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Effect of different land uses on soil quality indicators in Lixisols from La Sabana, Huimanguillo, Tabasco, Mexico

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ABSTRACT

Objective: To evaluate the physical indicators of the quality of soils subjected to four different land uses in Lixisols from La Sabana in Huimanguillo, Tabasco, Mexico.

Design/methodology/approach: Nine variables were evaluated in soil samples from Lixisols located in La Sabana, Huimanguillo: infiltration rate, resistance to penetration, bulk density, total porosity, aggregate stability, thinning, depth of the horizon, volume and weight of soil loss. We used a completely randomized sample design, with a factor with four levels (each land use: pasture, rubber tree, rubber-cacao and rubber-mahogany), and five treatment repetitions; each sampling point of the plot with the five-of-golds method, with the exception of the use with pasture, which was linear.

Results: The reference soil group (RSG) corresponds to a Ferric Lixisol (Cutanic, Endoloamic, Epiarenic, Humic, Profondic), whose RSG has not been reported for the study area. The quality indicators are within acceptable limits. In soil loss, the pasture has conserved more over time, storing greater volume and weight of soil per hectare; the use with rubber (monoculture) has lost a greater amount of soil from the A horizon, evidenced by the decrease in its depth, volume and weight per hectare.

Limitations on study/implications: Until a few years ago, in the study area within La Sabana in Huimanguillo, Acrisol had been described as the dominant RSG.

Findings/conclusions: The presence of Acrisol in the study area is ruled out. Soil quality for all uses is acceptable.

Keywords: soil quality, erosion, land-use change, bulk density, tropical agriculture.

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INTRODUCTION

Soils are an essential resource for the conservation of ecosystems and the welfare of society, since they are the main productive base of economic activities in the primary sector (Palma-López *et al.*, 2007; 2017). The lack of a correct management in their use, primarily due to anthropic causes, for example an intensive use that is not in accordance to their capacity, deforestation and the expansion of the agricultural frontier, change in land use, among others, negatively affects the physical, chemical and biological properties of the soils, inducing them to erosion and degradation (Drobnik *et al*., 2018). This is why evaluating the soil quality, understood based on Karlen *et al*. (1997), as the capacity of a soil type in particular to function within the limits of a natural or managed ecosystem through indicators, physical, chemical and biological, is at the same time a sustainability measure of the soil use and management practices. The objective of this study was to evaluate physical indicators of the soil quality in Lixisols with different land uses in La Sabana, Huimanguillo, Tabasco, Mexico.

MATERIALS AND METHODS

Study area and description

The study was conducted from 2020 to 2021 in the *Ejido* Tecominoacán, in Huimanguillo, Tabasco, inside the area of La Sabana, between coordinates 17° 55' 20.43" N and 93° 36' 18.787" W. The climate is warm humid with rains during the entire year Af(m) and temperatures between 26 and 28 °C annual mean, with records of total annual precipitation from 2000 to 3000 mm (Salgado-García *et al*., 2010; Tinal-Ortiz *et al*., 2020). Until a few years ago, the dominant soils in the region have been Acrisols (Palma-López *et al*., 2017).

Establishment of study plots

Four plots of 20×20 were established, each with a particular use and management of the soil: pasture (*Bracharia humidícola*) with 36 years of semi-stabling and alternate rotational grazing and 3 heads of livestock per hectare; rubber tree (*Hevea brasiliensis*) as

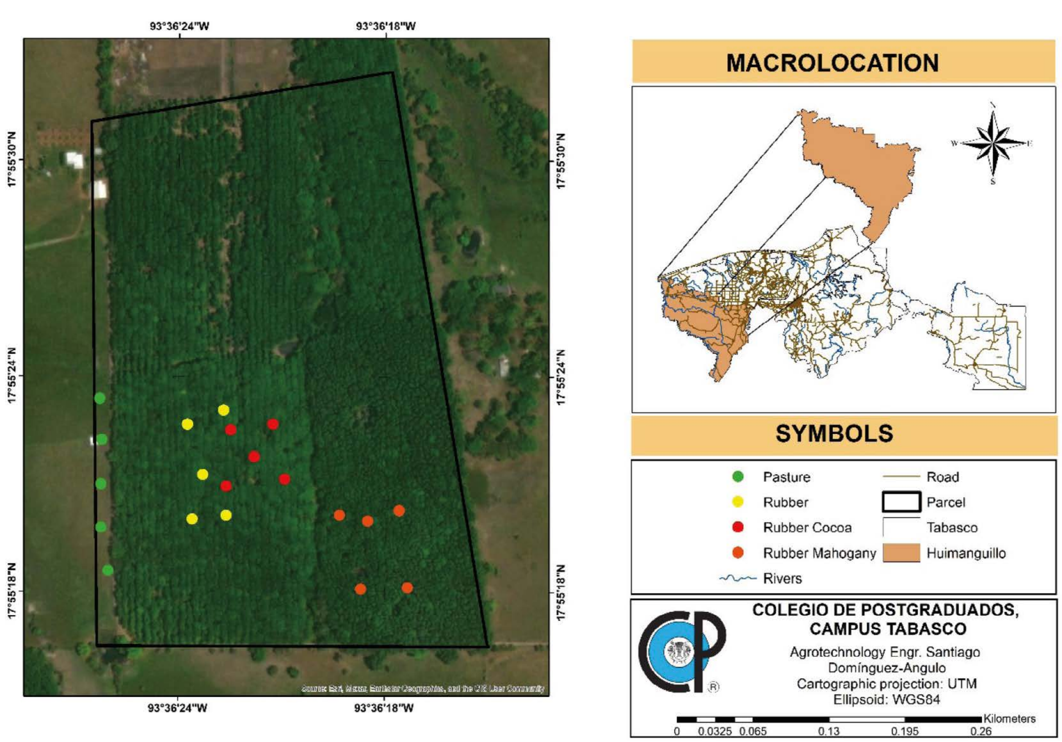

Figure 1. Localization of the study area.

monocrop with 6 years of conventional management with application of the following agrichemicals: Glyphosate, Paraquat, Diuron, Cypermethrin, Yaramila, Urea, DAP, KCl, Maxigrow and Bayfolan; the use with rubber-cacao (*Theobroma cacao*) with 6 and 3 years; and rubber-mahogany (*Swietenia macrophylla*) with 6 and 12 years of establishment, respectively. The soil preparation prior to the establishment of the plantations was executed with primary and secondary mechanized farming (four rake passes). The land uses were identified through field visits and semi-structured interviews with the cooperating producers. The plots with rubber-cacao and rubber-mahogany present the same management as the ones with rubber tree (monocrop), showing similar soil conditions to those of the monocrop.

Extraction of the samples and characterization of the reference soil group

Five simple samples were extracted of the A horizon for each land use, through the five-of-golds method and linear in the use with pasture. From the profile, four simple samples were taken by drilling, one for each horizon in different depths: 0-43; 43-84; 84-101 and 101-150 cm. Characterization in the field of a soil profile was made using the description manual by Cuanalo, 1990. The samples from the profile horizons were moved to the laboratory, previously identified and dried in the shade for their later analysis with the methods established in the NOM-021-RECNAT-2000 on the occasion of the RSG classification, according to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2015). Likewise, the samples from each land use were taken to the file identified to evaluate the physical indicators of the A horizon soil quality.

Variables evaluated and methods used

The methodologies from the "Guidelines for soil quality assessment in conservation planning" from the Soil Quality Institute (USDA, 2001) were used, to evaluate the following variables: bulk density (known cylinder method), total porosity (%), through the formula $\varphi = 1 - \frac{\rho_b}{\rho_p}$ (where: φ=total porosity, ρ_b=bulk density, and ρ_p=real density 2.65 t m^{-3}), infiltration speed, average evaluation of thinning, and stability of aggregates. The resistance to penetration was measured in the field with an AMS pocket piston penetrometer, brand Addag, model 77114, carried out on the soil surface at 30 cm from the excavation done to measure the depth of the A horizon, and the area selected was cleared of plant residues, roots, or other solid materials that could alter the reading of resistance to penetration. For each plot, the sheets of soil loss (reduction in depth), the volume (m^3 ha^{-1}) and the weight (t ha^{-1}) were estimated with the figure of the soil's bulk density and the depth of the horizon through the following formulas: $Vs = (ph)(s)$, where *Vs*=volume of soil in m^3 ha^{-1}, *ph*=horizon depth in meters, and *s*=surface (generally considered to be 10,000 m^2 or 1 hectare); and $Ps = (Vs)(\rho_b)$, where *Ps*=soil weight in t ha^{-1}, *Vs*=soil volume, and ρ_b=bulk density. To estimate the reduction in depth, the following was used: $pph = ushmsp - ushmp$, *pph*=depth lost from the horizon, *ushmsp*=soil use with the deepest horizon, *ushmp*=soil use with the least deep horizon.

Experimental design and statistical analyses

The experimental design was completely random, where each land use was a factor with four levels and five repetitions for each treatment, each sampling point within the plot was a repetition. The data were subjected to a one-way analysis of variance (ANOVA) and Tukey's multiple means comparison test was applied with significance of $p<0.05$ when differences were found between the treatments, through the free software Past 4.09 version 2022 and the Real Statistics complement for Excel 2013.

RESULTS AND DISCUSSION

The RSG of the study area resulted in a Ferric Lixisol (Cutanic, Endoloamic, Epiarenic, Humic, Profondic), differentiating from an Acrisol where the Lixisols have clay of low activity in the argic horizon and a high saturation of bases between 50-100 cm of depth, while the Acrisols, even though they also have clays of low activity in the argic horizon the base saturation is low in the depth of 50-100 cm. In this regard, no information was found reporting the presence of Luxisols in the hillside zone of La Sanana in Huimanguillo (La Chontalpa), although Zavala-Cruz *et al.* (2016) refers to their presence in Balancán and Tenosique in the river meadow zone (Región de los Ríos), and on the other hand, Palma-López *et al.* (2017) mention that until that year this type of soil had not been identified in Tabasco, although it was found since 2016 in regions between the municipalities of Tenosique and Balancán. The soil profile description in *ejido* Tecomatán, Huimanguillo, Tabasco, is shown in Table 1.

Depth of the A horizons

There are no significant differences ($p>0.05$) between the means of the depths of the A horizons of each land use (Table 2). The use with pasture has conserved more soil through time, since it obtained the greatest depth (30.4), while the rubber-cacao use has the second place, since it reduced 1.20 cm null mpas, followed by rubber-mahogany (1.80 cm), and the soil with rubber tree is the one that has been reduced most, 2.80 cm. Similarly, Alejandro-Martínez *et al.* (2019) did not observe significant differences between the depths of the A horizons of the land uses with: second growth forest, pineapple, yucca, sugarcane and pasture, in another *ejido* in La Sabana, Huimanguillo, Tabasco, where the A horizon of the use with second growth forest the deepest (42.50 cm) thanks to the plant cover of the soil that minimizes erosion; on the other hand, the pasture use was the lowest (17.50 cm), differing from this study where it was the most conserved.

Volume and weight of the A horizon

There are no significant differences between the volume of the A horizons from the different land uses (Table 2). On the contrary, Alejandro-Martínez *et al.* (2019) found highly significant differences in different land uses where the second growth forest (reference use) presents the highest volume (4250 m^3 ha^{-1}), probably due to a greater depth.

There are no significant differences between the weight of the A horizon and the land uses. In this regard, Alejandro-Martínez *et al.* (2019) indicate that they did not find significant differences when evaluating the weight of the A horizon of the soil with second

Table 1. Description of the profile in Ejido Tecominoacán, Huimanguillo, Tabasco.

Profile	Horizon (cm)	Soil description
	A1 (0-43)	Thin and horizontal transition; wet; black color (10 YR 2/2), with presence of roots; sandy loam texture; no stoniness; strongly developed structure, with subangular blocks and crumbs, thin and very thin in size; very friable wet consistency; sticky and slightly plastic very wet consistency; numerous pores, with small and very small diameter, continuous, chaotic orientation, inside and outside of aggregates, with tubular morphology; very fast permeability; extremely abundant roots, thin, small and medium size; with the presence of earthworm droppings, ants and termites; with a field pH of 5.5
	E (43-84)	Thin and horizontal transition; wet; black color (10 YR 2/2), with dark brown mottled (10 YR 3/3), marked contrast, common abundance, thin, medium and large size; sandy loam texture; no rockiness; moderately developed structure, subangular blocks, thin and medium size; friable wet consistency; slightly sticky and slightly plastic very wet consistency; cutans by eluviation, on faces of aggregates and pores, with clay minerals and iron oxides; numerous pores, with very small diameter, continuous, chaotic orientation, inside and outside of aggregates, with tubular morphology; very fast permeability; common roots, thin and very small in size; with the presence of earthworm droppings, ants and termites; with a field pH of 5
	Bt1 (84-101)	Medium and irregular transition; saturated moisture; brownish yellow color (10 YR 6/1), with red mottled (2.5 YR 6/8), thin, few specks, thin and very thin in size; sandy loam texture; with very few rockiness, grit, rounded quartz, heavily weathered; strongly developed structure, with subangular blocks, very thin, thin and medium in size; friable wet consistency; sticky and slightly plastic very wet consistency; cutans by eluviation, continuous, with clay minerals and iron oxides; frequent small and medium sized nodules, dark reddish brown color, with subangular shape, soft hardness, composition of iron oxides; frequent pores, thin to thick diameter, continuous, chaotic orientation, inside and outside of aggregates, with tubular morphology; fast permeability; few and very small roots; with a field pH of 5
	Bt2 (101-1-150)	Medium and irregular transition; saturated moisture; brownish yellow color (10 YR 6/1), with red (2.5 YR 6/8) and pale brown (10 YR 7/3) mottled, contrasting, many, thin and medium size; sandy clay loam texture; few rounded gravels of weathered quartz; strongly developed structure, with subangular blocks, thin and medium in size; friable wet consistency; sticky and slightly plastic very wet consistency; cutans by eluviation, continuous, with clay minerals and iron oxides, on faces of aggregates and pores; frequent small sized nodules, red color, with subangular shape, soft hardness, composition of iron oxides; frequent pores, thin to thick diameter, continuous, chaotic orientation, inside and outside of aggregates, with tubular morphology; moderate permeability; rare and thin roots; with a field pH of 4.2

growth forest, pineapple, yucca, sugarcane and pasture use, from among which the greatest weight was 4579.50 t ha^{-1} for second growth forest, exceeding by 1,320.61 t ha^{-1} what the A horizon weighs from pasture use.

Bulk density and total porosity

There were no significant differences between treatments of bulk density (Dap), although on average the Dap was accentuated in the pasture use (Table 3). Noguera & Vélez (2011) evaluated five land uses in three silvopastoril systems, concluding that the pasture use with Kikuyo (*P. clandestinum*) grass did not only obtain the highest Dap

Table 2. Soil quantity by land-use and horizon A reduction comparison.

Treatments	Horizon depth (cm)	Horizon volume (m^3 ha^{-1})	Horizon weight (t ha^{-1})
Pasture	30.4a	3040a	3258.39a
Rubber	27.6aa	2760a	2644.53a
Rubber-cocoa	29.2a	2920a	2943.06a
Rubber-mahogany	28.6a	2860a	2946.20a
VC (%)	19.01	19.01	19.81
F	0.88	0.88	0.45
Statistical differences	ND	ND	ND

The deepest land-use was pasture, soil sheets loss volume and weight was calculated, subtracting from the highest value the value of each land-use. Equal letters indicate the absence of statistical differences ($p>0.05$).

	Soil depth reduction					
Treatments	Soil depth loss (cm)*	Volume of soil lost (m^3 ha^{-1})*	Weight of soil lost (t ha^{-1})*	Soil depth loss (cm)**	Volume of soil lost (m^3 ha^{-1})**	Weight of soil lost (t ha^{-1})**
Pasture				12.10	1210	1311.6
Rubber	2.80	280	267.764	14.90	1490	1424.9
Rubber-cocoa	1.20	120	121.137	13.30	1330	1342.6
Rubber-mahogany	1.80	180	186.069	13.90	1390	1436.9

* Values estimated taking as reference the deepest horizon, in this case it was the use with pasture (30.4 cm).
** Values estimated considering the depth of the acahual (secondary vegetation) from Alejandro-Martínez *et al.* (2019).

(1.17 t m^{-3}), but rather was at par with the lowest values in the variables associated such as porosity and water conductivity, caused by indiscriminate and constant stomping of animals within the plot.

There were no significant differences between the means of porosity of the treatments (Table 3). If we consider the average results obtained, the lowest porosity corresponds to treatment one —the soil use with pasture, which at the same time represents the intensive use— with 59.09 %. It is necessary to stress that the percentage of porosity of the pasture

Table 3. Averages of the soil quality indicators. Different letters indicate statistical differences ($p<0.05$).

Treatments	Infiltration speed (cm water h^{-1})	Penetration resistance (MPa)	Bulk density (t m^{-3})	Porosity (%)	Aggregate stability (%)	Average soil meltdown (%)
Pasture	162.39b	0.40a	1.08a	59.09a	32.38a	5.94a
Rubber	657.35c	0.29a	0.96a	63.91a	24.76a	5.75a
Rubber-cocoa	1472.73a	0.29a	1.01a	61.91a	20.83a	5.82a
Rubber-mahogany	1317.89a	0.27a	1.03a	60.99a	22.5a	5.77a
VC (%)	63.18	29.56	10.10	6.33	65.27	3.48
F	0.008	0.13	0.30	0.30	0.70	0.49
Statistical differences	**	ND	ND	ND	ND	ND

use was considered high (50-60%), and on the other hand, the other uses fall into the category of Very high porosity (>60%) according to the interpretation table by Flores & Alcalá (2010). The low porosity is associated to the Dap evaluated and scarce organic matter, which implies problems such as water infiltration and storage with the restriction of growth and development of the roots (Drobnik *et al.*, 2018).

Thinning and stability of aggregates

No significant differences were observed ($p>0.05$; CV=3.480%) between the averages of thinning in the land uses. The average of thinning ranges between 5.31 and 6%. According to Francis *et al.* (2018), soil thinning is a physical process that is characterized by the rupture of the air-dried soil macroaggregates into microaggregates and much finer primary particles when they are drastically dampened. It is believed that the thinning results obtained could be related to a good organic matter content (OM), since it benefits the structure of the soil reducing the permeability, while it reduces the forces that destroy the aggregates from bursting (Gabioud *et al.*, 2011).

The stability of aggregates was not statistically different between the land uses ($p>0.05$) (Table 3). The stability of aggregates is low, since they fluctuate from 20.83 to 32.8% (USDA, 2001). Bernal & Hernández (2017), when evaluating the stability of aggregates in a red Ferralitic soil lixiviated under three uses, obtained the best stability values (44.5%) for the first 20 cm of depth under a forest system, considered satisfactory; this result is higher than those obtained for the use with rubber-cacao (20.83%), rubber-mahogany (22.5%), and rubber tree 24.76 (%).

Resistance to penetration and infiltration speed

There were no significant differences between treatments ($p>0.05$, CV=29.56) (Table 3). The resistance to penetration was greater in the land use with pasture (0.40 MPa), while the lowest value was observed in rubber-mahogany (0.27 MPa). Similarly, Noguera & Vélez (2011) did not find significant differences in the resistance to penetration at different depths (0-15 cm, 15-30 cm and 30-45 cm), although obtaining higher resistance values in grasses with livestock with 3 MPa (30.60 kgf cm^2) in the first five centimeters, which is very high compared to that found for the pasture evaluated (0.40 MPa). However, the low levels of resistance to penetration of all the soils suggest low physical degradation, since starting from 2 MPa (20.40 kgf cm^2), the soil can face significant restriction for the development of roots (López, 2002). White (2006) suggests that in forests, a resistance to penetration lower than 1 MPa (10.20 Kgf cm^2) represents low restriction for the roots and soils of better quality, which allows suggesting that the uses with rubber tree, rubber-cacao and rubber-mahogany present a good state.

Highly significant differences were observed ($p<0.001$, CV=63.181%) in the infiltration speed (Table 3). Although the results categorized all the treatments as with *very fast infiltration*, in the pasture land use the infiltration speed is affected since on average it is the lowest with 162.386 cm H_2O h^{-1} (centimeters of water sheet per hour), which agrees with the highest values in the variable resistance to penetration, lowest porosity, and high Dap (López, 2002). The values obtained were 657.536 and 1327.886 cm H_2O h^{-1} for rubber tree and rubber-mahogay, respectively, and the highest value was obtained with rubber-cacao with 1472.734 cm H_2O h^{-1}.

CONCLUSIONS

The classified RSG corresponds to a Ferric Lixisol (Cutanic, Endoloamic, Epiarenic, Humic, Profondic). The quality of the physical properties evaluated from the A horizon for all the land uses were found in acceptable levels. The results suggest that the pasture has conserved more soil through time and stores more volume and weight of soil per hectare. The physical variables for the use with pasture have the lowest average values in the case of infiltration speed, and highest for resistance to penetration, bulk density, total porosity, percentage of stability of aggregates, and thinning.

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