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Agri-environmental evaluation of traditional and alternative corn production systems in Chiapas, Mexico

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Abstract

This study evaluates the effects of environmental variables on traditional and alternative agroecosystems in three *Ejidos* (communal lands) in the Chiapas rainforest in Mexico. The tests occurred within two seasonal agricultural cycles. In spring-summer, experiments were performed with the traditional slash, fell and burn (S-F-B) system, no-burn systems and rotating systems with *Mucuna deeringiana* Bort., and in the autumn-winter agricultural cycle, three no-burn systems were compared to evaluate the effect of alternative sowing with corn (no-burn and topological modification of sowing). The results show a high floristic diversity in the study area (Sörensen Index $S_S = 4 – 23\%$), with no significant differences among the systems evaluated. In the first cycle, the analysis of the agronomical variables of the corn indicated better properties in the fallowing systems, with an average yield of 1,950 kg ha $^{-1}$, but there was variation related to the number of years left fallow. In the second cycle, the yields were positive for the alternative technology (average yield 3,100 kg ha^{-1}). The traditional S-F-B systems had reduced pests and increased organic matter and soil phosphorous content. These results are the consequence of fallow periods and adaptation to the environment; thus, this practice in the Chiapas rainforest constitutes an ethnocultural reality, which is unlikely to change in the near future if the agrosystems are managed based on historical principles.

Keywords: Traditional land use, slash-and-fell-and-burn, environmental indicators, maize, indigenous, Chiapas

1 Introduction

Farming is the main economic activity in the Selva region of the State of Chiapas in the south of Mexico. Approximately 70% of the smallholders use traditional agricultural methods and techniques that date back to pre-Columbian times. Farm work is dependent on environmental conditions (seasonal agriculture); basic grains are cultivated using family labour. Corn (*Zea mays*) is the main crop in Mexico and Chiapas (Perales *et al.*, 2005) and is considered to be the crop of the poor (Bellon *et al.*, 2005).

In the complex and diversified Mexican society, corn is necessary for survival (Keleman *et al.*, 2009). Since the time of most ancient societies and the first ethnic groups, people have depended heavily on this grain. The *Zea mays* L. species, which originated in Mesoamerica (Wellhausen *et al.*, 1985; Bellon *et al.*, 2005; Brush & Perales, 2007; Keleman *et al.*, 2009), has been cultivated under different production systems. In Chiapas, the *milpa* agroecosystem is the most important agricultural production system; corn is the dominant grain within this intercropping system (Brady, 1996; Ochoa-Gaona & González-Espinosa, 2000; Ávila-Romero, 2007). Approximately 85% of the national corn crop comes from subsistence production; a large percentage of the volume is for self-consumption (SIAP, 2007).

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The itinerant or migratory system, known in Latin America by different names and in Mexico as *Roza-Tumba-Quema*, or slash, fell and burn (S-F-B), consists of cutting down existing vegetation with a machete or an axe and burning the residual dry vegetation (Brady, 1996). Felling is applied only when the vegetation is over 10 m high. If the plants are still small, the system is known as *roza-quema* (slash and burn) (S-B).

High vegetation is a consequence of the land being left fallow for a certain period (Terán & Rasmussen, 1994), which is also long enough to allow the land to recover its productive capacity and soil fertility for tree regeneration (Neugebauer, 1988; Harwood, 1996; Mendoza-Vega & Messing, 2005; Serrano-Altamirano & Cano-García, 2007). There are two seasonal agricultural cycles related to the climate. The spring-summer cycle extends from April to September and is known traditionally as *milpa de año* (yearly milpa), or *cholel* in ch'ol, and the autumn-winter cycle, known as *tornamil* or *mol* in ch'ol, extends from November to April. Despite the enormous importance of S-F-B agriculture in Chiapas, this system has not been studied sufficiently under current growing conditions.

Due to the demographic explosion and the resulting increased pressure on the land in southern Mexico, the sustainability of the complex *milpa* itinerant agriculture production system is being affected by the shortening of the fallow period (Mendoza-Vega & Messing, 2005; Serrano-Altamirano & Cano-García, 2007). In 2005–2010, the mean annual population growth rate in the State of Chiapas was 2.2%, which is higher than the national annual mean of 1.8% (INEGI, 2011). In native families in the region, annual population growth is as high as 3.7% (INEGI, 2005, 2011). At the same time, the productive potential of the land has diminished considerably, putting the sustainability of the nomadic system at risk (Hernández *et al.*, 1995; Mendoza-Vega & Messing, 2005).

Mucuna deeringiana is a fast-growing cover crop used as green manure in Chiapas that associates well with corn. It contributes nutrients to the soil (mainly nitrogen by the symbiosis of legumes and the bacteria of the *Rhizobium* genus), adapts well to high precipitation and steep slopes, retains moisture, reduces erosion, develops well on tropical soils and is effective at weed suppression (Aguilar-Jiménez, 1997; Bernardino-Hernández *et al.*, 2006; Serrano-Altamirano & Cano-García, 2007; Ayala Sánchez *et al.*, 2009). *Mucuna* is used in the *abonera* system and in a closed cycle. It sprouts naturally during the biological cycle of corn and develops freely when the cereal is collected. The biomass from the *abonera* is of great agricultural interest for conservation and soil improvement in the mountain tropics (Louis, 1996; Bernardino-Hernández *et al.*, 2006; Serrano-Altamirano & Cano-García, 2007; Ayala Sánchez *et al.*, 2009).

The corn borer is the main pest affecting corn in the study area. The larvae of the corn borer attacks early, within the first 30 days, inhibiting plant growth (i.e., the plants are stunted and sometimes die). Some damaged plants manage to grow, but their yield is less than that of healthy plants. The characteristics of the *Diatraea liniolata* (Walker.), a species of the Pyralidae family (Lepidoptera), which is widely distributed in the tropics, have been reported by King (1984) and CATIE (1990). This species has yellow eggs and white larvae with black to coffee-coloured patches on each segment. It goes through seven stages, and when young (2–3 days, before penetrating the stem), it feeds on tender leaves. Diapause depends on environmental conditions; pupation occurs inside the stalk, and the moths have beige front wings and cream-coloured hind wings. The females are larger than the males. At this point, damage to the plant increases and perforations may be observed.

The objective of this study was to analyse the current dynamics of itinerant agriculture in the humid tropical environment of Chiapas, Mexico and to evaluate its agricultural and environmental sustainability based on strategic indicators associated with fallow periods of different lengths. We determined the impact of alternative practises such as no burning, crop rotation with *Mucuna deeringiana* as green manure and a modified sowing distribution.

2 Materials and methods

2.1 Study area

The study was performed in the Ignacio Allende, Venustiano Carranza and Cuctiepa *ejidos* (communal lands) in the Municipality of Tumbalá, Selva 6 th Socioeconomic Region, State of Chiapas, Mexico (400 m.a.s.l., 17°16'N, 92°09'W). These *ejidos* are located in the middle of the Tulija Valley macro catchment (INEGI, 2000a); they are highly marginalised communities inhabited by natives (INEGI, 2000b).

Due to the geographic proximity of the *ejidos* to one another, their mountainous topographic conditions are similar, with an average slope of 30 to 40%. The climate is tropical with a mean annual temperature of 22.1 ºC and a mean annual precipitation of 2,071 mm (INEGI, 2011).

Table 1: *Studied cultivation systems in Chiapas, Mexico*

First cycle – milpa			*Second cycle – tornamil*		
I.	20-year fallow with burning	20ACQ	I.	5-year continuous traditional cultivation	5ACCT
II.	15-year fallow with burning	15ACQ	II.	5-year continuous alternative cultivation	5ACCA
III.	10-year fallow with burning	10ACQ	III.	2-year continuous traditional cultivation	2ACCT
IV.	5-year fallow with burning	5ACQ	IV.	2-year continuous alternative cultivation	2ACCA
V.	5-year permanent cultivation with no burning	5ASQ	V.	Continuous traditional cultivation with *Mucuna* sp.	CCCNT
VI.	2-year permanent cultivation with no burning	2ASQ			
VII.	No burning and with *Mucuna*	SQCN	VI.	Continuous alternative cultivation	CCCNA
VIII.	Undisturbed evergreen forest (control)	VNP			

According to the FAO/UNESCO (1968) land cover classification, the predominant soils are lithosols with associated rendzinas and chromic luvisols (INEGI, 2000b). They are fertile and moderately developed with a depth of less than 60 cm. They are well drained, acidic and alluvial, and they are made up of unconsolidated terrigenous deposits with a granulometry varying from thick sand to gravel at the foot of the mountains and to mud and clay toward less sloping lands (INEGI, 1990). Their profile is wet practically all year long. The topography of the land and the presence of lime rocks are not conducive to the use of mechanised farming.

As a consequence of the nomadic nature of S-F-B agriculture, the primary vegetation in the study area has been modified considerably. At present, there are only small scattered areas of high evergreen jungle with mostly secondary low vegetation (*acahuales*), in different periods of fallow (Ochoa-Gaona & González-Espinosa, 2000). The main local economic activity is the cultivation of varieties of Tuxpeño corn, beans and coffee (Wellhausen *et al.*, 1985).

2.2 Experimental design

During the first seasonal agricultural cycle (*milpa*), eight cultivation systems were studied in the Ignacio Allende *ejido*. During the second agricultural cycle (*tornamil*), six cultivation systems were studied in the Venustiano Carranza and Cuctiepa *ejidos* (Table 1). During the first cycle, the cultivation systems were stratified in five-year periods because no significant effects were observed over shorter periods (Mariaca *et al.*, 1995).

In the first cycle, four sampling plots per system (in a total of 32 sampling plots), each measuring 0.5 ha, were studied. Corn cultivation, no-burning and the use of *Mucuna deeringiana* were the alternative production systems. The sowing dates were set by the producers according to traditional sowing patterns (15 April to 15 May).

In the second cycle, four sampling plots per system were studied (in a total of 24 sampling plots), each measuring 0.5 ha. These six cultivation systems were divided into three traditional, and three alternative management systems with modified sowing distances between the rows and plants. In each case, one traditional and one alternative system were located at the farm of a single producer. The plots had mainly *alcahuales* (secondary vegetation) in continuous use; due to the rainy season, the vegetation had not been burned.

The alternative sowing technology in the second cycle was performed along with the producers, with a sowing distance of 1 m between rows and 0.5 m between plants. Two seeds were sown at each point for a population density of 40,000 plants per ha. In the traditional system, the average distribution was 1.25 m^2 between rows and plants with five to six seeds deposited at each point for a density of 30,000 plants per ha.

2.3 Floristic inventory

The floristic inventory was performed in three ecosystems: (1) *acahuales*, (2) corn fields (weeds) and (3) seed banks. In the *alcahuales*, sampling was performed before slashing. A 2×2 m square was used for the inventory, and three replicates were performed for each sampling unit. Floristic diversity was determined using the Shannon & Weaver (1949) Index, and similarity among the communities was found using the Sörensen Index (Krebs, 1985). The Shannon-Weaver Index (H')

was calculated based on the number of species in each sampling unit (S), the total number of individuals (n) and the number of individuals of each species (n_i):

$$H' = -\sum_{i=1}^{S} \frac{n_i}{n} \times \ln \frac{n_i}{n} \tag{1}$$

The Sörensen Index (S_S) was calculated based on the number of species in Population 1 (s_1), Population 2 (s_2) and the total number of species in both populations (c):

$$S_S = \frac{2c}{s_1 + s_2} \tag{2}$$

Species evenness was calculated using Pielou's evenness index (J')

$$J' = \frac{H'}{H'_{max}} \tag{3}$$

where H'_{max} is

$$H'_{max} = -\sum_{i=1}^{S} \frac{1}{S} \times \ln \frac{1}{S} = \ln S \tag{4}$$

The biomass of the trees was calculated by measuring the height of the trunk, the diameter at breast height (*dbh*) and the number of trees per hectare with a mean perimeter of over 0.3 m (Young, 1991). During *milpa*, these variables were measured on the felled trees before burning. In undisturbed evergreen forest (VNP) areas, the volume of trees was measured using a hypsometer.

For the seed bank, composite samples were collected in pans at a depth of 0 to 0.2 m and placed in 0.3 × 0.5 × 0.3 m wooden boxes (after Mariaca *et al.*, 1995). The three replicates per sampling unit were dried outdoors in the plots.

2.4 Physical-chemical characteristics of Mucuna deeringiana

The phenological variables, days to emergence and days to flowering, were determined as described in López *et al.* (1993). During three legume development periods, ten sampling points were located in a zigzag in each sampling unit, and at each point, the data were taken for ten consecutive plants using the quadrat (1 m^2) method (Krebs, 1985). A fresh sample was taken of the whole biomass and of its parts (leaves, stems, flowers, and fruit). The samples were dried for 72 hours at ambient temperature, and the whole biomass and its individual parts were weighed before and after drying (wet mass and dry mass). Nitrogen was measured using the Micro-Kjeldahl method, and phosphorous (colorimetry) and potassium (atomic absorption) content were determined.

2.5 Phenological and chemical characteristics of Zea mays

The method of López *et al.* (1993) was used to determine the phenological variables of corn. These variables were days to emergence, days to male and female flowering and physiological maturity. The agronomical variables were sowing distances between rows and plants, number of seeds per point (unit), plant height, ear height, leaf area, number of ears, number of grains per ear, ears per plant and plants harvested.

The same methodology was applied to evaluate the damages caused by stalk lodging and by the neotropical corn borer *Diatraea lineolata*. Ten sampling points were located in a zigzag in each sampling unit. At each point, the data were taken for ten consecutive plants for a total of 100 samples. The samples were examined to determine the presence or absence of the larvae of corn borer.

To estimate grain yield, the number of plants in five linear meters within the crop were counted. The ears from these plants were harvested and placed in order from larger to smallest. The medium sized ears were selected, and the number of rows per ear and grains per row were counted to obtain the total number of grains per ear. The yield per hectare was calculated using the Lafitte (1994) method, which is defined as:
(*plants per hectare*) × (*number of ears per plant*) × (*number of grains per ear*) × 0.0002857.

2.6 Soil and erosion

Physical and physical-chemical characterisations of the soil were made during the first evaluation cycle. To describe the soil profile, morphogenetic methodology was used (Caunalo, 1990). Sampling was performed before burning and after harvesting at a depth of 0 to 0.2 m. The methods listed in Table 2 were used to determine the main agronomical properties. Soil loss was estimated by the method of Anaya *et al.* (1991). Sampling was performed during the cultivation stage when soil was the most erodible and completed when the land was invaded by vegetation.

2.7 Statistical analysis

An analysis of variance (ANOVA) was performed using PASW Statistics 18 (PASW, 2009). Due to the nature of the research and the uniformity of the experimental sites, the analysis used a simple classification model in keeping with the systems studied (Dixon & Massey, 1972). To detect significant differences among the systems, a multiple comparison of means (Duncan's multiple range test) was performed with a 5% level of

Table 2: *Methods used to determine and interpret the physical and physical-chemical soil indicators*

Physical Determination	*Method of Determination*	*Classification of Interpretation*
Texture	Bouyucos hydrometer	Textural Classification (López, 1996)
Bulk density	Excavation	Cairo & Fundora (1994)
pH	Potentiometer, water-soil ratio 1:5	Letelier (1967)
EC	Conductivity meter, water-soil ratio 1:5	Richards (1972)
N	Macro Kjeldahl	Tavera (1985)
P	Olsen	CSTPA (1980)
K	Cations extractable with Morgan solution	Moreno (1978)
OM and C:N	Walkley and Black Oxidation	Moreno (1978)
Ca and Mg	Versenate Method	Moreno (1978)
Erosion	Nail Method	Anaya *et al.* (1991)

significance using Cochran & Cox (1999) and García-Villalpando *et al.* (2001) criteria. The data were given as percentages, and the counts were not transformed. Finally, a Principal Components Analysis (PCA) was applied to the phenological characteristics of the corn and the chemical characteristics of the soils.

3 Results

3.1 Floristic inventory

The analysis of floristic similarity in the *acahuales* (Table 3) detected no significant differences among the burning systems (ACQ), the no-burn systems (ASQ), the systems with *Mucuna* and the undisturbed evergreen forest.

The number of species, individuals and families decreased as the fallow period lengthened (Table 4). The Shannon-Weaver Index of diversity showed similar trends for all the systems. The highest estimated volume of tree trunk biomass was observed in a system with 2-year fallow with burning. A lower species evenness was observed in all the systems ($J' < 0.4$).

The regression analysis model for the flora in the *acahuales* (y) showed that

$$\begin{aligned} y = 0.225 + 0.06\,(\text{number of families}) \\ - 0.0006\,(\text{number of individuals}), \\ R^2 = 67.7\% \end{aligned}$$

The obtained equation shows high diversity due to the high number of species of different taxa with few individuals. The model also predicts that, for the conditions studied, the index of individuals is disproportional; that is, as the number of individuals of a species rises, the index is gradually reduced.

Table 3: *Multiple comparisons of means for flora variables in the acahuales. First cycle.*

Nº Communities	*Community Interaction*	*Common species*	*Sörensen similarity (%)*
1	20ACQ-15ACQ	8	10.95
2	20ACQ-10ACQ	14	13.72
3	20ACQ-5ACQ	16	16.49
4	20ACQ-5ASQ	11	12.50
5	20ACQ-2ASQ	6	6.06
6	20ACQ-SQCN	11	10.28
7	20ACQ-VNP	8	9.30
8	15AC-10ACQ	7	7.86
9	15AC-5ACQ	12	14.28
10	15AC-5ASQ	8	10.66
11	15AC-2ASQ	4	4.65
12	15AC-SQCN	8	8.51
13	15AC-VNP	5	6.84
14	10ACQ-5ACQ	26	23.00
15	10ACQ-5ASQ	10	9.61
16	10ACQ-2ASQ	16	13.91
17	10ACQ-SQCN	21	17.07
18	10ACQ-VNP	10	9.80
19	5ACQ-5ASQ	12	12.12
20	5ACQ-2ASQ	12	10.90
21	5ACQ-SQCN	19	16.10
22	5ACQ-VNP	11	11.34
23	5ASQ-2ASQ	14	17.82
24	5ASQ-SQCN	18	16.51
25	5ASQ-VNPQ	6	6.81
26	2ASQ-SQCN	18	15.00
27	2ASQ-VNP	4	4.04
28	SQCN-VNP	7	6.54

Table 4: *Multiple comparisons of means for flora variables in the acahuales. First cycle.*

System	*Number of species*	*Number of individuals*	*Number of families*	*Index of diversity (H')*	*Species evenness (J')*	*Tree volume*
20ACQ	14.0 ^{abc}	116.5 ^{a}	11.3 ^{ab}	0.7 ^{ab}	0.3 ^{ab}	7.0 ^{b}
15ACQ	10.0 ^{a}	191.5 ^{a}	7.5 ^{a}	0.5 ^{a}	0.2 ^{a}	1.4 ^{ab}
10ACQ	21.3 ^{bc}	163.0 ^{a}	13.5 ^{b}	0.9 ^{ab}	0.3 ^{ab}	1.0 ^{ab}
5ACQ	18.5 ^{abc}	90.5 ^{a}	14.0 ^{b}	1.0 ^{b}	0.4 ^{b}	0.4 ^{a}
5ASQ	15.5 ^{abc}	297.0 ^{a}	11.0 ^{ab}	0.8 ^{ab}	0.3 ^{ab}	–
2ASQ	22.0 ^{bc}	308.8 ^{a}	13.0 ^{b}	1.0 ^{ab}	0.3 ^{ab}	–
SQCN	23.0 ^{c}	214.0 ^{a}	14.0 ^{b}	1.0 ^{ab}	0.3 ^{ab}	–
VNP	13.00 ^{ab}	47.3 ^{a}	11.3 ^{ab}	0.9 ^{ab}	0.4 ^{b}	24.7 ^{c}
$Es\bar{x}$:	2.8	85.1	1.6	0.1		1.9

Table 5: *Multiple comparison of means for flora in seed banks variables. First Cycle.*

System	*Number of species*	*Number of individuals*	*Number of families*	*Plant height (cm)*	*Index of diversity (H')*
20ACQ	4.8 ^{a}	8.3 ^{a}	3.5 ^{abc}	22.9 ^{ab}	0.5 ^{bc}
15ACQ	2.5 ^{a}	4.3 ^{a}	2.5 ^{ab}	52.8 ^{b}	0.4 ^{b}
10ACQ	6.5 ^{ab}	12.8 ^{ab}	5.0 ^{bc}	12.6 ^{ab}	0.6 ^{bc}
5ACQ	13.3 ^{b}	55.0 ^{b}	7.0 ^{c}	20.1 ^{ab}	0.7 ^{c}
5ASQ	4.5 ^{a}	14.8 ^{ab}	3.8 ^{abc}	41.2 ^{ab}	0.4 ^{bc}
2ASQ	5.5 ^{a}	18.8 ^{ab}	4.3 ^{abc}	22.3 ^{ab}	0.6 ^{bc}
SQCN	4.3 ^{a}	18.8 ^{ab}	3.3 ^{ab}	19.7 ^{ab}	0.4 ^{bc}
VNP	0.8 ^{a}	2.3 ^{a}	0.8 ^{a}	2.3 ^{a}	0.0 ^{a}
$Es\bar{x}$:	2.26	13.55	1.07	12.89	0.11

At seed banks, the Shannon-Weaver Index was very similar in all the evaluation systems (Table 5). In a system with 15-year fallow and burning, a species in the Rubiaceae family predominated and gradually modified the index, which is sensitive to disproportionality. The results for the 5-year and 2-year permanent cultivation with no burning and for undisturbed evergreen forest show that the stages of plant succession are not strongly modified by different periods of fallow.

3.2 *Physical-chemical characteristics of Mucuna deeringiana*

The results varied across the samples; in the third and last sampling, the volumes were 18.4 and 4.8 t ha^{-1} for wet and dry biomass, respectively. These values are more than double the average values (Fig.1). The regression analysis for the *Mucuna deeringiana* dry biomass volume (y) (t ha^{-1}) gave the model:

$$y = 0.074 + 0.440\,(\text{wet stem}),\ R^2 = 99.1\%$$

This model was adequate under the study conditions, and the majority of the dry biomass is provided by the stem.

For the major element extractions (Fig. 2), the mean amount extracted from the leaves was 36.2 kg N ha^{-1}, which is higher than the mean amount extracted from the stems (16.8 kg N ha^{-1}). However, the sampling site does not have a statistically significant effect on leaf values, in contrast to growth stage. Phosphorous was highest in the leaf while potassium was highest in the stem (26.4 kg K ha^{-1}). The total N, P and K extractions from the plant parts (stem, leaf, flower and fruit) were 54.5 kg N ha^{-1}, 3.0 kg P ha^{-1} and 42.34 kg K ha^{-1}.

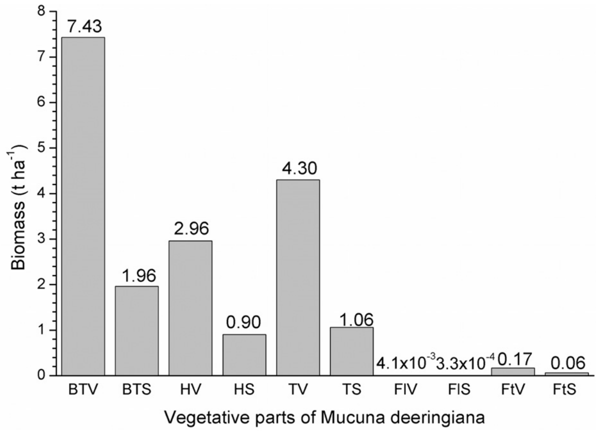

Fig. 1: *Mean biomass of the plant parts for the first cycle: total plant wet biomass (BTV) and dry biomass (BTS), wet leaf (HV) and dry leaf biomass (HS), wet stem (TV) and dry stem biomass (TS), wet flower (FlV) and dry flower (FIS) and wet fruit (FtV) and dry fruit (FtS).*

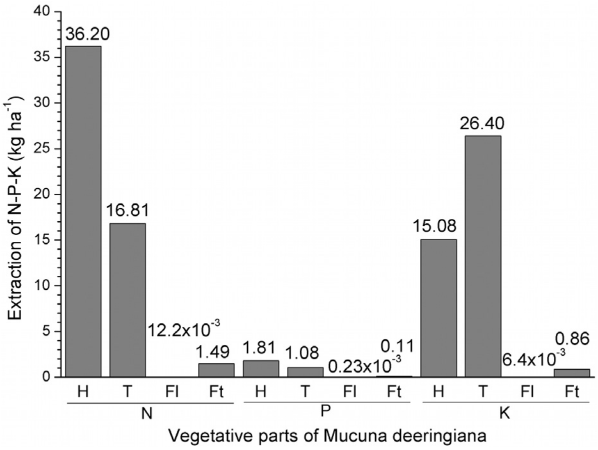

Fig. 2: *Extraction values of the elements N, P and K from the Mucuna plant parts of the first cycle: leaf (H), stem (T), flower (Fl) and fruit (Ft).*

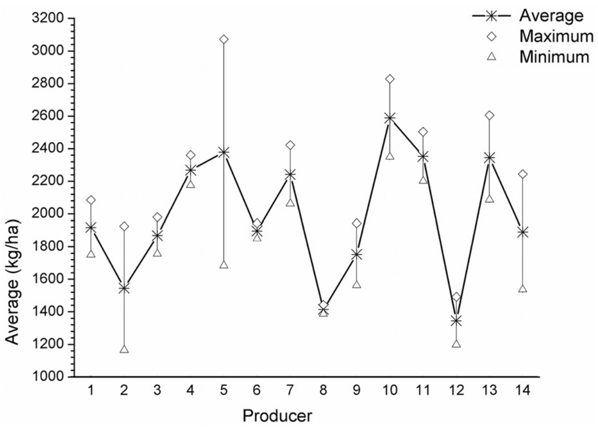

Fig. 3: *Effects of producer management on corn grain yield during the first cycle.*

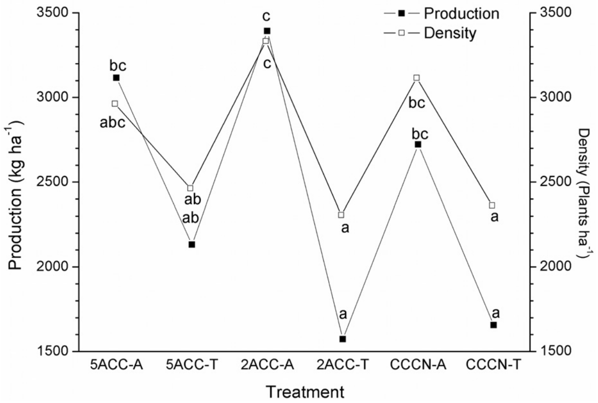

Fig. 4: *Population density and grain yield of corn in traditional and alternative systems during the second cycle.*

3.3 *Phenological and chemical characteristics of Zea mays*

During the first cycle, neither the phenological nor the agronomical characteristics of the corn differed when comparing traditional S-F-B systems, regardless of the fallow period, with alternative systems. No significant differences were observed for grain yield components: plants per hectare, number of ears per plant and number of grains per ear (Table 6). However, the yields varied slightly among the farms (Fig 3).

In the second cycle, significant differences in the agronomical variables, namely number of ears, ears per plant, plants per hectare and grain yield, were observed among the evaluated systems. In all cases, higher values were found in the alternative systems. The benefits of the alternative practices were observed in grain yield during *tornamil* (Fig. 4). The alternative systems had an average grain yield of 3,076.8 kg ha^{-1}, whereas the traditional systems had only 1,786.7 kg ha^{-1}.

The PCA generated two components that together explained 90.58% of the total variance (Fig. 5). In the first cluster, the alternative systems showed the positive effect of the modified population densities on grain yield, which is consistent with previous results.

Table 6: *Multiple comparison of means for phenological and agronomic variables of corn. First cycle.*

System	*Emergence*	*Male flowering (days)*	*Female flowering (days)*	*Physiological maturity (days)*	*Plant height (m)*	*Ear height (m)*	*Leaf area (cm^2)*
20ACQ	7.5 ^{b}	71.0 ^{abc}	74.5 ^{abc}	128.5 ^{ab}	3.1 ^{a}	1.9 ^{a}	11592.8 ^{b}
15ACQ	6.0 ^{a}	68.0 ^{a}	71.5 ^{a}	123.0 ^{a}	3.0 ^{a}	1.8 ^{a}	10278.0 ^{ab}
10ACQ	5.5 ^{a}	68.0 ^{a}	73.0 ^{ab}	125.5 ^{a}	3.2 ^{a}	2.0 ^{a}	10599.4 ^{ab}
5ACQ	6.0 ^{a}	69.5 ^{ab}	73.0 ^{ab}	126.0 ^{a}	2.8 ^{a}	1.7 ^{a}	9160.2 ^{ab}
5ASQ	6.0 ^{a}	74.5 ^{bc}	78.0 ^{bc}	128.0 ^{ab}	2.7 ^{a}	1.6 ^{a}	9884.6 ^{ab}
2ASQ	6.5 ^{a}	76.0 ^{c}	79.0 ^{c}	132.0 ^{b}	2.8 ^{a}	1.6 ^{a}	10250.9 ^{ab}
SCN	5.5 ^{a}	72.0 ^{abc}	76.0 ^{abc}	127.0 ^{ab}	1.7 ^{a}	1.6 ^{a}	8566.2 ^{a}
$Es\bar{x}$:	0.3	1.7	1.8	1.8	0.1	0.2	808.8

System	*N^{o} ears in 10 m*	*Rows per ear*	*Grains per row*	*Grains per ear*	*Ears per plant*	*Plants per hectare*	*Yield (kg ha^{-1})*
20ACQ	10.6 ^{a}	14.0 ^{a}	24.1 ^{a}	334.4 ^{a}	0.8 ^{a}	22738.3 ^{a}	1732.1 ^{a}
15ACQ	12.2 ^{a}	13.5 ^{a}	25.3 ^{a}	340.0 ^{a}	0.8 ^{a}	28138.9 ^{a}	2068.3 ^{a}
10ACQ	12.9 ^{a}	12.9 ^{a}	27.3 ^{a}	350.2 ^{a}	0.8 ^{a}	27462.7 ^{a}	2137.2 ^{a}
5ACQ	11.1 ^{a}	13.2 ^{a}	20.2 ^{a}	329.8 ^{a}	0.7 ^{a}	26499.7 ^{a}	1829.0 ^{a}
5ASQ	12.8 ^{a}	13.6 ^{a}	27.1 ^{a}	369.5 ^{a}	0.8 ^{a}	25879.1 ^{a}	2170.8 ^{a}
2ASQ	11.7 ^{a}	14.2 ^{a}	24.1 ^{a}	342.3 ^{a}	0.7 ^{a}	26467.3 ^{a}	1849.3 ^{a}
SCN	13.6 ^{a}	13.6 ^{a}	23.7 ^{a}	333.1 ^{a}	0.8 ^{a}	28156.0 ^{a}	2055.7 ^{a}
$Es\bar{x}$:	1.2	0.5	2.7	21.0	0.03	2095.0	248.9

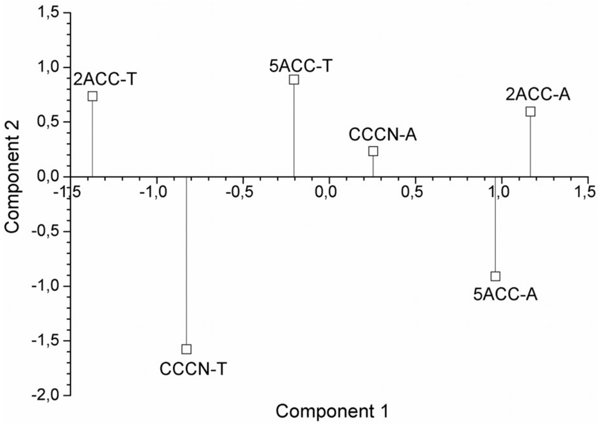

Fig. 5: *PCA for agronomical variables of corn in traditional and alternative practices during the second cycle.*

3.4 Plant damage through stalk lodging and Diatraea liniolata

The corn borer *Diatraea liniolata* was identified as the main pest in corn, causing damage that is both severe and frequent. Out of the 10 observed in the S-F-B system, damage was highest in the 2-year permanent cultivation with no burning (Table 7), which is significantly different from the other systems. Stalk lodging was observed only in the 20-year and 10-year fallow with burning and in the 5-year permanent cultivation with no burning. A positive, but not statistically significant, correlation was observed between the presence of damage caused by stalk lodging and the damage caused by the corn borer for the 10-year fallow with burning (0.118). In contrast, a negative correlation was observed for the 20-year fallow with burning (–0.789) and the 5-year permanent cultivation with no burning (–0.433).

Table 7: *Multiple comparison of means for variables, corn borer and stalk lodging in corn. First cycle.*

System	*Corn borer* (in 10 plants samples)	*Stalk lodging*
20ACQ	3.1 ^{a}	0.5 ^{ab}
15ACQ	1.9 ^{a}	0.0 ^{a}
10ACQ	3.6 ^{a}	0.8 ^{b}
5ACQ	3.4 ^{a}	0.0 ^{a}
5ASQ	3.5 ^{a}	0.3 ^{a}
2ASQ	7.3 ^{b}	0.0 ^{a}
SQCN	1.8 ^{a}	0.0 ^{a}

Table 8: *Multiple comparison of means for physical-chemical properties of soil before burning (depth 0–20 cm). First cycle.*

System	*Sand (%)*	*Clay (%)*	*Silt (%)*	*Bulk density (g/cm^3)*	*pH*	*EC (mS/m)*	*OM (%)*
20ACQ	23.7 ^{a}	41.6 ^{bc}	34.7 ^{ab}	0.9 ^{cd}	6.1 ^{a}	0.1 ^{a}	13.5 ^{cd}
15ACQ	39.2 ^{ab}	11.7 ^{a}	49.2 ^{bc}	0.8 ^{bc}	7.0 ^{d}	0.1 ^{a}	16.1 ^{d}
10ACQ	29.2 ^{a}	34.0 ^{abc}	36.8 ^{ab}	0.9 ^{d}	6.8 ^{bcd}	0.1 ^{a}	13.3 ^{cd}
5ACQ	21.2 ^{a}	42.6 ^{c}	36.2 ^{ab}	0.9 ^{cd}	6.4 ^{abc}	0.1 ^{a}	13.1 ^{cd}
5ASQ	25.7 ^{a}	41.1 ^{bc}	33.3 ^{ab}	1.0 ^{e}	6.2 ^{a}	0.4 ^{b}	9.4 ^{bc}
2ASQ	36.6 ^{ab}	8.6 ^{a}	54.9 ^{c}	0.8 ^{ab}	7.0 ^{d}	0.1 ^{a}	6.0 ^{ab}
SCN	34.2 ^{a}	25.2 ^{abc}	40.7 ^{abc}	0.9 ^{bcd}	7.0 ^{d}	0.1 ^{a}	4.6 ^{a}
VNP	56.4 ^{b}	15.0 ^{ab}	28.6 ^{a}	0.7 ^{a}	6.3 ^{ab}	0.1 ^{a}	12.5 ^{cd}
$Es\bar{x}$:	6.7	8.0	5.8	0.03	0.2	0.02	1.4

System	*N (%)*	*P (ppm)*	*K (ppm)*	*Ca (ppm)*	*Mg (ppm)*	*C:N*
20ACQ	0.6 ^{cd}	27 ^{a}	267 ^{a}	4554 ^{abc}	3038 ^{abc}	12.2 ^{bc}
15ACQ	0.7 ^{c}	75 ^{bc}	257 ^{a}	6039 ^{d}	3863 ^{c}	12.6 ^{c}
10ACQ	0.6 ^{bc}	50 ^{abc}	270 ^{a}	4900 ^{bc}	3450 ^{bc}	12.1 ^{bc}
5ACQ	0.6 ^{ab}	44 ^{abc}	256 ^{a}	4653 ^{abc}	2513 ^{ab}	13.0 ^{c}
5ASQ	0.5 ^{a}	35 ^{ab}	303 ^{ab}	3762 ^{a}	2025 ^{a}	11.7 ^{bc}
2ASQ	0.7 ^{c}	50 ^{abc}	373 ^{b}	5050 ^{c}	2643 ^{ab}	4.8 ^{a}
SCN	0.7 ^{bc}	84 ^{c}	357 ^{b}	4000 ^{ab}	3071 ^{abc}	4.0 ^{a}
VNP	0.7 ^{c}	41 ^{ab}	273 ^{a}	5150 ^{c}	2464 ^{ab}	9.4 ^{b}
$Es\bar{x}$:	0.04	12	26	301.58	354	0.9

Table 9: *Multiple comparison of means for physical-chemical properties of soils after harvesting (depth 0–20 cm). First cycle.*

System	*Sand (%)*	*Clay (%)*	*Silt (%)*	*pH*	*EC (mS/m)*	*OM (%)*
20ACQ	34.7 ^{a}	33.8 ^{a}	31.5 ^{a}	7.2 ^{cd}	0.2 ^{b}	13.1 ^{ab}
15ACQ	34.8 ^{a}	24.3 ^{a}	40.9 ^{a}	7.6 ^{d}	0.1 ^{ab}	14.6 b
10ACQ	31.3 ^{a}	28.3 ^{a}	40.4 ^{a}	7.3 ^{cd}	0.1 ^{a}	12.1 ^{ab}
5ACQ	28.2 ^{a}	31.3 ^{a}	41.0 ^{a}	7.1 ^{bcd}	0.1 ^{ab}	13.0 ^{ab}
5ASQ	24.6 ^{a}	33.5 ^{a}	42.0 ^{a}	6.6 ^{ab}	0.1 ^{a}	8.7 ^{a}
2ASQ	42.9 ^{ab}	27.1 ^{a}	30.1 ^{a}	6.5 ^{ab}	0.1 ^{a}	16.2 b
SCN	41.1 ^{ab}	29.5 ^{a}	29.4 ^{a}	6.9 ^{abc}	0.1 ^{a}	12.1 ^{ab}
VNP	56.4 ^{b}	15.0 ^{a}	28.6 ^{a}	6.4 ^{a}	0.1 ^{ab}	12.5 ^{ab}
$Es\bar{x}$:	6.5	6.2	5.5	0.2	0.03	1.8

System	*N (%)*	*P (ppm)*	*K (ppm)*	*Ca (ppm)*	*Mg (ppm)*	*C:N*
20ACQ	0.6 ^{ab}	67 ^{ab}	441 ^{b}	6980 ^{de}	724 ^{ab}	11.8 ^{a}
15ACQ	0.7 ^{b}	71 ^{ab}	325 ^{ab}	7216 ^{e}	1931 ^{cd}	12.1 ^{a}
10ACQ	0.6 ^{ab}	86 ^{b}	262 ^{a}	6508 ^{cde}	100 ^{ab}	10.9 ^{a}
5ACQ	0.6 ^{ab}	85 ^{b}	308 ^{a}	6037 ^{cde}	1344 ^{bc}	12.4 ^{a}
5ASQ	0.5 ^{a}	42 ^{a}	269 ^{a}	4197 ^{ab}	517 ^{a}	11.2 ^{a}
2ASQ	0.7 ^{b}	64 ^{ab}	278 ^{a}	5518 ^{bcd}	775 ^{ab}	13.2 ^{a}
SCN	0.5 ^{ab}	67 ^{ab}	276 ^{a}	3735 ^{a}	620 ^{ab}	17.6 ^{a}
VNP	0.7 ^{b}	41 ^{a}	273 ^{a}	5150 ^{abc}	2464 ^{d}	9.4 ^{a}
$Es\bar{x}$:	0.07	10	41	495	233	3

3.5 *Physical-chemical properties of the soil*

The data collected on the study site before burning (Table 8) and after harvesting (Table 9) showed that the soil was fertile with a high nutrient content, a slightly acid pH and good physical properties. The texture varied only slightly among the systems studied, both before burning and after harvesting. The soil pH was neutral, as shown by the results before sowing and after harvesting. After harvesting, the soil pH was higher for the systems with burning than for the permanent cultivation systems (with no burning).

These soils are very rich in organic matter. Before burning, a positive correlation was observed between the lengthening of the fallow periods and the organic matter content, approaching an amount that was not significantly different from the control system (VPN). In the 5-year and 2-year permanent cultivation with no burning, the organic matter contents were lower, with the lowest percentages in the no-burn system and in the system with *Mucuna* where the soil had recently incorporated this technology (two agricultural cycles). At the end of the crop cycle, there were more similarities among the systems with respect to organic matter levels, with important increases in the no-burn system and the system with *Mucuna*.

In all of the systems, the soils were very rich in nitrogen before and after harvesting. No specific properties were linked to the evaluated technologies, and the nitrogen levels for all of the systems were similar to the levels in the undisturbed evergreen forest. Before burning and after harvesting, nitrogen, similar to organic matter, was found at the lowest levels in the 5-year permanent cultivation with no burning. There were no significant differences among the systems in phosphorous levels, either before burning or after harvesting.

The analysis of the main soil components before burning (Fig 6) identified two components that together accounted for 84.96% of the total variance. The first component was positively represented by nitrogen and the C:N ratio, and the second was positively represented by nitrogen and phosphorous. Potassium was negatively represented in the first component. The S-F-B components were positively clustered around the chemical properties of the soil in the cluster of systems before burning (Fig 6). After harvesting (Fig 7), three components were generated that together accounted for 83.33% of the total variance; macro elements had the most important matrices.

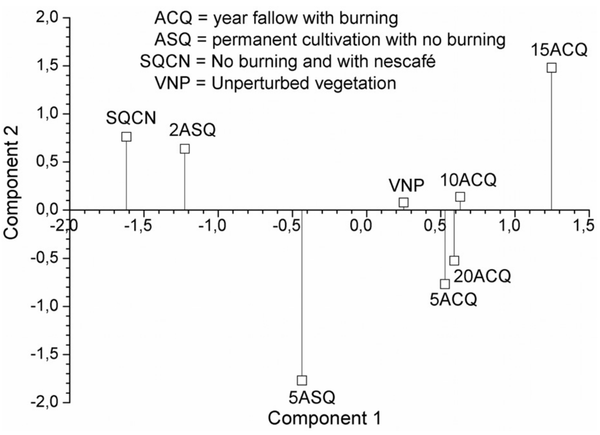

Fig. 6: *PCA for soil chemical properties before burning in slash-fell-burn agriculture in alcahuales. First cycle.*

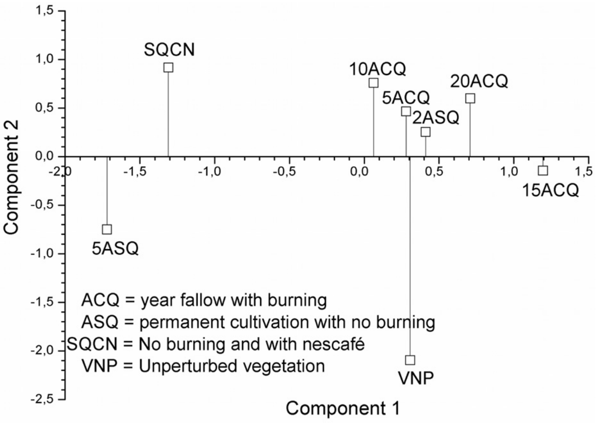

Fig. 7: *PCA and chemical properties for soil after harvesting in alcahuales. First cycle.*

3.6 *Erosion*

Large volumes of erosion were observed in the study area from the beginning of the cultivation cycle, with the highest soil loss in the burning systems (Fig. 8). There was no correlation between the slope of the land and the volume of eroded soil (Pearson's coefficient of 0.244).

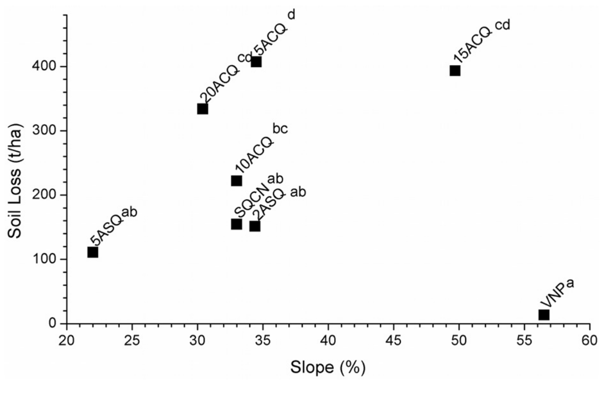

Fig. 8: *Soil losses on different slopes. First cycle.*

4 Discussion

4.1 Floristic inventory

The results of the regression analysis model and the Shannon-Weaver Index show great floristic diversity in the study zone. This relationship is mainly due to the presence of predominant species with better adaptation and growth characteristics. The Shannon-Weaver Index is approximately one in all the systems, with the exception of the 15-year permanent cultivation with no burning. Similar figures were found by Margalef (1991), who mentioned that modified tropical ecosystems show irregular indices. The results confirm that, for studies of absolute flora, the sampling quadrants should be large enough to contain 80% of the species (Margalef, 1991). Moreover, the sampling sites should be chosen with the goals and purposes of the study in mind. The figures for tree trunk biomass indicate that the region has agroforestry potential and provide evidence of the importance of improved management of fallow lands. Ramachandran (1997) stresses the importance of developing agroforestry technologies in rainforest areas. An introduction of these techniques in the region could promote more productive, profitable, diverse and sustainable land-use systems.

The results at seed banks in the 5-year and the 2-year permanent cultivation with no burning and the undisturbed evergreen forest demonstrates the strong adaptation of the species found in the study area to S-F-B conditions. Under these conditions, innate, induced and exogenous dormancy appear to dominate the ecosystem (Harper, 1977). In the undisturbed evergreen forest, the Shannon-Weaver index was 0 due to the lack of light in the underbrush. Granados & López (2001) and Wesson & Wareing (1969) stated that light is a primary condition for germination and concluded that induced and forced dormancy are appropriate if they are interrupted under favourable conditions.

4.2 Physical-chemical characteristics of *Mucuna deeringiana*

The variation in plant development at the different sampling sites demonstrates the difficulty of establishing *abonera* systems using *Mucuna deeringiana* on very rocky land. These differences may also be due to the high interspecies competition with endogenous weeds. Quiroga-Madrigal (2000) reports higher values of wet and dry biomass (>50%) under controlled experimental conditions in Chiapas, where *Mucuna* was planted in 500 m^2 plots using a randomised complete block design.

Most of the dry *Mucuna* biomass is provided by the stem. Similar results were reported by Quiroga-Madrigal (1994), who evaluated the biomass of the aerial parts of tropical legumes. The synthesis and accumulation of the major elements, mainly N, is influenced by seasonal dynamics, which affect the growth of *Mucuna*. Despite the constraints of *Mucuna* growth in the study area, the results show that even under such ecological restrictions, it is likely that in the future, organic fertiliser production could increase the soil fertility and its economic and ecological value. The fact that *Mucuna* has great potential as a cheap and sustainable fertiliser suggests, that more studies on its implementation as an *abonera* system in the study area are needed.

4.3 Phenological and chemical characteristics of *Zea mays*

The variability of yield among farms may be due to an effect of specific soil conditions on the final harvest volume. However, despite the natural and technological homogeneity, differences in the grain yield were observed within the same production unit (each farm had two sampling units). This difference was greater in production units two and five. The difference in grain yield was attributed to the producer's specific management practices.

Competing weeds can make significant inroads in crops because of the large amount of manual labour needed to control them (15 man-days ha^{-1}). Competition from weeds influences corn development, especially when weed occurs intermittently, and it affects final crop production. Hernández *et al.* (1995) referred to the complexity of the factors that determine the final volume of the yield in traditional agricultural systems in tropical regions and underlined the importance of crop management, especially weed control.

The results of the second cycle show that sowing with a shorter distance between rows and plants and depositing only two seeds per point had an impact on the quantity and quality of the harvested ears. Reta-Sánchez *et al.* (2003) also found that modifying the topological arrangement had a positive effect on corn productivity. However this effect has not been observed in modern corn hybrids (Porter *et al.*, 1997; Widdicombe & Thelen, 2002). At present, in contrast to the indigenous producers, "*mestizo*" producers tend to prefer commercial improved corn varieties (Brush & Perales, 2007) because the *creole* corn has the advantage of being better adapted and providing more possibilities for post-harvest handling. Becerril & Abdulai (2010) argued that improved varieties of corn in Chiapas would increase expenses by approximately 136 MXN per capita household (around 7.50 EUR) while reducing the likelihood of households falling below the poverty line by 31%.

The differences in grain yield that would result from modifying the topological arrangement of crops, as shown in the alternative systems, would provide a significant increase in production volume in the study area. The increase would be greater for corn production based on the S-F-B system. However, the practise of sowing densities is continuing to be an open subject of research on agriculture on slopes and under different management systems.

The positive effect of the modified topological arrangement, showed by the first cluster of the PCA, refers to the importance of managing population densities in *Zea mays* L. systems (Lafitte, 1994).

4.4 *Plant damage due to stalk lodging and Diatraea liniolata*

Until recently, the corn borer *Diatraea liniolata* was not found in the study region, wherefore the crop damage caused by the corn borer was new to the indigenous population. The study found a higher presence of the pest in the no-burn systems, probably because fire helps to control this pest. Higher pest incidence was associated with the absence of rainfall and with higher slope altitudes, where humidity is lower due to runoff. The pest usually attacks in the early growth stages when the stalks are soft, causing underdevelopment and affecting population density. In the study area, no clear correlation was found between damage caused by stalk lodging and damage caused by the corn borer. Most of the systems did not show damage caused by stalk lodging. In the study area, stalk lodging in corn was produced mainly by strong winds due to the large size of the stalk when the corn was in the flowering or grain-filling period. More studies on this topic are needed to determine the abundance and severity of this pest. The immigration of the corn borer into the Selva Region of Chiapas must have occurred recently because it is unknown to the smallholders, and there are no official reports describing its distribution in this region.

4.5 *Physical-chemical properties of the soil*

As was previously shown by INEGI (1990), high levels of organic matter have a significant effect on soil properties. This finding reaffirms the need for spatial planning in the area because the potential of the soil resource is a shared natural heritage.

The different systems did not cause spatio-temporal variations in soil texture fractions. The soil textures are considered to be agronomically adequate for corn. Corn is widely distributed over Mexico in soils with different textures, particularly in seasonal agriculture (Contreras-Benítez *et al.*, 2002). The bulk density before sowing and after harvesting was medium, with no great variation among the systems, and was adequate for growing the cereal. Sánchez (1981) reports similar results. Lower bulk density values in the undisturbed evergreen forests are due to the high levels of organic matter accumulated over time. De las Salas (1987) suggested that the main changes to physical soil properties in the tropics related to migratory agricultural practices are in its structure and infiltration capacity.

Lafitte (1994) reported that a neutral soil pH value is adequate for cultivating corn. In general, the pH value was higher at the end of the cultivation cycle because of the accumulated ash with its high calcium content (Sánchez, 1981; De las Salas, 1987; Serrano-Altamirano & Cano-García, 2007). The pH tends toward acidity due to the geographic location and environmental conditions of the study area (high temperature and precipitation).

Mendoza-Vega & Messing (2005) suggested that organic matter increases as the fallow period is extended. The organic matter decreases in no-burn systems where the clay-humic complexes are not stabilised with finer fractions of soil. At the end of the crop cycle, the increase of the organic fraction in no-burn systems is attributed to the decomposition of the vegetation incorporated during tillage for the next cycle due to the dynamics of microorganisms with high humidity and temperature. The results are similar to those found by Pool & Hernández (1995) and Serrano-Altamirano & Cano-García (2007) in itinerant agriculture. They showed that burning decreases organic matter immediately. Sánchez (1981) stated that, as traditionally thought, the burning period in the tropics is not long enough to affect the amount of organic matter. However, according to Gliessman (2002), a temperature of 200–300ºC for 20 to 30 minutes can reduce organic matter by up to 85%.

The high nitrogen content may be due to the soil management under S-F-B. Sánchez (1981), and Serrano-Altamirano & Cano-García (2007) showed that burning volatises most of the carbon, sulphur, potassium and nitrogen present in the vegetation, although studies in tropical agroecosystems show that burning and ash do not affect total soil nitrogen content in the short term.

Phosphorous is slightly higher after harvesting in systems with burning due to the effect of ash (Sánchez, 1981; De las Salas, 1987). In Mexico, soils with a high phosphorous content tend to be located in the tropics, especially in zones with annual precipitations of over

1,500 mm (Contreras-Benítez *et al.*, 2002). Ten-year studies by Mazzarino *et al.* (1993) on soils under agroforest management revealed no effect on phosphorous levels. There is no evidence of phosphorous deficiency in the nomadic agricultural systems in humid tropical regions (Sánchez, 1981).

The nature of the soil and its management also affect potassium levels. Potassium appears to be an important element for growing corn because it is extracted from the soil in each harvest, and it is found in all of the cells of the plant in relatively large amounts. It is an enzymatic activator, favouring the chlorophyll function by transporting carbohydrates and regulating the osmotic pressure of plant cells (León, 1984). Potassium affects the phenological characteristics (mainly male and female flowering) of the cereal but not the grain yield.

Our PCA results before burning agree with those of Sánchez (1981), De las Salas (1987), Ramachandran (1997) and Astier *et al.* (2000), who stated that fallow periods have a positive impact on soil fertility. After harvesting, the macro elements were considered as strategic indicators for determining the sustainability of the agroecosystems. Similar results were observed for soil sampling before burning, indicating that the high fertility of the territory is not affected by burning or by the corn agricultural cycle. Sánchez (1981) showed similar findings.

4.6 Erosion

The study area showed a high erosivity, similar to that observed by Ramírez-Cruz & Oropeza-Mota (2001) for agriculture in the tropical mountains in La Frailesca, Chiapas, especially in S-F-B systems. Soil losses are statistically higher in S-F-B systems than in alternative systems, which show more erosion on steep slopes with heavy rainfall. Serrano-Altamirano & Cano-García (2007) emphasised that the most important effect of *Mucuna* is the reduction in soil loss, finding that only 96.42 kg ha^{-1} of soil was lost in one agricultural cycle.

The results show that the fallow periods do not significantly influence soil erosion; there was no correlation between eroded volume and fallow period. The erosion process appears to be similar to erosion on burned land with no plant cover, where slopes and specific topography maintain a similar geoform with small variations. Moreover, stumps, branches and trunks scattered around the surface by S-B (size was correlated positively with the length of the fallow period) did not impede soil erosion. Sánchez (1981) stated that after S-B, the erosion rate depends on soil properties and management.

5 Conclusion

The environmental sustainability of traditional agricultural land use under S-F-B systems is not affected by shorter fallow periods. As a result, the floristic diversity increases because the better adapted species have less time to crowd out the others. Fire, which is used in the S-F-B system, inhibits the development of stem borers by eliminating entomophagous inocula. Finally, erosion from water can be reduced in no-burn systems using green manure.

The use of *Mucuna* in *abonera* systems, as well as long fallow periods, can increase the production capacity of the soil. However, certain unfavourable characteristics of the study area (stony land and interspecies competition) limit the implementation of this system. Further studies are needed on *abonera* systems in stony lands. The topological arrangement has a direct positive influence on corn production and on weed control.

Because of the low productivity of the region, which limits the establishment of primary activities such as the traditional agricultural use of the land by the indigenous societies, there is an urgent need to establish alternative measures that assure the basic food security of the indigenous populations. The reduction of fallow periods, the introduction of *abonera* systems and changes to the topological arrangement crops are measures that could be used to improve the agricultural systems of the study area. At the same time, the introduction of new measures should respect as much as possible the traditions of the indigenous people.

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