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Soil Fertility in Two Shifting Cultivation Mayan Systems of Yucatan, Mexico

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Abstract

The Slash and Burn (SB) System, practiced by the Mayan farmers of Yucatan, is one of the oldest forms of land use. After SB the soil is cultivated with corn by two or three consecutive years and then abandoned for a fallow period of 15 to 40 years to restore soil fertility when new vegetation is cut and burned again. There are contrasting points of view related to the advantages of SB on soil fertility. So, this work aimed to evaluate changes in the soil fertility of two Mayan farmers (*Leoncio* and *Epitacio*), practicing SB in five different agroecosystems of Yucatan, Mexico. Three soil subsamples, at 0 - 20 cm deep, were taken per each agroecosystem and mixed to form a composite sample to analyse: pH, Organic Matter (OM), Nitrogen (N) as Nitrates (N-NO_3), Available Phosphorus (P), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Zinc (Zn^{2+}). There was a general trend to increase OM, N-NO_3, P, K and Mg in SB of *Leoncio* but Zn decreased. In *Epitacio*'s OM, P and K increased with SB. Long fallow periods showed the lowest pH values while the highest ones in the SB showed the influence of ashes. All agroecosystems showed High and Very High contents of OM although the contents of N-NO_3 and P were Low, except the Very High content of N-NO_3 in the Agroecosystem 3 of *Epitacio* in the *rendzic Leptosol* (*rz LP*). In all agroecosystems K and Ca were High whilst Mg was Medium. The overall average Zn content in *Leoncio*'s was Lower (0.38 ppm) than *Epitacio*'s ecosystem (2.76 ppm). A *rendzic Leptosol* showed extreme higher contents of all nutrients than the red *Cambisol*.

Subject Areas

Agricultural Engineering-Environmental Sciences

Keywords

Nutrients, Heterogeneity, Critical Levels, *Chac Lu'um*, *Pus Lu'um*

1. Introduction

At the end of the 1970's deforestation rates for the humid tropics were estimated to be 6.9 million hectares per year [1] and doubled to 14.8 million in 1991 [2]. The number of people who depend on shifting cultivation, practicing Slash and Burn (SB), for their livelihoods has been estimated at about 250 to 300 million [3] [4].

SB system is mainly to establish subsistence crops, it is not a primitive or incipient cultivation method but a specialized technic one, which has evolved in response to specific climatological and soil conditions in the tropical lowlands [5]. However, it has been reported [6] that the world was losing about half of its forests to agriculture and other uses, and the remaining were heavily altered. About 72 percent of the original 1450 million hectares of tropical forests have been converted to other uses [7] [8].

In Yucatan Mexico, corn production continues to be carried out mainly under rainfed conditions in approximately 130 thousand hectares and 90 percent is being produced under SB cultivation. This is an ancient Mayan production system so-called Mayan Milpa (MM) involving different activities [9] and since the 70's, considerable efforts were made to understand why Mayan peasants were facing important corn yield reduction in the MM [10].

MM based on SB is considered a locally managed system that alters the ecosystem less than other modern agricultural production ones [11]. Professor Hernández Xolocotzi commented that MM is an efficient system that takes advantage of the forest resources and it is adaptable to the Calcareous soils of Yucatan [12] but its productive capacity can be maintained just if the land is to be rested for a minimum of 7 years until the forest is regenerated. Soil fertility is related to the litter accumulation, nutrients circulation and fallow periods. The Organic Matter (OM) and nutrients are incorporated through the ashes [13].

In the MM the fallow periods have been reduced from 20 to 7 years and soil fertility has decreased, being the basic regulator of the agroecosystem and the grade of competition between weeds and crops is mainly an adaptation to the low soil fertility [14].

The problem being faced is the use of fire, provoking a decrease in the initial values of Organic Matter (OM) when temperatures are above 450˚C. Some other works suggest that in low intensity fires the effect is the opposite when ashes are accumulated on the soil [15]. Fire can also alter the OM quality when acting as an agent that accelerates mineralization rates and in the post-fire decomposition, the humus is more resistant to microbial degradation [16] [17].

On the other hand, burning increases mineralization of organic forms of nitrogen, but volatilization losses result in a negative balance for this element [18] and the higher amount of P, after burning, can be explained by the increase in soil temperature, favoring organic P mineralization [19] and releasing the phosphates occluded in the soil aggregates [20].

Due to the uncertainty about the advantages of the SB system, this work aimed to better elucidate the fertility changes that soils undergo when they are subjected to different fallow periods and uses in the MM where SB is being practiced.

2. Materials and Methods

2.1. Location and Agroecosystems Studied

The study was carried out in calcareous karstic soils of a Mayan community of Nuevo Tezoco, municipality of Tizimin in the state of Yucatan, located at: 21˚18'24.94" North Latitude and 87˚33'42.00" West Longitude with a height of 13 meters above sea level with an Aw_2 climate [21].

Two Mayan systems were selected. *Leoncio Loria Chimal* (System 1) and *Epitacio Ku Puc* (System 2) being the representative farmers of the MM who have been managing the forest with multi-crops forming different agroecosystems. The MM is being practiced in red soils (*Cambisols*) located in the low part of the landscape associated with black soils with loose stones (*rendzic Leptosols*) in the upper part of the landscape (**Figure 1**). Both soils are classified as *Chac Lu'um* and *Pus Lu'um* respectevely in Mayan terminology [22] [23] [24].

In **Table 1** are described the 5 agroecosystems, under shifting cultivation, per each farmer. The agroecosystems consisted on forests with fallow periods of 30 and 5 years (*Leoncio* 1 and 2) and 10 years (*Epitacio* 1) and the other ones with

(a) (b)

Figure 1. Natural and common association of a typical *Cambisol-Chak Lu'um* (Red soil in the low position of the landscape) and a typical *rendzic Leptosol-Pus Lu'um* (Black soil with loose stones in the upper position of the landscape) where Slash and Burn has been practiced in the studied area. (a) Red *Cambisol* in Yucatan with SB; (b) *rendzic Leptosol* in Yucatan with SB.

Table 1. Mayan Agroecosystems studied in the Maya community of Nuevo Tezoco, Municipality of Tizimin, Mexico.

Farmer	Agroecosystem (N˚)	Soil	Description
Leoncio Loria Chimal	1	Red-CM	30 years old forest
	2	Red-CM	5 years old forest
	3	Red-CM	Recent SB, cultivated with corn, after clearing a 5 years old forest
	4	Red-CM	3 consecutive years planted with corn after SB a 5 years old forest
	5	Red-CM	3 consecutive years planted with fruit trees intercropped with corn after SB a 5 years old forest
Epitacio Ku Puc	1	Red-CM	10 years old forest
	2	Red-CM	Recent SB, cultivated with maize, after SB a 10 years old forest
	3	Black-rz LP	Recent SB, cultivated with maize, after SB a 10 years old forest
	4	Red-CM	Intercropped fruit trees, corn and beans in a soil previously cultivated with tropical grasses after SB a 10 years old forest
	5	Red-CM	8 continuous years cultivated with corn after SB a 25 years old forest

different cropping systems. All agroecosystems are on red *Cambisols* (CM) except *Epitacio*'s Agroecosystem 3 resting on a *rendzic Leptosol* (rz LP). The agroecosystems were separated for no more than 100 meters each other and soil samples were taken randomly.

2.2. Soil Sampling and Chemical Analytical Tests for Nutrients

Three soil subsamples, at 0 - 20 cm deep, were taken per each agrecosystem and mixed until forming a composite sample in order to analyze: pH, Organic Matter (OM), Nitrogen as Nitrates (N-NO_3), Assimilable Phosphorus (P), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Zinc (Zn^{2+}) as a micronutrient.

The pH was measured with a potentiometer in a 1:1 soil:water ratio, the OM (%) was determined by Walkley and Black, the N-NO_3 (ppm) by the Brusina method, the P (ppm) by Bray method. K (meq/100gr), Ca (meq/100gr) and Mg (meq/100gr) were extracted with Ammonium Acetate pH 7 and Zn (ppm) with DTPA extraction [25].

2.3. Reference Soil Values for Soil Fertility

The reference critical levels, for comparison purposes, were taken from the Official Mexican Standard that establishes specifications for fertility, salinity and soil classification. Studies, sampling and analysis suggested (**Table 2**) by SEMARNAT (2002) [26].

Table 2. Reference levels of soil attributes suggested by SEMARNAT (2002) [26].

Soil attributes	Soil test reference		
	High	Medium	Low
OM (%)	3.6 - 6.0	1.6 - 3.5	0.6 - 1.5
$N-NO_3$ (ppm)	40 - 60	20 - 40	10 - 20
P (ppm)	>11.0	5.5 - 11.0	<5.5
K (Cmol/kilo)	>0.6	0.3 - 0.6	0.2 - 0.3
Ca (Cmol/kilo)	>10.0	5.0 - 10.0	2.0 - 5.0
Mg (Cmol/kilo)	>30.0	1.3 - 3.0	0.5 - 1.3
Zn (ppm)	>1.0	0.5 - 1.0	<0.5

All samples with lower contents than the Medium rate were graded as Deficient and those ones with higher values than the Medium Rate were considered as Sufficient or even in excess.

2.4. Statistical Analysis

Coefficient of Variation (CV) to all soil attributes, per each farm system, were calculated as well as the Coefficient of Correlation (r) and Determination (R^2) to measure the grade of relationship between soil attributes.

The CV was expressed as a percentage (%) resulted of dividing the standard deviation (Sd) of a sample by the arithmetic mean [27]. The higher the CV value the greater the heterogeneity of the soil attribute; and the lower the CV the greater the homogeneity. Normally, in agricultural field trials, CV's are considered low when they are less than 10%; medium from 10% to 20%, high from 20% to 30% and very high above 30% [28].

When CV's are lower than or equal to 30% the data set is "*Homogeneous*" and when exceeding 30%, it is "*Heterogeneous*". Muñoz *et al.*, (2006) [29] reported CV values of 20% to 40% as Medium and less than 10% as Low variability.

The r measured the linear dependence between two quantitative random variables (dependent-y and independent-x) and was considered as an index to measure the degree of relationship between two soil attributes.

The R^2 quantified the proportion (%) of the total values of the *dependent-y* soil attribute which can be explained by changes on the *independent-x* soil variable. It can range between 0 and 1 (0% - 100%). An R^2 closer to 1 (100%) means a tight relationship between two soil properties.

3. Results and Discussion

3.1. Soil Reaction (pH)

The pH of the studied agroecosystems, according to Phytomonitor Labs, (2020) [25] ranged from 6.85 to 7.64 (**Table 3**) with a general mean of 7.17 and 7.31 for *Leoncio* and *Epitacio* systems respectively. Agroecosystems numbered 1 with

Table 3. Grade of alkalinity, indicated by the soil pH in different agroecosystems of the two shifting cultivation Mayan System in Nuevo Tezoco, Municipality of Yucatan, Mexico.

Farmer	Agroecosystem (N˚)	Soil pH	Grade
Leoncio Loria Chimal	1	6.85	Neutral
	2	7.05	Neutral
	3	7.36	Neutral
	4	7.15	Neutral
	5	7.46	Fairly Alkaline
	Average	**7.17**	**Neutral**
	Sd	**0.22**	
	CV (%)	**3.04**	**Very Low**
Epitacio Ku Puc	1	6.93	Neutral
	2	7.38	Fairly Alkaline
	3	7.64	Fairly Alkaline
	4	7.33	Neutral
	5	7.28	Neutral
	Average	**7.31**	**Neutral**
	Sd	**0.23**	
	CV (%)	**3.12**	**Very Low**

long fallow periods, corresponding to the 30 (*Leoncio*) and 10 (*Epitacio*) years old forests, showed the lowest values with 6.85 and 6.93 respectively. The other agroecosystems, where slash and burn has been practiced, had the highest pH values showing the influence of ashes accumulated during the shifting process.

The lowest pH may be related to the influence of OM decomposition during the fallow period and could be a function of the Nitrification process where four hydrogens ($4H^+$) are released from two Ammonium (NH_4^+) molecules as Ortiz Villanueva [30] suggested.

On the other hand, the increment of pH, toward alkalinity, could be due to the contributions of ashes after burning of vegetation. The ashes contain significant amounts of P, K, Ca and Mg as oxides, hydroxides and carbonates with alkaline effects in the soil [31]. Soil pH is one of the chemical properties more affected by fire. The remaining ashes contain large amounts of potassium carbonate (CO_3K_2) with a basic (high alkalinity) reaction when it is hydrolyzed [15].

On the other hand, the soil pH among agroecosystems, for both *Leoncio* and *Epitacio* systems, were highly homogeneous as it was shown by the very low CV's with 3.04 and 3.12% respectively.

3.2. Soil Organic Matter and Primary Essential Nutrients (*N*, *P*, *K*) under Shifting Cultivation Systems

3.2.1. Organic Matter (*OM*) and Nitrogen (*N-NO*$_3$)

Very high OM contents were found in all ecosystems (Table 4), with an overall

Table 4. Changes in soil *OM* and primary essential nutrients (*N-P-K*) at 0 - 20 cm deep in different agroecosystems of two Maya farmers practicing slash and burn cultivation.

Farmer	Agroecosystem (N°)	OM (%)	$N-NO_3$ (ppm)	P (ppm)	K ($Cmol \cdot kg^{-1}$)
Leoncio Loria Chimal	1	4.42 (H)	12.00 (L)	6.00 (L)	0.56 (H)
	2	5.70 (H)	13.60 (L)	4.00 (L)	0.84 (H)
	3	4.36 (H)	28.00 (L)	8.00 (L)	1. 02 (H)
	4	4.02 (H)	19.20 (L)	8.00 (L)	1.10 (H)
	5	3.08 (H)	18.40 (L)	8.00 (L)	1.33 (H)
	Average	**4.31 (H)**	**18.24 (L)**	**6.80 (L)**	**0.96 (H)**
	Sd	**0.84**	**5.60**	**1.6**	**0.46**
	CV	**19.51 (M)**	**30.69 (VH)**	**23.53 (H)**	**48.19 (VH)**
Epitacio Ku Puc	1	5.16 (H)	14.40 (L)	8.00 (L)	0.84 (H)
	2	3.75 (H)	17.60 (L)	2.00 (L)	1.18 (H)
	3	19.43 (VH)	111.80 (VH)	12.00 (L)	1.28 (H)
	4	26.13 (VH)	16.00 (L)	6.00 (L)	0.82 (M)
	5	17.768 (VH)	17.60 (L)	10.00 (L)	1.38 (H)
	Average	**14.46 (VH)**	**35.48 (M)**	**7.60 (L)**	**1.1 (H)**
	Sd	**8.64**	**38.18**	**3.44**	**0.23**
	CV	**59.79 (VH)**	**107.61 (VH)**	**45.28 (VH)**	**20.86 (M)**
	Critical Limits	1.6 - 3.5	20 - 40	20 - 30	0.3 - 0.6

Note: H = High, M = Medium, L = Low.

average of 4.3% for *Leoncio* and an excesive very high OM value of 14.46% for *Epitacio*. The critical limits reported by the Official Mexican Standard are from 2.5 to 3.0% [26].

The influence of the fallow period on the OM is noted in the *Leoncio* ecosystems where the highest OM contents were found in the 30 and 5 years old forests with 4.42 and 5.70% respectively. Similar values (5.36%) were found by Medina *et al.* [32] in an over 30 years old forest in Campeche Mexico.

On the other hand, the ecosystem 5 of *Leoncio*, referred to a 3 years of fruit trees and corn, after clearing a 5 years old forest, obtained the lowest OM content with 3.08%; This is also in agreement with Medina *et al.*, (2017) [32] who reported that in soils cultivated with mango (1 to 5 years) the OM content was 3.26%.

It is remarkable the behaviour of the ecosystems 3, 4 and 5 of *Epitacio* where excessive amount of OM was found with 19.43, 26.13 and 17.76%. The first value is related to the thin black soil classified as *rendzic Leptosol* (Pus Luum) located in the upper part of the landscape with loose stones, where corn was sown in the spring-summer cycle after a 10 years old forest was slashed and burned. The second highest value (26.13%) is for an ecosystem in red soils (*Cambisol*) currently cultivated with fruit trees in substitution of tropical grasses after slashing and burning a 10 years old vegetation. The third value (17.76) refers to a red soil with 8 consecutive years of use after burning a 25 years old forest.

Regarding to the available inorganic nitrogen (N-NO_3), it could be observed that despite of the high and excessive OM, most ecosystems showed N-NO_3 contents below the critical level, except for ecosystem 3 of *Leoncio* with 28 ppm and Ecosystem 3 of *Epitacio* with 111.8 ppm. The agroecosystems 3, 4 and 5 of *Leoncio* (recently slashed and burned) also showed higher important values of N-NO_3 than agroecosystems 2 and 3 (30 and five years old forests).

The low relationship between OM and N-NO_3 can be based on the quality of the OM prevailing in each ecosystem studied and this has to do with the C/N Ratio, which is a quality index. High values imply that the organic matter decomposes slowly because the microorganisms immobilize the nitrogen for plant tissues decomposition. The few amount of N-NO_3 released to the soil solution could have been lost by leaching to deep soil horizons due to high infiltration rates. The karst of the state of Yucatan is of the *holokarst* type, where water is drained to the subsoil [33].

Ecosystem 4 of *Epitacio*, previously managed with grasses, obtained the highest OM content with 26.13%. However, the amount of N-NO_3 (16 ppm) is below the critical range of 20 - 40 ppm. This may be due to the fact that the remaining roots of grasses, with high lignin, have a high Carbon/Nitrogen ratio (C/N) so microorganisms faced very strong difficulties to mineralize the OM.

The extreme exception was Ecosystem 3 of *Epitacio* since very high amounts of N-NO_3 (111.8 ppm) were found. However, the productivity of the stony soil can drastically decrease due to the very restricted area for root development in a shallow thin soil.

The variability of the soil OM and N-NO_3 depended on the management and conditions of both production systems. The CV of OM in *Leoncio* was lower than that in *Epitacio*, graded as Medium (19.51%) and Very High (59.79%) heterogeneity respectively. In the case of N-NO_3 the heterogeneity was Very High for both systems although for *Epitacio* the CV was extremely high with 107.61%. This very high heterogeneity is given by the extreme high content of N-NO_3 in the agroecosystem 3. Eliminating the extreme value, the CV would only be 8%.

Unlike other ecosystems, nitrogen mineralization in arid and semi-arid ecosystems occurs in patches, in a heterogeneous way, in response to microclimate conditions and contribution of organic matter. Soil fertility is distributed in island depending on the presence and abundance of the vegetation. N mineralization values are higher under the trees and shrubs canopies than the adjacent open spaces [34].

3.2.2. Available Phosphorus (*P*)

The P contents in all ecosystems were well below the critical limits of 20 - 30 ppm. The lowest values were found in the ecosystems 2 of *Leoncio* and *Epitacio* with 4.0 and 2.0 ppm respectively, corresponding to a 30 and 5 years old forest.

Even the ecosystem 3 of *Epitacio*, with the highest P content (12 ppm), did not reach the optimum range of P (20 - 40 ppm) being 40% below the minimum value (20 ppm) of the critical level.

The foregoing can be related to the calcareous origin of the Yucatan Peninsula where insoluble precipitates such as dicalcium and tricalcium phosphates can be formed, converting P into a non-available nutrient by the plants [35]. However, there was a general trend of increasing P in those SB agroecosystems.

Inclusion of P, in a strategic plan for proper management of inorganic and organic fertilizers is fundamental. It has to be considered the heterogeneous spatial distribution of P since CV's ranged from High (*Leoncio*) to Very High (*Epitacio*).

3.2.3. Available Potassium (*K*)

Potassium (K) like Nitrogen (N) and Phosphorous (P) is a primary essential element required in large quantities depending on the crop. Studies carried out in Yucatán have confirmed that the amounts of exchangeable K in soils are well above than the sufficiency range of 100 to 250 ppm. This is also manifested in the ecosystems of the MM where K were in excess; mainly in those ecosystems most recently slashed and burned.

The highest K contents are referred to ecosystems 5 of *Leoncio* and *Epitacio* with 1.33 and 1.38 $Cmol\cdot kg^{-1}$ respectively. Both ecosystems corresponded to a surface where slash and burn was practiced 3 and 8 years ago; the former with a 5 years old vegetation and the later with a 25 years old one. This must be related to the residual effect and contribution of ashes after burning the vegetation. All soils were well above the sufficiency range and only Agroecosystem 1 of *Leoncio* (30-year-old forest) was in a satisfactory normal range with 218 ppm.

3.2.4. Calcium (*Ca*), Magnesium (*Mg*) and Zinc (*Zn*) in Soils under Shifting Cultivation

In Table 5 are shown the Ca, Mg and Zn contents in soils of the two different ecosystems studied. The general average of Ca was found to be 29.82 and 28.39 $Cmol\cdot kg^{-1}$ for *Leoncio* and *Epitacio* systems respectively, exceeding more than 190% the upper critical limit (10.0 $Cmol\cdot kg^{-1}$) suggested in Table 2.

Remarkable extreme overall average values for Ca (71.0 $Cmol\cdot kg^{-1}$) and Mg (7.32 $Cmol\cdot kg^{-1}$) were found, again, in the ecosystem 3 of *Epitacio.* This is an area located in the upper part of the landscape with black soil and loose stones (*rendzic Leptosol*) recently cultivated with maize after slashing and burning a 10 years old forest. This is the same agroecosystem with one of the highest content of OM as well as the highest pH, N-NO_3, P and K values founded. Similar results have been reported by different authors [36].

Since all ecosystems exceeded the critical limits of Ca, phosphorus (P) could be a limiting nutrient for crops. Above pH 7, Calcium forms complexes with phosphorus as Tricalcium Phosphate $Ca_3(PO_4)_2$; which is a none available form of P to plants [37].

In the case of Mg, the overall average for both *Leoncio* and *Epitacio* systems

Table 5. Changes in secondary essential soil nutrients (Ca, Mg) and Zinc as a micronutrient at 0 - 20 cm deep in different agroecosystems of two Maya farmers practicing slash and burn cultivation.

Farmer	Agroecosystem (N˚)	Ca (meq/100gr)	Mg (meq/100gr)	Zn (ppm)
Leoncio Loria Chimal	1	35.60 (H)	2.63 (M)	0.40 (L)
	2	29.50 (H)	1.43 (M)	0.70 (M)
	3	26.50 (H)	1.51 (M)	0.40 (L)
	4	34.00 (H)	2.47 (M)	0.40 (L)
	5	23.50 (H)	2.31 (M)	0.00 (L)
	Average	**29.82 (H)**	**2.07 (M)**	**0.38 (L)**
	Sd	**4.52**	**0.50**	**0.22**
	CV (%)	**15.14 (M)**	**24.20 (H)**	**58.61 (VH)**
Epitacio Ku Puc	1	25.00 (H)	2.95 (M)	1.00 (M)
	2	24.00 (H)	2.39 (M)	0.80 (M)
	3	71.00 (H)	7.32 (H)	10.20 (H)
	4	24.00 (H)	2.15 (M)	0.90 (M)
	5	26.50 (H)	2.87 (M)	0.90 (M)
	Average	**28.39 (H)**	**3.54 (H)**	**2.76 (H)**
	Sd	**18.47**	**1.92**	**3.72**
	CV	**65.07 (VH)**	**54.16 (VH)**	**134.80 (VH)**
	Critical Limits	5.0 - 10.0	1.3 - 3.0	0.5 - 1.0

Note: H = High, M = Medium, L = Low.

were 2.07 and 3.54 Cmol·kg^{-1}; *Leoncio* being inside the optimum range of 1.3 - 3.0 Cmol·kg^{-1} and *Epitacio* a little bit higher. With the exception of the higher Mg content of the agroecosystem 3 of *Epitacio* all others were in the optimum range.

One third of the soils of the world are calcareous [38] with important micro-elements disorders like Zinc (Zn) due to high concentrations of carbonates (CO_3^{2-}) and (hidoxides) OH^-. The availability of this element depends on the pH and decreases 100 times for each unit increase in pH.

Corn is a highly Zinc-demanding crop and it is probable that more than the 396 thousand hectares planted with corn in the Yucatan Peninsula are being affected by Zn deficiencies [39]. This is the case of *Leoncio* where Zn deficiencies were found in all agroecosystems with an overall low average of 0.38 ppm whilst *Epitacio* ranked High with 2.76 ppm.

With the exception of Agroecosystem 3 of *Epitacio* the others were qualified as Medium whilst for *Leoncio* the Agroecosystems showed to have Low Zn contents except Agro ecosystem 2 with Medium content. The High general mean Zn value in *Epitacio* is mainly due to the influence of the extreme content of Zn

(10.20 ppm) in Agroecosystem 3. This extreme increase of Zn is beyond all expectations since a drastic decrease was expected based on the higher calcium content obtained.

The exceptional high nutrients content in the black stony *Pus Lu'um* soil (rz LP) have been reported [21] to have the best chemical quality of nutrients as compared to the other stony soils of Yucatan. High contents of OM, N-NO_3, P and micronutrients have been recorded. There are those who suggest that the application of fertilizers could be no functional [40].

The foregoing discussion should admit that shifting cultivation, based on slash and burn system, is a very complex ecosystem and it needs more scientific research to better understand and explain properly the soil fertility changes. Although *Leoncio* and *Epitacio* are Mayan farmers dedicated to manage their vegetation under shifting cultivation both have different agroecosystems with different forest ages and soils.

The soil fertility in those systems are very changeable in time and space depending on the distribution and quality of the vegetation. The kind of vegetation depends on the type of soil and, the amount of nutrients incorporated will also depend on the biomass and quality of the forest to be burned. It has been mentioned [41] that in the flat areas with red soils the trees tend to be larger and more widely spaced than those in the upper parts of the landscape with stony black soils.

On the other hand, mineralogy of soils needs to be considered for further studies since clay mineralogy is one of the most important indicators of soil quality and it is basic when considering the application and management of fertilizers as mentioned by Kogge Kome *et al*. [42]. By the way, although limestone rock is the underlying material of the studied area of Yucatan, the parent materials are rich in different types of clays such as: illite, kaolinite, smectite, montmorillonite, chlorite and powders carried by the wind from Africa. The soils in the upper part of the microrelief do not present secondary pedogenetic carbonates as those of the lower parts do [43].

3.2.5. Correlation between Soil Attributes

The intensity of the relationship between the soil attributes for both *Leoncio* and *Epitacio* systems, as reflected by the Correlation Index (r) and the Determination Coefficient (R^2), are being shown in **Table 6**.

Although the Correlation Coefficient between OM and pH, in *Leoncio*'s agroecosystems, was graded as Medium negative one ($r = -0.59$) and the Determination Coefficient was low ($R^2 = 0.35$) the general trend was that the pH decreased while OM increased as it is shown in **Figure 2**. However, the opposite happened in *Epitacio*'s Agroecosystems where the relationship between OM and pH ranked as Medium positive $r = 0.45$ with $R^2 = 0.21$ and the pH increased when OM increased too (**Figure 3**).

There was not found any good relationship between OM and N-NO_3 in both *Leoncio*'s and *Epitacio*'s Agroecosystems and the Higher correlations between

Table 6. Grade of relationship between Independent (x) and Dependent (y) variables as related to their corresponding Coefficients of Correlation (r) and Determination (R^2) in two shifting cultivation systems.

Region	Independent variable (x)	Dependent variable (y)	r	R^2
Leoncio Loría Chimal	OM	pH	−0.59 (M)	0.35
	OM	$N\text{-}NO_3$	−0.30 (L)	0.09
	OM	P	−0.84 (H)	0.72
	OM	K	−0.64 (M)	0.41
	OM	Zn	0.96 (H)	0.94
	P	pH	0.65 (M)	0.43
	K	pH	0.91 (H)	0.84
	Ca	pH	−0.87 (H)	0.76
	Zn	pH	−0.62 (M)	0.39
Epitacio Ku Puc	OM	pH	0.45 (M)	0.21
	OM	$N\text{-}NO_3$	0.22 (L)	0.05
	OM	P	0.44 (M)	0.20
	OM	K	0.00 (L)	0.00
	OM	Zn	0.28 (L)	0.08
	P	pH	0.20 (L)	0.042
	K	pH	0.56 (M)	0.32
	Ca	pH	0.70 (M)	0.50
	Zn	pH	0.70 (M)	0.50

Note: H = High, M = Medium, L = Low.

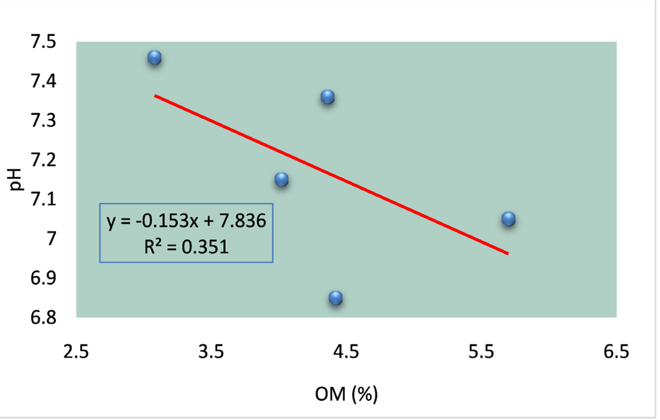

Figure 2. Correlation between Organic Matter and pH at 0 - 20 cm deep in soils of *Leoncio*'s Agroecosystems.

soil attributes corresponded to *Leoncio* with OM vs. P (r = −0.84), OM vs. Zn (r = 0.90), K vs. pH (r = 0.91) and Ca vs. pH (r = −0.87).

In **Figures 4-6** are shown some of the most important trend regression lines, the equations and the R^2 of *Leoncio*'s Agroecosystems characterized by having only red *Cambisols*. The available P decreased as OM increased (**Figure 4**) with a High negative r = −0.84 (**Table 6**) and high $R^2 = 0.72$ which means that P contents depended 72% on OM changes in a negative relationship. In contrast, as it was shown in **Table 6**, P had a positive relationship with the pH; the higher the pH the higher the P content in the soil. And, as it was discussed before, the highest pH's were found in those Agroecosystems with SB cultivation as compared to those of old vegetation.

Although fire can induce to the mineralization of organic P [19] and therefore more available P can be released to the soil solution, the levels of P never reached sufficiency due to the negative influence of native carbonates. The same trend of P, was for K. The OM and K showed a negative relation (**Table 6**) but a High positive one with the pH. The line trend, the equation and the High $R^2 = 0.84$ shown in **Figure 5** explain that the pH depended 84% on K contents in a positive relationship. This has to do with the alkaline effect of the K-carbonates-rich ash after burning.

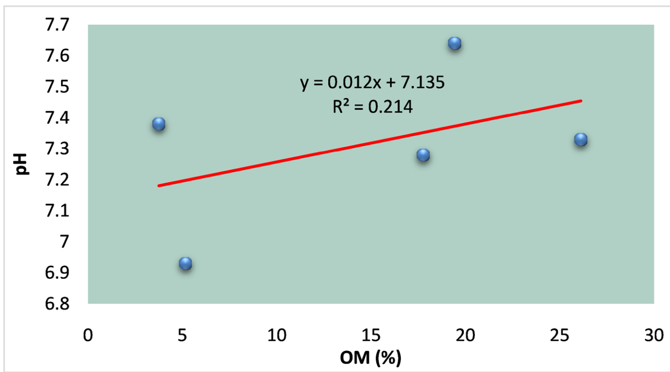

Figure 3. Correlation between Organic Matter and pH at 0 - 20 cm deep in soils of *Epitacio*'s Agroecosystems.

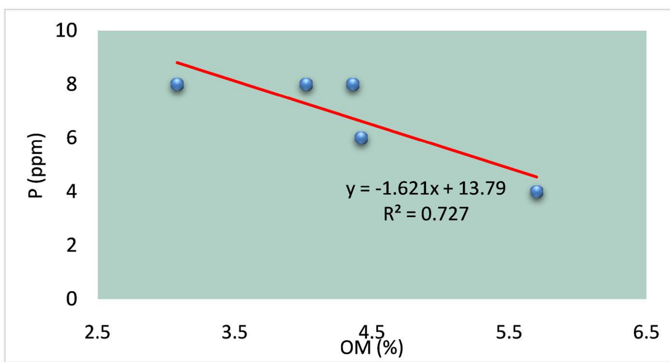

Figure 4. Correlation between Organic Matter (%) and P (ppm) at 0 - 20 cm deep in soils of *Leoncio*'s Agroecosystems.

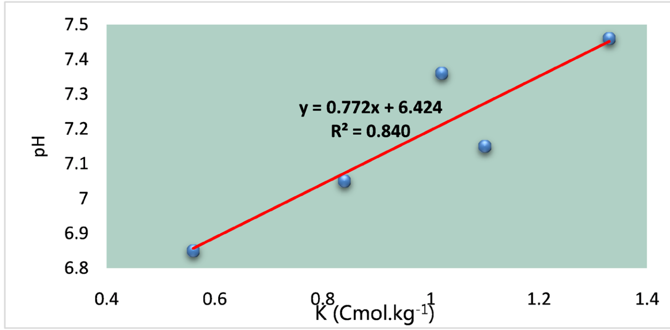

Figure 5. Correlation between exchangeable K and pH at 20 cm deep in soils of *Leoncio*'s Agroecosystems under slash and burn cultivation.

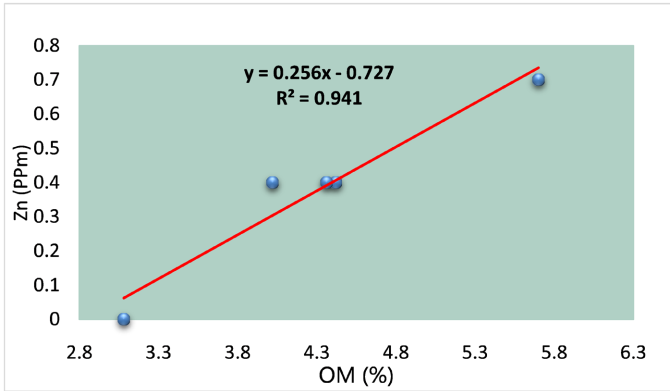

Figure 6. Correlation between OM (%) and Zn (ppm) at 20 cm deep in soils of *Leoncio*'s Agroecosystems under slash and burn cultivation.

Zn depended on the OM in a Very High positive way ($R^2 = 0.94$) as it is being shown in Figure 6. In contrast, the Correlation Coefficient (Table 6) between pH vs. Zn was a Medium negative one ($r = -0.62$) with an $R^2 = 0.39$. Despite the influence of OM on Zn contents, it seems that the influence of pH was greater than that of the OM. As pH increased more Hydroxides ions (OH^-) are in the soil and therefore more Zn can be converted as $Zn(OH)_2$, a non-available form of the nutrient.

4. Conclusion

Agroecosystems with long fallow periods, showed the lowest pH values. The other Agroecosystems, where slash and burn have been practiced, pH values tend to be higher due to the influence of ashes. All Agroecosystems showed High and Very High contents of OM although $N\text{-}NO_3$ and P was Low, except the Very High content of $N\text{-}NO_3$ in the Agroecosystem 3 of *Epitacio* located in the *rendzic Leptosol*. In all Agroecosystems K and Ca were High whilst Mg was Medium. The overall average Zn content in *Leoncio*'s was Lower (0.38 ppm) than Epitacio's ecosystem (2.76 ppm). Remarkable extreme overall average values for all soil attributes were found in Agroecosystem 3 of *Epitacio* in the *rendzic Lepto-*

sol. There was not found any good relationship between OM and N-NO_3 in both *Leoncio*'s and *Epitacio*'s Agroecosystems but the Higher correlations between soil attributes corresponded only to *Leoncio*'s. There was a general trend for nutrients to increase with the slash and burn system; however, it is compulsory to better explain each nutrient behavior and its interactions, including mineralogy, from a strictly scientific point of view.

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Conflicts of Interest

The authors declare no conflicts of interest.

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