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Quality of a Cambisol at different times of agricultural use in the region of Los Ríos, Tabasco, Mexico

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ABSTRACT

Objective: To evaluate the quality of a Cambisol at different times of agricultural use in the Los Ríos region (RR), Tabasco, Mexico.

Design/Methodology/Approach: Four agricultural uses were selected on a Cambisol (CM): rainfed crop (RC), annual crop (AC), pasture (Pa), and secondary vegetation (SV). These were established at three different times (1984, 2000, and 2019) with four replications. Soil was collected using an auger at a depth of 0-30 cm. The physicochemical properties of the soil —such as texture (T), bulk density (BD), aggregate stability (AS), pH, electrical conductivity (EC), organic matter (OM), total nitrogen (N), phosphorus (P), and potassium (K)— were determined. A factorial analysis of variance was performed (significance level $p=0.05$). Variables that showed a statistically significant effect were subjected to Tukey's multiple comparison test (significance level $p=0.05$).

Results: Statistically significant differences ($p \leq 0.05$) were obtained for OM, P, K, and BD contents. The high OM content present in CM with SV in all years shows a better soil quality compared to CM with RC and AC. The high BD recorded in CM with Pa since 1984 shows soil quality degradation by compaction resulting from grazing due to extensive livestock farming.

Study limitations/Implications: Sustainable management practices are required to recover degraded CM.

Findings/Conclusions: OM and BD contents were the best quality indicators for the CM affected by the change in agricultural use and time of use in RR, Tabasco.

Keywords: Organic matter, Bulk density, Annual crops, Rainfed crops, Secondary vegetation.

INTRODUCTION

Quality of soil is defined as soil's capacity to function and promote the sustainability of plants, animals, and human beings, as well as to maintain or improve the quality of water,

Image by PublicDomainPictures at Pixabay air, and the environment (Bünemann *et al.*, 2018). This functional concept allows us to assess this resource through qualitative and quantitative indicators (Pouladi *et al.*, 2020). These indicators integrate data on soil properties and characteristics in order to assess the response of soil productivity or functionality, and to indicate whether quality improves, diminishes, or remains the same (Schloter *et al.*, 2018).

Quality studies are necessary because soil is an essential resource in the creation of goods and services for ecosystems and for social wellbeing (Bünemann *et al.*, 2018), especially to meet water, energy, and food security needs (FAO and ITPS, 2015). However, soils have been subjected to degradation processes, mostly by erosion, and their health and crop yields have diminished as a consequence of the replacement of natural vegetation with agricultural uses (Jian *et al.*, 2020) and the implementation of unsustainable land uses and practices, which has led to infertility in one third of the world's soils (FAO and ITPS, 2015).

Soil degradation and the reduction in its quality threaten the future of human societies and the achievement of sustainable development objectives that guarantee the wellbeing of people and the environment (Keesstra *et al.*, 2016). Soils in 52.9% of the Mexican territory are degraded, and 70% of soils in the State of Tabasco show degradation related to unsustainable agricultural uses (Ortiz-Solorio *et al.*, 2011), with changes in physical, chemical, and quality properties (Geissen *et al.*, 2009). The objective of this work was to assess the physical and chemical quality of Cambisol with agricultural use at different times in the establishment of agricultural practices in the Los Ríos region, Tabasco, Mexico.

MATERIALS AND METHODS

Study area

The study was conducted in the municipalities of Balancán, Emiliano Zapata, and Tenosique in the Los Ríos region (RR), which is located east of the State of Tabasco in an area of 6234.2 km^2 (24.7% of the state). It borders the states of Campeche and Chiapas to the north and west, and the Republic of Guatemala to the east and south (Figure 1). Climates prevailing from north to south are warm sub-humid with summer rains (Aw2), warm humid with abundant summer rains (Am(f)), and warm humid with abundant rains all year round (Af(m)). Average annual rainfall varies between 1600 and 2000 mm and average annual temperature ranges from 26 to 28 °C (Aceves-Navarro and Rivera-Hernández, 2019). Cambisol (CM) covers 14% of the RR (Figure 1); it is found in alluvial plains and sandstone, shale, and limestone hills. This type of soil is used for cattle pastures, rainfed and annual crops, forestry plantations, oil palm, and secondary vegetation (Salgado-García *et al.*, 2017).

Selection of agricultural uses in Cambisols

Based on land use mapping created by Ramírez-García *et al.* (2022), In CM soils (Salgado-García *et al.*, 2017), four land uses were selected with three times of establishment (1984, 2000, and 2019): a) rainfed crops (RC) of corn, beans, squash, and watermelon; b) annual crop (AC) of sugarcane; c) pasture (Pa); and d) secondary vegetation (SV).

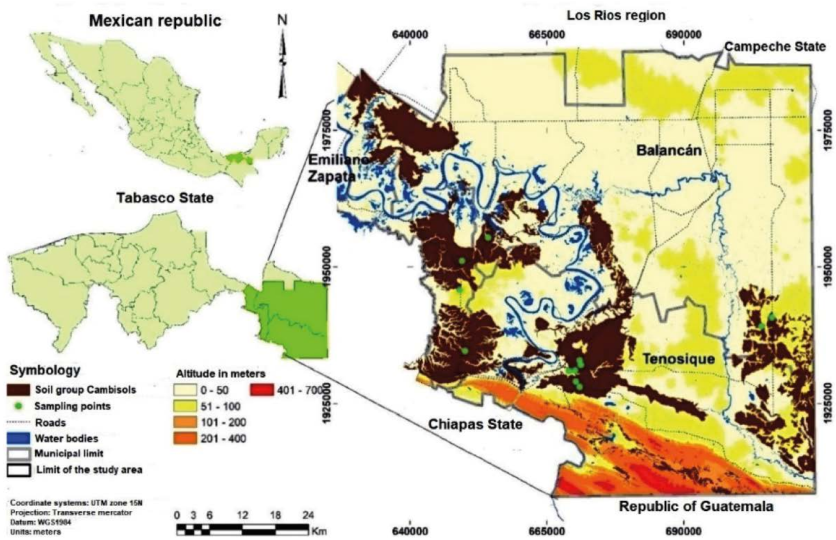

Figure 1. Location of the Los Ríos region, State of Tabasco, Mexico.

Soil sampling

For each land use —considering the three establishment times—, four sites were selected for sampling to estimate soil quality. At each site, a sample comprising 15 subsamples was obtained at a depth from 0 to 30 cm in an area of 400 m^2, following a zigzag pattern. The sample was then homogenized, and 1 kg of soil was set apart. To determine bulk density (BD), undisturbed soil was collected with a cylinder auger at 10 cm below the surface layer.

Laboratory analysis

Soil samples were air-dried at room temperature in the Laboratorio de Análisis de Suelos, Plantas y Aguas (LASPA) of the Tabasco Campus. For the physical and chemical analyses, samples were crushed, homogenized, and passed through a 2 mm sieve, or through a 0.5 mm sieve for the organic matter (OM) and total nitrogen (TN) analyses. To determine BD, soil samples were dried in an oven at 105 °C, then dry weights were calculated using the formula proposed by USDA (1999).

Aggregate stability (AS) was determined by the dry sieving method (Eynard, 2004). The following analyses were performed in compliance with the Official Mexican Standard NOM-021-RECNAT-2000: organic matter (OM) (Walkley and Black), total nitrogen (TN) (Semimicro Kjeldahl), phosphorus (P) (Olsen), potassium (K) (extraction with 1 N ammonium acetate, pH 7, and quantification by atomic absorption), texture (Bouyoucos method), pH (2:1), and electrical conductivity (EC) (1:5) (SEMARNAT, 2002).

Statistical analysis

A database of the soil physical and chemical properties used as quality indicators was generated, including four uses: RC, AC, Pa, and SV, with three times of establishment (1984, 2000, and 2019) and four repetitions. Land uses and establishment times were considered as factors (RC, AC, Pa, and SV), along with three levels (1984, 2000 and

2019). The factorial analysis of variance was carried out considering the CM physical and chemical properties as response variables with a significance level of p=0.05.

The assumptions of normality for the physical and chemical property values were verified with the Shapiro-Wilk test on residuals, and the Levene test for homoscedasticity was used on absolute residuals (Tassano *et al.*, 2021). Square-root, power, logarithmic, and Johnson transformations were applied using the Minitab Software v. 20.7 to achieve compliance with the assumptions on the variables (pH, EC, OM, N, P, K, BD, and AS) (Yañez-Vazquez *et al.*, 2018). A Tukey's multiple comparison test was conducted on variables having a significant effect on any of the factors or their interaction (Ajayi *et al.*, 2021). First, land uses were analyzed per year of establishment, then the same was done with all land uses in different years. Statistical analyses were processed using the statistical software InfoStat 2017.1.2. (Tassano *et al.*, 2021).

RESULTS AND DISCUSSION

Cambisol quality between agricultural uses with different years of use

The factorial analysis to determine the physical and chemical properties impacting CM quality with agricultural uses with different establishment times (years of use) showed statistically significant differences ($p \leq 0.05$) in OM content (Table 1). The highest OM content was observed in SV at all three times of establishment (1984, 2000, 2019) (Table 1). This is attributed to leaf litter and root residue decomposition by microorganisms, which favors an increased OM (Alabi *et al.*, 2019). In contrast, RC had very low OM values in 2019, due to continuous tillage practices that rapidly reduce OM in soil (Wang *et al.*, 2021). It should be noted that the CM of the RR showed medium to high levels of OM (2-6%) in its various land uses (SEMARNAT, 2002).

The highest K concentrations were found in RC of 2000, which can be attributed to the use of fertilizer (Alabi *et al.*, 2019), while Pa and SV of 1984 had the lowest values. With the studied land uses, CM showed low K values (<0.3 (cmol(+) kg^{-1}) (SEMARNAT, 2002).

Table 1. Mean values of the CM quality indicators between land uses with different establishment times (years of use) in the RR.

Year	Use	pH	EC ($\mu S\ cm^{-1}$)	OM (%)	TN (%)	P ($mg\ kg^{-1}$)	K (cmol(+) kg^{-1})	BD ($g\ cm^3$)	AE (WMD)	Clay (%)	Silt (%)	Sand (%)
1984	RC	6.8a	85.5a	2.5ab	0.1a	40.4a	0.3ab	1.2a	1.4a	36.1abc	31.8a	32.1ab
2000	RC	6.7a	89.6a	3.8ab	0.2a	35.0a	0.65a	1.1a	0.7a	62.3a	16.9a	20.8ab
2019	RC	6.1a	48.4a	1.7b	0.3a	37.8a	0.35ab	1.4a	0.8a	20.6bc	14.9a	64.4a
1984	AC	6.4a	71.0a	3.2ab	0.2a	30.4a	0.3ab	1.1a	0.8a	45.5abc	20.4a	34.1ab
2000	AC	7.0a	80.1a	2.5ab	0.2a	32.3a	0.33ab	1.3a	1.6a	51.3ab	21.4a	27.3ab
2019	AC	7.3a	107.1a	4.1ab	0.3a	27.3a	0.43ab	1.1a	1.4a	53.5ab	30.4a	16.1b
1984	Pa	6.1a	60.5a	2.9ab	0.2a	77.9a	0.18b	1.4a	0.5a	22.3abc	9.3a	68.4a
2000	Pa	7.1a	76.8a	3.9ab	0.3a	26.7a	0.23ab	1.4a	0.7a	27.3bc	26.8a	45.9ab
2019	Pa	7.1a	122.3a	5.3ab	0.3a	46.5a	0.38ab	1.1a	0.6a	52.1ab	19.4a	28.4ab
1984	SV	6.6a	86.4a	6.5a	0.3a	57.0a	0.2b	1.2a	0.9a	26.5abc	16.8a	56.7a
2000	SV	6.2a	60.2a	4.6ab	0.2a	60.2a	0.25ab	1.2a	1.1a	15.1c	10.8a	74.1a
2019	SV	6.5a	96.4a	5.6ab	0.3a	56.3a	0.35ab	1.0a	1.3a	58.6a	17.4a	24.0ab

In terms of grain-size percentages, sand —and to a lesser extent clay— showed statistically significant differences for the different uses and years. Changes in soil texture stem from the mineralogy of the parent material and the degree of weathering, because it is an inherent property of soil and is controlled by formation processes (Mulat *et al.*, 2021). This is confirmed by the varied-aged rocks where the CM of the RR develops, such as Holocene alluvium, Miocene detrital sediments, and Eocene limestones and marls (Salgado-García *et al.*, 2017).

The properties that did not show significant differences between the factors of use and establishment year were the following: a) pH, with a prevalence of neutral over moderately acidic (7.3 to 6.1) (SEMARNAT, 2002); acidic pHs in agricultural soils are due to intensive farming and the continuous use of acid-forming inorganic fertilizers (Mulat *et al.*, 2021); b) EC showed low values, characteristic of CM (Salgado-García *et al.*, 2017); this property helps crops assimilate other soil nutrients better (Navarro-García and Navarro-García, 2013); c) N presented low values —especially in RC and AC—, closely related to low to medium OM values, which reduces the mineralization level of N (Alabi *et al.*, 2019); d) P showed high values due to cattle excreta and applied fertilizers (Ramírez-Iglesias *et al.*, 2017); e) BD was higher in Pa, associated with compaction as a result of extensive livestock farming (Xu *et al.*, 2021); and f) AS had a low WMD in RC and Pa, which indicates a structural stability loss, while the increase in AC is related to the OM content; when attached to soil mineral particles, they form clay-metal-humic bonds that increase structural stability (De Freitas *et al.*, 2018).

Cambisol quality between agricultural uses

When analyzing the factor of land use type in the CM, significant statistical differences were observed in OM contents (Table 2): the highest was found in SV, and the lowest in RC and AC. This coincides with low records in cultivated soils, compared with derelict soils and soils with pastures (Alabi *et al.*, 2019; Wang *et al.*, 2021). Soil tillage increases susceptibility to erosion and OM loss (Jin *et al.*, 2021).

Cambisol Quality by agricultural use time

Data analysis of CM with land uses grouped by year (time of use) showed statistically significant differences in OM, P, K, and BD (Table 3). The highest OM contents were recorded for SV in 1984 and 2019, while the lowest corresponded to RC, AC, and Pa in 1984. These results evince the effect of use time on CM after 35 consecutive years with

Table 2. Mean values of CM quality indicators between land uses in the RR.

Use	pH	EC (μS cm^{-1})	OM (%)	TN (%)	P (mg kg^{-1})	K (cmol(+) kg^{-1})	BD (g cm^{3})	AE (DMP)
RC	6.5a	74.5a	2.7b	0.2a	37.8a	0.43a	1.2a	1.0a
AC	6.9a	86.0a	3.3b	0.2a	30.0a	0.35a	1.2a	1.2a
Pa	6.7a	86.6a	4.0ab	0.3a	50.4a	0.26a	1.3a	0.6a
SV	6.4a	81.0a	5.5a	0.3a	57.9a	0.27a	1.2a	1.1a

Different letters in the columns indicate significant differences (Tukey, $p \leq 0.05$).

Table 3. Mean values of CM quality indicators for grouped land uses per year (use time) in the RR.

Year	Use	pH	EC (μS cm^{-1})	OM (%)	TN (%)	P (mg kg^{-1})	K (Cmol(+) kg^{-1})	BD (g cm^3)	AE (DMP)
1984	RC	6.8a	85.5a	2.5b	0.1a	40.4b	0.3a	1.2ab	1.4a
	AC	6.4a	71.0a	3.2b	0.2a	30.4b	0.3a	1.1b	0.8a
	Pa	6.1a	60.5a	2.9b	0.2a	77.9a	0.18a	1.4a	0.5a
	SV	6.6a	86.4a	6.5a	0.3a	57.0ab	0.2a	1.2ab	0.9a
2000	RC	6.7a	89.6a	3.8a	0.2a	35.0a	0.65a	1.1a	0.7a
	AC	7.0a	80.1a	2.5a	0.2a	32.3a	0.33b	1.3a	1.6a
	Pa	7.1a	76.8a	3.9a	0.3a	26.7a	0.23b	1.4a	0.7a
	SV	6.1a	60.2a	4.6a	0.2a	60.2a	0.25b	1.2a	1.1a
2019	RC	6.1a	48.4a	1.7b	0.3a	37.8a	0.35a	1.4a	0.8a
	AC	7.4a	107.1a	4.1a	0.3a	27.3a	0.43a	1.1a	1.4a
	Pa	7.0a	122.3a	5.3a	0.3a	46.5a	0.38a	1.1a	0.6a
	SV	6.5a	96.4a	5.6a	0.3a	56.3a	0.35a	1.0a	1.3a

Different letters in the columns indicate significant differences (Tukey, $p \leq 0.05$).

crops and pastures. The OM level decreased 55.8% compared to the CM with vegetation; on the contrary, the CM with SV denotes the soil conservation ecosystem service provided by natural vegetation, in contrast to cultivation systems (Jin *et al.*, 2021).

The highest P contents were observed in Pa in 1984, while the lowest were found in RC and AC of the same year (Table 3). The P value in Pa is consistent with reports on pasture soil by Burst *et al.* (2020) and can be attributed to the application of P mineral fertilizers (Alabi *et al.*, 2019) and to grazing residues (cattle manure and urine) that increase the availability of P in the soil (Ramírez-Iglesias *et al.*, 2017).

The K content was higher for RC in 2000, and lower for other uses in the same year (Table 3). The level of K in RC is associated with the frequent use of fertilizers (Pouladi *et al.*, 2020) that diminish when agricultural activity ceases (Xu *et al.*, 2021).

In terms of BD, the highest values for Pa were registered in 1984 (Table 3), which confirms the soil compaction attributed to cattle trampling for 35 years. This coincides with reports by Ajayi *et al.* (2021), who observed a BD increase from 1.4 to 1.6 g cm^3 in 24-year-old pastures. This process devalues soil quality, as it generates resistance to root growth; alters the distribution and connectivity of soil pores (Burst *et al.*, 2020); modifies water retention, infiltration, and availability, as well as soil aeration, affecting the edaphic biota (Wu *et al.*, 2021). In addition, compaction increases water erosion by surface runoff, as well as evaporation and soil temperature, and reduces its productivity (Burst *et al.*, 2020; Ajayi *et al.*, 2021). The low BD showed a statistically significant difference in AC in 1984 (Table 3); this was due to tillage carried out before planting sugarcane, since this activity decreases the BD (De Freitas *et al.*, 2018).

CONCLUSIONS

The high organic matter (OM) contents of Cambisols (CM) with secondary vegetation (SV) in the three assessed years (1984, 2000, and 2019) evidenced a higher soil quality compared to CM with rainfed (RC) and annual (AC) crops in the region of Los Ríos (RR), Tabasco. The high apparent density (BD) registered in CM with pastures (Pa) dating from 1984 indicate depreciation of soil quality due to compaction, as a consequence of extensive livestock grazing for 35 years. Fertilizer application is the cause of the high potassium (K) contents in RC of several years, as well as the high phosphorus (P) contents in Pa of 1984. The P levels in Pa are possibly supplemented by residues, such as cattle manure and urine. The OM and BD contents were the best quality indicators for the Cambisol soil due to the effects of agricultural use and time in the RR, Tabasco, since the highest and lowest values were obtained in 1984.

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