	0.0780	0.074	0.00011	0.0030
Cob width	R ²	0.4220	1.000	0.432	0.701	0.280	0.641	0.6530	0.8520	0.785	0.73000	0.6550
	α	0.1710	0.000	0.160	0.011	0.377	0.024	0.0210	0.0000	0.002	0.00700	0.0200
Cob length	R ²	0.5480	0.432	1.000	0.084	0.822	0.715	0.7500	0.7820	0.821	0.73900	0.6690
	α	0.0650	0.160	0.000	0.793	0.001	0.008	0.0040	0.0020	0.001	0.00600	0.0170
Cobs per row	R ²	0.0030	0.701	0.084	1.000	0.033	0.583	0.3100	0.4860	0.493	0.29800	0.2400
	α	0.9910	0.011	0.793	0.000	0.917	0.046	0.3260	0.1090	0.103	0.34500	0.4500
Grains per row	R ²	0.3700	0.280	0.822	0.033	1.000	0.825	0.6540	0.6060	0.693	0.48900	0.3460
	α	0.2360	0.377	0.001	0.917	0.000	0.001	0.0200	0.0360	0.012	0.10600	0.2690
Grains per cob	R ²	0.3180	0.641	0.715	0.583	0.825	1.000	0.7200	0.7890	0.854	0.58200	0.4320
	α	0.3120	0.024	0.008	0.046	0.001	0.000	0.0080	0.0020	0.000	0.04600	0.1600
Grains per m ²	R ²	0.8800	0.653	0.750	0.310	0.654	0.720	1.0000	0.7880	0.812	0.93400	0.7670
	α	0.0000	0.021	0.004	0.326	0.020	0.008	0.0000	0.0020	0.001	0.00000	0.0030
Cob weight	R ²	0.5270	0.852	0.782	0.486	0.606	0.789	0.7880	1.0000	0.981	0.85900	0.7180
	α	0.0780	0.000	0.002	0.109	0.036	0.002	0.0020	0.0000	0.000	0.00000	0.0080
Grain weight	R ²	0.5320	0.785	0.821	0.493	0.693	0.854	0.8120	0.9810	1.000	0.84700	0.7030
	α	0.0740	0.002	0.001	0.103	0.012	0.000	0.0010	0.0000	0.000	0.00050	0.0100
Yield	R ²	0.8690	0.730	0.739	0.298	0.489	0.582	0.9340	0.8590	0.847	1.00000	0.8620
	α	0.0002	0.007	0.006	0.345	0.106	0.046	0.0001	0.0000	0.000	0.00000	0.0003
Stratum	R ²	0.7680	0.655	0.669	0.240	0.346	0.432	0.7670	0.7180	0.703	0.86200	1.0000
	α	0.0030	0.020	0.017	0.450	0.269	0.160	0.0030	0.0080	0.010	0.00000	0.0000

The soil seed bank offered the highest diversity indexes among T1 and T2, registering values of 1.0340 and 1.1892, respectively. T3 had a value of 0.7630 and T4, a value of 0.6003, which show they have less similarity. The 0-5 and 0-10 year strata had similar values, 51.16 and 51.61%, respectively. The comparison of the 0-15 and 5-10 year strata with mucuna use showed intermediate values 38.46 and 47.61%, while the comparison of the 5-15 and 10-15 year strata revealed values of 32.43 and 32.00%, respectively, making them the strata with least similarity.

Yield components and grain yield: The results of grain yield in the Tukey multiple comparisons of averages revealed statistically inferior values in T1. The treatments T2 and T3 were statistically equal and the highest yield value was calculated in T4 (Table 2).

In the analysis of correlation it was observed that the variables that determine yield are population density ($r^2 = 0.6307$), the number of cobs per square metre ($r^2 = 0.869$), cob width ($r^2 = 0.730$), cob length ($r^2 = 0.739$), grains per square metre ($r^2 = 0.934$), cob weight ($r^2 = 0.859$) and grain weight per cob ($r^2 = 0.847$) (Table 3).

DISCUSSION

Soils: The chemical analyzes carried out at the beginning and end of the maize cycle make it possible to elaborate an edaphic description for the sampling points in the region of Tulijá Valley. By nature, the soils are rich in basic nutrients for farming. The textures found in the study site and at the sampling points, demonstrate that

this area is adequate for maize farming and the utilization of green manures in the wet tropics (Ochse, 1972; Contreras-Benítez *et al.*, 2002). Contreras-Benítez *et al.* (2002) state that maize has widely spread in Mexico because of this characteristic, especially in seasonal farming. In addition, Ochse (1972) indicate that maize can be grown in any type of soil.

The high levels of N content in the topsoil are attributed to the fertilizing effect of the green manure type mucuna. In T1, these levels are the result of the slash-and-fell farming system, which leaves the land fallow for approximately three years. This fallow period gives rise to high levels of biomass due to the fact that plant litter is not burned during the cycle and is later incorporated into the soil when the time comes for land preparation.

The P content results coincide with those reported by Triomphe (1995), who, in a 10-year study of the effects of mucuna on the fertilizing systems along the coast of Honduras, found higher amounts of P in treatments where the legume was grown. This increase positively correlates with the years of growth, quantifying lower amounts in the treatment without mucuna. The high K content is a result of the composition of the soils themselves (luvisols, acrisols, regosols and nitrosols) and the traditional practise of slash-and-fell.

The highest O.M. contents in T1 fields are attributed to the autumn-winter farming system cycle of slash-and-fell. In this system burning is foregone to favour the rapid growth of vegetation and avoid soil deterioration. The lands used only for the autumn-winter farming cycle

are left fallow for between 2 and 5 years. The fallow period allows vegetation growing that is to be incorporated into the soil at the slash. Together, this process, along with high precipitations, high temperatures and the type of prevalent vegetation give rise to a rapid decomposition of the plant litter. Moreover, these conditions give rise to a dynamic and systematic decomposition of the O.M. that is later incorporated into the soil when the mucuna is cut during land preparation prior to sowing.

The systems that resort to burning following the harvest register the highest acid pH values, in comparison with permanent crop systems (without burning). This suggests higher acidity as a result of the ashes and their high Ca content (Sánchez and Camacho, 1981).

The prevalent conditions in the wet tropics cause N losses through lixiviation and volatilization, considering it is a highly mobile element, especially in soils with light textures. For these reasons it is important to constantly incorporate O.M. into the soil. Using legumes as green manure represents a highly viable method of maintaining a sustainable farming system. The highest levels of N and NO₃ were calculated and stabilized in the treatments with mucuna use. This demonstrates the agroecological sustainability of the farming method evaluated in this research. The land maintains adequate and stable levels of fertility making it possible to carry out a sustainable, year-round, cropping cycle on the same fields, which are fertilized using an ecological process.

Weeds: The Shannon-Weaver Index results reveal greater diversity in the treatment without mucuna, which gradually decreases in the treatments with mucuna as a result of its allelopathic effects.

The similarity values revealed that the use of mucuna over time selects the species of weeds, with only those that develop a capacity to adapt or co-evolve with the legume surviving.

The high importance value of *Mucuna* is precisely the case in the final stages of the maize growing cycle when mucuna begins an important period of growth in order to establish itself.

Yield components and grain yield: Significant statistical differences were observed in the yield components: Population density, number of cobs per square metre, cob length, grain per square metre, cob weight, grain weight per cob and grain yield. All of these proved to be higher in the treatments with mucuna.

CONCLUSION

The treatments with the maize-mucuna system, up to a 50% increase in N content was observed in the

topsoil (0-15 cm) in comparison with the traditional maize farming system with no green manure rotation. A similar tendency was observed for the other analyzed nutrients. A direct correlation was not found between the nutrient content and the years of mucuna rotation. The diversity of weed growth was higher in the treatment without successive mucuna usage, with a Shannon-Weaver diversity index of 1.54. The similarity of species decreased in accordance with longer use of the green manure. The species found in the seed bank were observed to be similar. Grain yield rose 50% on the treatments farmed with mucuna in comparison with the traditional maize farming system that does not use the legume. This also correlated positively with the duration of usage. It was determined that use of the maize-mucuna agroecosystem increases and maintains agroecological sustainability over time. Moreover, the results validate and support this practise, which has been adapted and utilized by the indigenous Choles of the Tulijá Valley in Chiapas for more than 30 years. Youths will play an important role in the continuance of this agricultural sustainability practice, which need to possess a positive attitude so that they would promote their participation in agricultural activities and have positive mind-sets that would encourage them to be inclined towards sustainable farming practices (D'Silva *et al.*, 2010).

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